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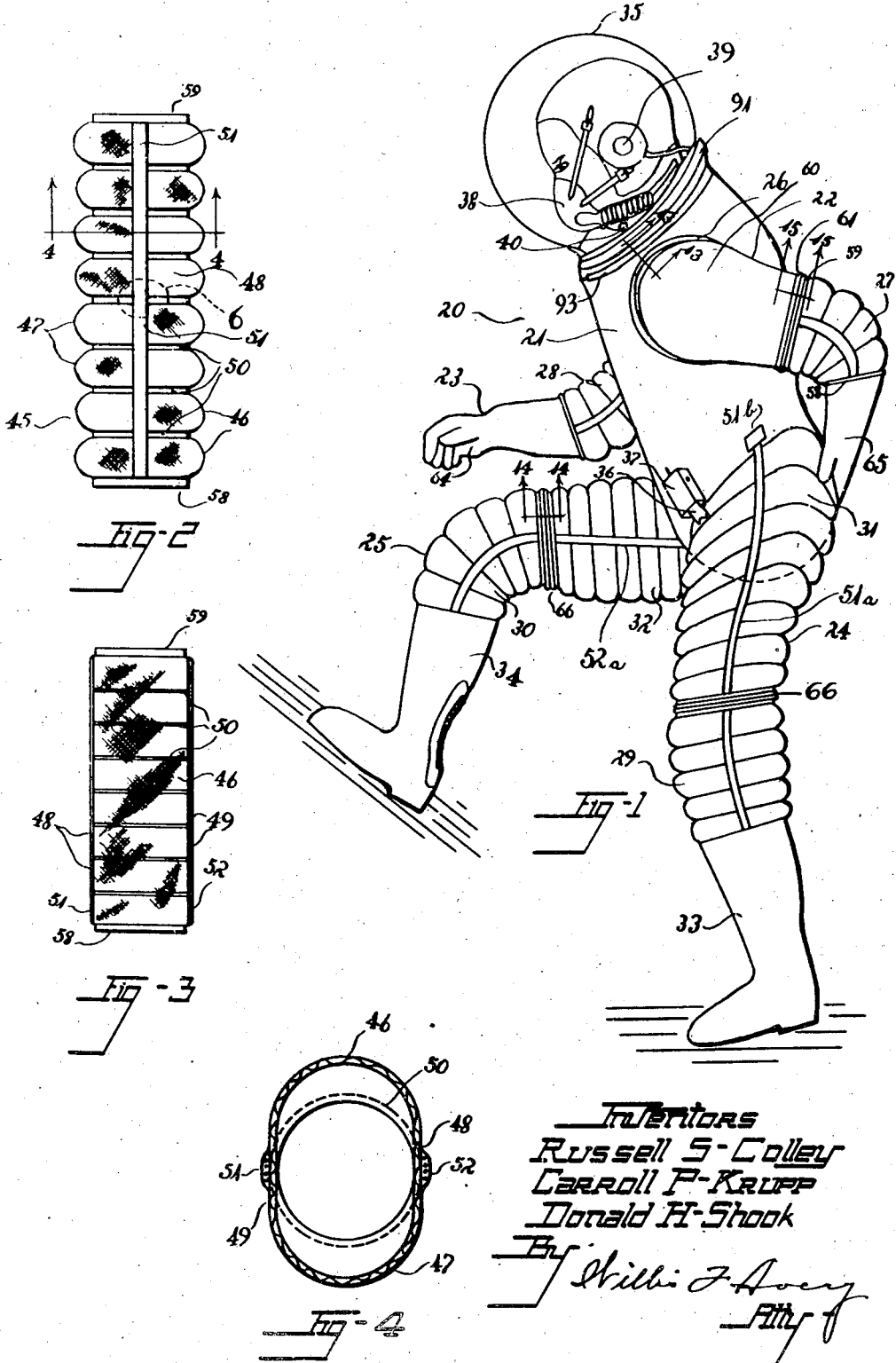
R. S. COLLEY ET AL

2,410,632

INFLATABLE SUIT

Filed Aug. 3, 1943

4 Sheets-Sheet 1



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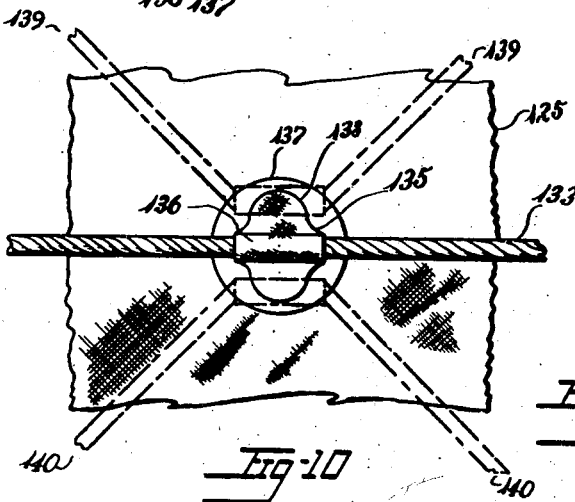
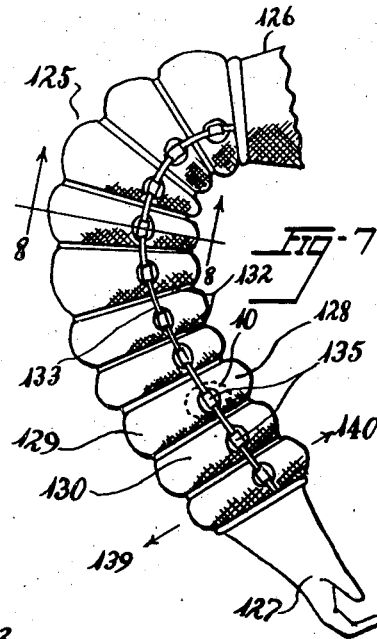
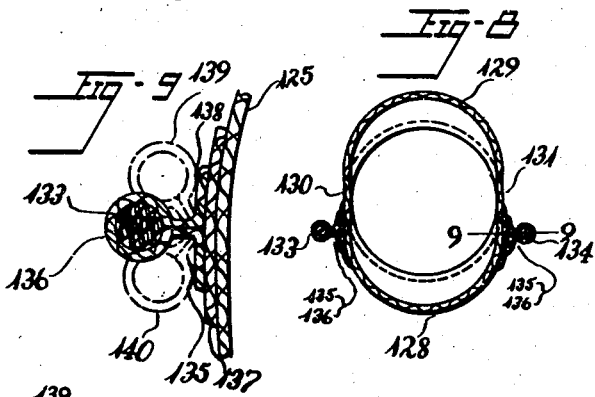
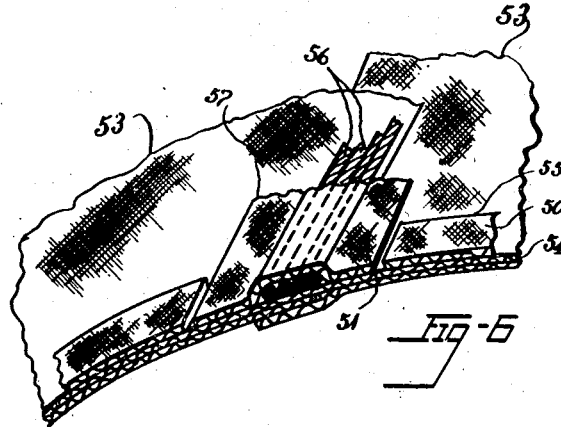
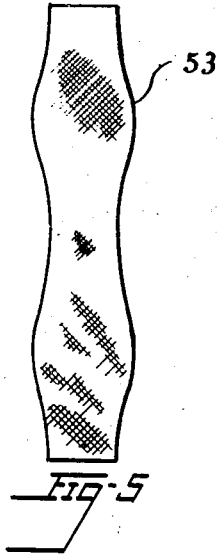
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INFLATABLE SUIT

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4 Sheets-Sheet 2



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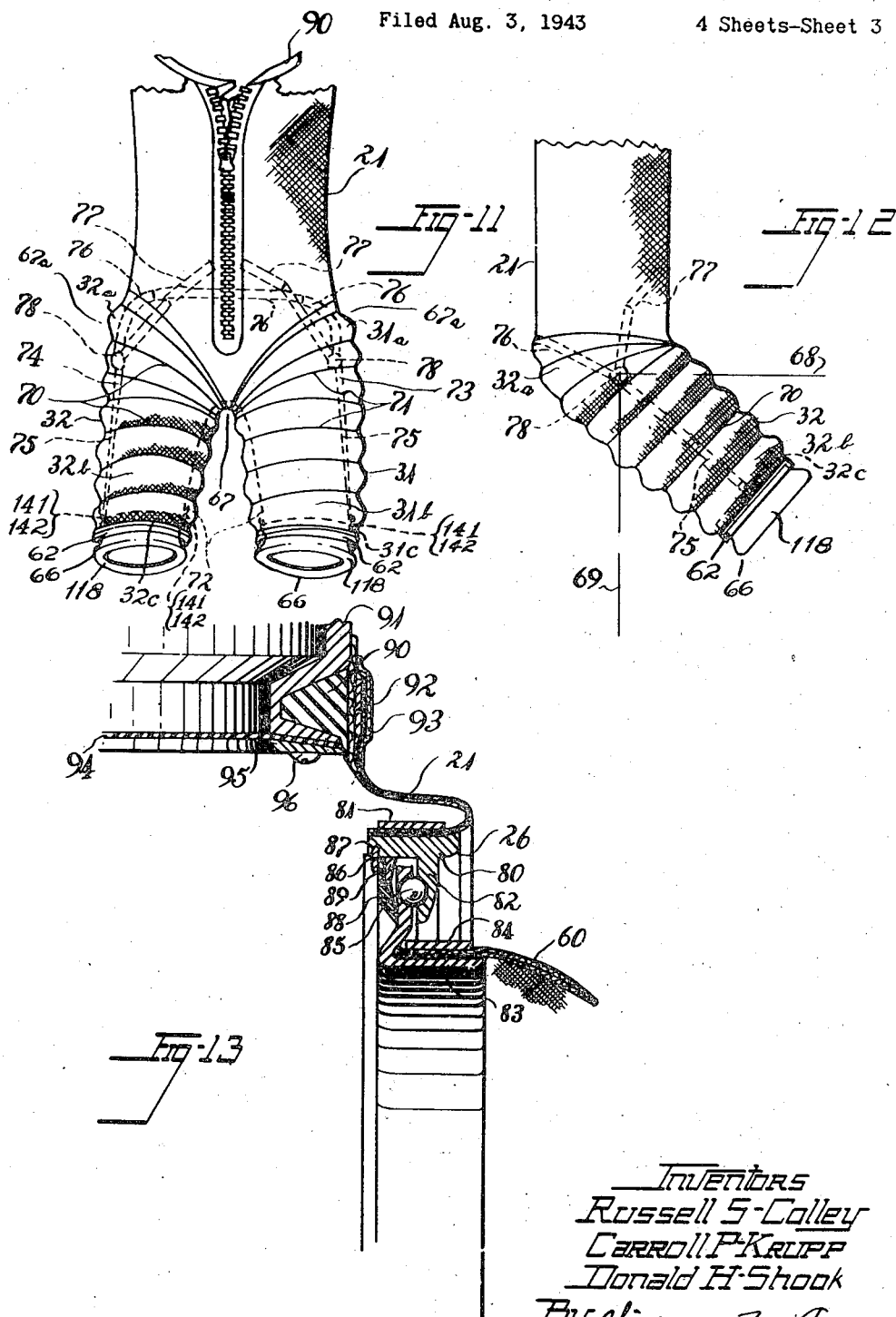
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INFLATABLE SUIT

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4 Sheets-Sheet 3



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INFLATABLE SUIT

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4 Sheets-Sheet 4

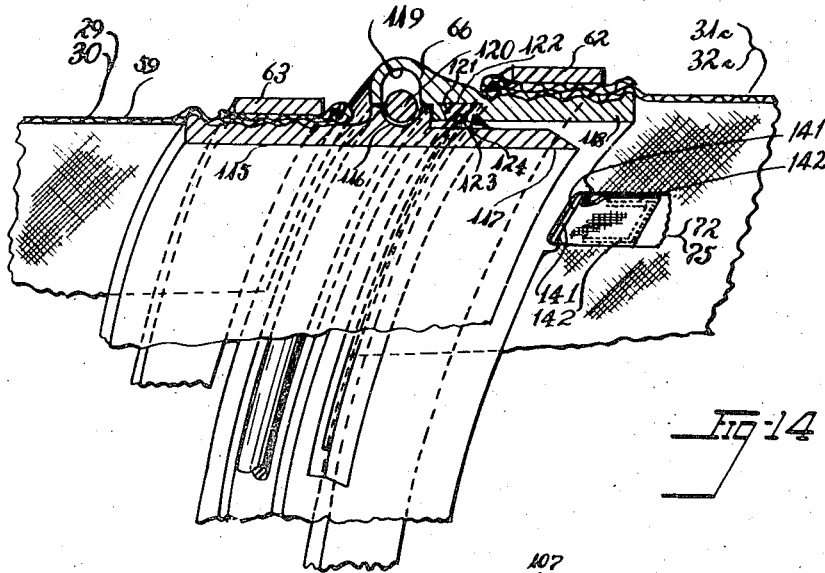


FIG-14

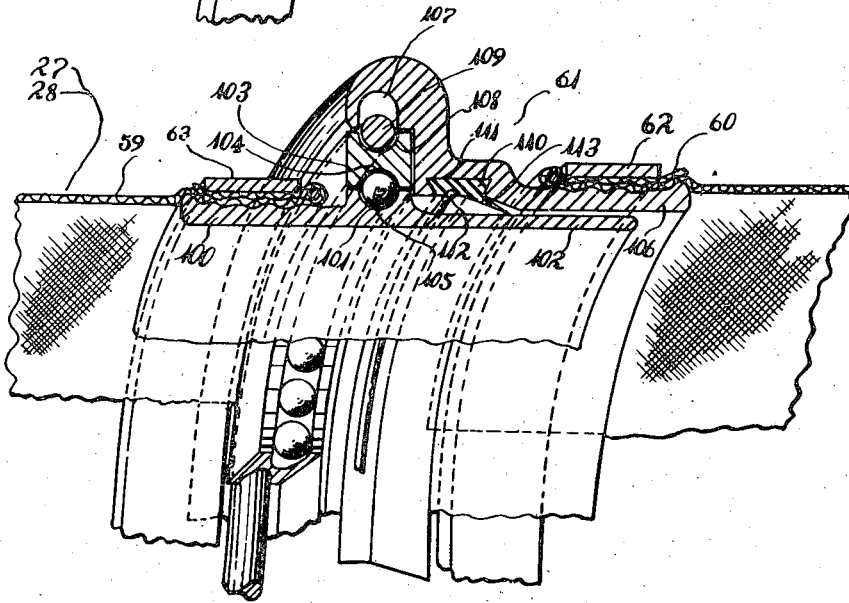


FIG-15

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# UNITED STATES PATENT OFFICE

2,410,632

## INFLATABLE SUIT

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13 Claims. (Cl. 2-2.1)

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This invention relates to inflatable suits and especially to suits for use at high altitudes where the air density and pressure are low. Flight at high altitudes has many advantages for civil and military aviation, but such flight has been limited heretofore in part by physiological problems, for example aero-embolism, for the crews and passengers. A suitable inflatable suit offers a solution of these problems and the requirements of such a suit are primarily concerned with the physiological factors involved and ways for protecting the wearer against the harmful effects of such factors.

In the construction of inflatable suits for this purpose considerable difficulty has been encountered in providing effective joints giving the desired degree of freedom and flexibility of movement by the wearer, which difficulty has arisen through the inherent rigidity of the hollow portions comprising the suit, which rigidity is caused by surface tension stresses established as a result of the inflation pressure therein.

An object of this invention is to provide a compact, light-weight inflatable suit of flexible wall material having movable joints of a construction whereby extensive freedom of movement may be had by the wearer notwithstanding the stiffening of the walls by their distension from an internal pressure which exceeds that of the outer atmosphere. Another object of the invention is to provide joint constructions suitable for an inflatable suit whereby a maximum degree of free movement of adjacent portions of the suit may be obtained with a minimum of effort. A further object is to provide a flexible joint for a limb covering which provides for extensive flexible movement of the limb by virtue of flexure of the joint over a substantial extent of the limb covering as distinguished from localized flexure. A still further object is to provide for great freedom of movement at the region of the hip of the wearer while preventing undue bulging of the wall of the inflatable suit at the region of the hip to facilitate sitting, standing, walking and bending actions.

More specific objects are to provide for detachably engaging the flexible joint with an adjacent part of the suit while providing for relative rotating movement between the joint and the adjacent part, to provide a joint for detachably connecting adjacent parts of the suit which joint is capable of withstanding internal pressure with wholly none or only negligible air leakage, and to provide a joint for substantially unrestricted

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and full-circle turning or rotating movement of adjacent portions of the suit.

These and other objects and advantages of the invention will be apparent from the following description and the accompanying drawings which form a part of this specification and in which like numerals are employed to designate like parts throughout the same.

Fig. 1 is a side view in elevation of an inflatable suit including flexible joints constructed in accordance with and embodying the invention.

Fig. 2 is a side view of an embodiment of the flexible joint for a limb covering.

Fig. 3 is a front view in the direction of forward and rearward swinging movement of the flexible joint shown in Fig. 2.

Fig. 4 is a sectional view in an enlarged scale taken along line 4-4 of Fig. 2.

Fig. 5 is a plan view of a fabric strip in a flattened condition which may be arranged for providing bulges in opposite portions of the flexible joint shown in Fig. 2.

Fig. 6 is a sectional view in perspective of the region at 6 in Fig. 2 and showing longitudinal and circumferentially extending restraining elements, parts being broken away.

Fig. 7 is a side elevation of another embodiment of the flexible joint.

Fig. 8 is a sectional view in an enlarged scale taken along line 8-8 of Fig. 7.

Fig. 9 is a sectional view in an enlarged scale taken along line 9-9 of Fig. 8.

Fig. 10 is an enlarged side view of the region at 10 in Fig. 7, parts being broken away.

Fig. 11 is a front view in elevation of the inflatable suit showing a hip covering arrangement, parts being broken away.

Fig. 12 is a side view of Fig. 11.

Fig. 13 is a sectional view taken along line 13-13 of Fig. 1.

Fig. 14 is a sectional view taken along the line 14-14 of Fig. 1.

Fig. 15 is a sectional view taken along the line 15-15 of Fig. 1.

An inflatable suit should possess desirably certain characteristics and be capable of performing certain functions as described more fully hereinafter for meeting the requirements of extended and safe service at high altitudes. Such service may be exemplified by an operator's manipulation of the controls and accessories of a military airplane, for example, wherein extensive freedom and flexibility of movement is desirable and wherein undue bulkiness of the suit is objectionable since the space within the operating com-

partment is generally of limited extent, and also by such actions as sitting, standing, bending, and reaching.

The phenomenon that an inflatable tubular element possesses great inherent rigidity due to surface tension stresses and strongly resists bending and flexure thereof, has made difficult the successful solution of the problem of providing suitable joints for the inflated suit for obtaining maximum freedom of movement with minimum human energy expenditure.

Our invention provides means for obtaining the desired extensive freedom and flexibility of movement of adjacent portions of the inflatable suits, whether such movement be turning or bending, or both in combination and provides also for a substantially fluid-tight separable connector structure which may include rotatable means for detachably inter-connecting an elbow or a knee joint to an upper part of the limb covering. The invention provides a suitable rotatable connector including sealing means for interconnecting a limb portion with a torso portion of the inflatable suit for providing relative full-circle rotating movement between the torso and the limb covering. Further, the invention provides for an effective construction of the inflatable suit at the region of the hips of the wearer whereby free flexible movement between the respective leg coverings and the torso covering may be obtained without undue bulging and flexure of the torso covering especially at the front wall thereof.

In many actions of the wearer, as when he stoops to pick up an object, most if not all these movements of the suit are required simultaneously and in combination.

It is desirable that pressure within the suit be maintained at a value such that the pressure upon the enclosed body of the wearer will correspond to an atmospheric pressure existing at some more desirable lower altitude so that the objectionable physiological effects on the wearer, as noted hereinabove, are avoided. In view of this the suit including the joints should function satisfactorily under an appreciable range of differential pressures existing between the inside thereof and the outside atmosphere.

In the illustrative embodiment of the invention as shown in Figs. 1 to 6 and 11 to 15, provision is made for attaining these and other ends. Fig. 1 shows an inflatable suit 20 including joints permitting extensive freedom of movement by the wearer notwithstanding the stiffening of wall portions of the suit due to an internal pressure exceeding the outer pressure. The suit 20 includes a torso covering or portion 21 having an aperture at the neck and desirably an elongated opening for admitting the body of the wearer, arm coverings or portions 22 and 23 and leg coverings or portions 24 and 25 which may have air-tight foot covering extensions. The walls of these portions are made desirably from a suitable substantially impervious flexible wall material preferably of square-woven fabric having a resilient rubber impregnation or coating and which permits some give or distortion under twisting stresses which give is beneficial especially in the limb coverings. The suit also includes a rotatable connector 26 at each shoulder, flexible joints 27 and 28 at the region of the elbows of the wearer, flexible joints 29, 30 at the region of the knees of the wearer and hip covering arrangements 31 and 32 at the region of the hips of the wearer all of which provide for movably attaching the several portions or parts of the suit and permitting extensive

and substantially free flexible movement by the wearer when the inflatable suit is under an appreciable internal pressure. All seams and joints of the flexible wall material and all other joints and connector structures connecting the several parts of the suit are sealed to prevent air leakage and to withstand the internal pressure.

Aviation type boots 33 and 34 may be worn over the foot covering extensions of the leg portions to protect the wearer's feet against the extreme cold of high altitudes. A head piece or helmet 35 of suitable shape, having provision for vision, is attached in a detachable manner to the torso portion 21 at the region of the neck of the wearer to complete the enclosure of the wearer's body.

Air, oxygen and electrical conductors are admitted into the suit from the flexible hose 36 through a suitable detachable connection 37, the hose 36 being in communication with suitable sources of supply in the aircraft. Thus air for pressurizing the interior of the suit, oxygen for breathing by means of a face mask 38, and electrical services for an intercommunication means including a radio arrangement having ear phones 39 and a throat microphone 40, and for electrically heated underclothing are provided. The internal air including exhaled air may be exhausted to the atmosphere in any suitable manner such, for example, as through a valve member (not shown) which may be disposed at any suitable location on the suit and preferably at the region of the knee.

The flexible joint shown in Figs. 2 to 6, inclusive, may be used, for example, as an elbow joint 27, 28 or as a knee joint 29, 30, the number of bulges, and therefore the length of the joint, however, being altered to suit the particular application. As noted above, if the limb covering for the arm or leg were provided simply as a tube of flexible material the stiffness of such tube resulting from inflation would render bending, as at the knee or elbow, exceedingly difficult even though the flexibility of the material permits some beneficial give or distortion under twisting stresses. Accordingly, the invention provides several constructional features cooperating in producing the result of maximum ease of flexure throughout a wide range. The stiffness and resistance to bending existing in the inflated flexible covering may be overcome in part by changing the shape of the covering at the joint, such, for example, as by providing a series of outwardly bulged portions in the direction of forward and rearward swinging movement so that the continuity of covering stiffness is interrupted throughout a substantial extent thereof. In the arrangement shown in Figs. 1 to 6, inclusive, the flexible joint provides this result whereby adjacent portions or parts of the arm coverings 22 and 23 and the leg coverings 24 and 25, themselves possessing considerable stiffness against bending by virtue of their inflated condition, are permitted to tilt with relation to the bulged portions of the flexible joint somewhat in the manner, for example, in which a valve stem on an inflated innertube is capable of tilting about the region of the innertube where the stem joins it despite the inflated condition of the tube.

The flexible joints 27, 28, 29 and 30 each comprise a series of outwardly bulged portions for facilitating extensive and free flexible movement of the limb coverings at the region of the elbow and the knee. The flexible joint may have, for example, four bulged portions for the elbow joint and five bulged portions for the knee joint as

shown in Fig. 1, or may have eight bulged portions as shown in Figs. 2 and 3, or may have ten bulged portions as shown in Fig. 7, the number of such portions comprising the series being such as to provide the desired extent of flexibility and movement.

With reference to the embodiment of Figs. 2 and 3, the flexible joint includes a tubular member 45 comprising flexible material, preferably tricot-knit fabric impregnated or coated with rubber-like material, the fabric being arranged such that the substantially circumferentially extending threads are in a substantially stretched condition while the substantially longitudinally extending threads have a lesser extent of stretch for providing longitudinal give to the wall of the joint and restraining circumferential give of said wall under flexure of the joint. The flexible material has substantial fullness at spaced-apart positions along the tubular member in opposite front and back portions in the direction of forward and rearward swinging movement whereby a series of outward bulges contiguous with one another, as shown, for example, in Figs. 1, 2 and 3, in such opposite portions is provided. Each of the outwardly bulged portions 46 and 47 are interconnected by sidewall portions 48 and 49 which sidewall portions, as shown in the drawings, extend longitudinally along side regions of the member 45 substantially coextensive with and between the front and back bulged portions 46 and 47 and are of lesser fullness as compared to the bulged portions for promoting swinging movement of the adjacent parts of the limb covering in the forward and rearward direction by flexure of the series of bulged portions 46 and 47 over a substantial extent of the limb covering. The sidewalls 48 and 49, being restrained against outward bulging by virtue of their lesser fullness as compared to the bulged portions 46 and 47 may in addition thereto function to restrain longitudinal separating movement of the adjacent parts of the limb covering. This arrangement relieves in a large measure the flexible material of the tubular member of stresses in its surface in the longitudinal direction of the covering, thus appreciably increasing its flexibility which facilitates the bending action of the series of bulged portions throughout a much wider range and with greater ease than is obtainable with a non-restrained sidewall construction.

While a flexible joint constructed as described hereinabove provides desirable flexibility of movement, we have found that maximum flexibility of the joint and ease of movement throughout an extremely wide range is made possible by disposing circumferentially extending band elements 50 of flexible material between adjacent bulged portions 46 and 47 for restricting outward bulging of the tubular member to the bulged portions and for promoting swinging movement of the limb covering in the forward and rearward direction by limiting flexure of the tubular member to the series of bulged portions, and by disposing strip elements 51 and 52 of flexible material along the tubular member at the sidewall portions, preferably at the central region of such sidewall portions, for restraining longitudinal separating movement of the adjacent parts of the limb covering and for additionally restraining outward bulging of such sidewall portions. The details of construction at the strip element 51 are more fully shown in Fig. 6. The construction at the strip element 52 at the opposite side-

wall portion 48 of the joint is of similar construction.

While the tubular member may be a sleeve of suitable flexible material, the member is made desirably from a series of shaped pieces 53, as shown especially in Fig. 5, assembled to form a series of bulged portions including restrained and interconnected sidewalls, which arrangement, we have found, facilitates the bending action of the joint throughout a wide range with greater ease of free flexible movement as compared to the sleeve construction. Each of the shaped pieces may be joined to one another by means of a suitable adhesive such, for example, as rubber cement, the adjacent margins being in overlapped relationship.

The circumferentially extending band elements 50 may include one or more cords 54, of cotton material, for example, and a fabric strip 55 having a suitable impregnation or coating of rubber-like material, the cords and fabric strips being adhered to the tubular member by a suitable adhesive. The strip elements 51 and 52 may comprise one or more tension elements 56 of cotton cord, for example, and a fabric covering strip 57 of suitable flexible material, the tension elements and fabric covering strip being adhered to the sidewall portions as shown especially in Fig. 6, by a suitable adhesive. With this arrangement the strip elements 51 and 52 prevent longitudinal separating movement of the adjacent parts of the limb covering while also additionally restraining outward bulging of the sidewall portions. Each end 58, 59 of the tubular member may be attached to the upper and lower parts of the limb covering in any suitable manner such, for example, as by a suitable adhesive but preferably in the manner described hereinafter.

For the arm coverings 22 and 23 an upper part 60 of each such coverings may be secured at the upper margin thereof at the region of the shoulder to the respective annular rotatable connectors 26, 26 in the manner shown especially in Fig. 13 and described more fully hereinafter with respect to said Fig. 13, which arrangement makes possible full-circle relative rotating movement between the arm coverings and the torso covering through the turning movement of the rotatable connectors 26, 26; while the lower margin of the upper part 60 may be attached, for example by a suitable adhesive and clamping band 62, to a detachable connector structure 61 preferably including rotatable means as shown especially in Fig. 15, which latter attachment is described more fully hereinafter with respect to Fig. 15. The end 59, for example, of the tubular member 45 of the flexible joint comprising the elbow joint 27, 28 may be attached to the connector structure 61 by a suitable adhesive and a clamping band 63. The other end 58 of the member 45 of the flexible joint 27, 28 may be joined to the lower part of the limb covering, for example, a glove 64, 65, as by a suitable adhesive. This arrangement for the arm covering 22, 23 provides for a maximum of free forward and rearward bending of the arm covering and for detachably interconnecting the elbow joint to the upper part 60 while providing unlimited relative rotating movement between the elbow joint and the upper part. This arrangement also provides full-circle relative rotating movement between the arm covering and the torso covering at the region of the shoulder, all of which contribute to and facilitate moving and flexing the arm covering despite the internal pressure, even to plac-

ing the hand at the back of the torso covering or, for example, at the back of the neck, as well as in various forward positions as may be required during manipulation of the controls of the aircraft.

With respect to the leg covering 24, 25, the flexible joint for the knee joint 29, 30, which flexible joint may include the tubular member 45 having ends 58 and 59 may be attached to a lower part or foot covering extensions, as by a suitable adhesive and may be interconnected with an upper part including a hip covering 31, 32 by a detachable connector structure including rotatable means as shown in Fig. 15, but inasmuch as a lesser extent of relative rotation between the respective parts of the leg covering is required than that required of the arm covering, the desired relative rotation may be provided by the give of the flexible wall material by virtue of which the flexible joint 29, 30 may be interconnected with the hip covering 31, 32 by a detachable connector structure 66 shown especially in Fig. 14. The attachment of the tubular member 45 of the knee joint 29, 30 to the connector structure 66 or, if more extensive relative rotative movement is desired, to the connector structure 61 is described more fully hereinafter with respect to Figs. 14 and 15.

For providing flexible swinging movement in the forward and rearward direction between the leg covering 24, 25 and the torso covering 21, hip coverings 31, 32, arranged as shown in Fig. 1, flexibly interconnect the lower part of the leg covering including the flexible joint 29, 30 with the torso covering. As shown especially in Figs. 11 and 12, each hip covering 31, 32 of suitable flexible material includes a series of outwardly bulged substantially annular portions 31a, 32a, tapering from the outer region 67a of the hip of the wearer to the inner region 67 at the central junction of the leg coverings 24, 25 and the torso covering 21 and may include a series of substantially uniform longitudinal and circumferential ring portions 31b, 32b, also outwardly bulged which provide additional flexibility in bending action of the hip covering through cooperation with the tapered annular portions. Each hip covering is arranged to assume under inflation conditions a position intermediate a position 68 at right angles to the torso covering and a position 69 along the longitudinal axis of the torso covering, whereby the leg coverings 24, 25 including the hip coverings pivot substantially at the pivotal axis of the hips of the wearer for swinging movement in the forward and rearward direction relative to the torso covering while preventing undue bulging and bending of the torso covering 21 especially at the front wall portion thereof intermediate the leg coverings. If desired, the hip covering may be provided with restrained sidewall portions as shown in Fig. 1, and for such a construction the hip covering is provided with strip elements 51a and 52a adhered by the rubber so as to be attached thereto along the sidewalls for further restraining the sidewalls and for preventing longitudinal separating movement of the knee joint and the torso covering, each strip element 51a being also attached to the torso by a fastening patch 51b of suitable fabric and a suitable adhesive. Band elements 70 and 71 of suitable flexible material are disposed circumferentially between adjacent outwardly bulged portions 31a and 31b, 32a and 32b for restricting the outward bulging of the hip covering to such

and 32b and for facilitating and promoting swinging movement of the leg portion in the forward and rearward direction by limiting flexure of the hip coverings to these outwardly bulged portions. During such swinging movement the bulging of the portions 31a and 31b and 32a and 32b is of lesser extent in some parts thereof than in other parts.

In order to restrain longitudinal separating movement of the lower portion of the leg covering with respect to the torso covering at the inner region of the hip coverings 31, 32, a strap element 72 of suitable flexible material such, for example, as a woven fabric tape, extends continuously along the hip coverings inside the suit at such inner region and extends continuously between and is attached only at the respective lower margins 31c and 32c of the hip coverings, as shown especially in Figs. 11 and 12. The respective ends of the strap 72 may be attached to the detachable connector structures 66, 66 for the respective leg coverings 24, 25 by a looped arrangement thereof extending through one of diametrically opposite slotted apertures 141 in a sleeve structure 118 of each of such connector structures 66, 66 and the overlapping looped portions of said ends of the strap adjacent the sleeve structure 118 may be sewed together along their margins at 142 in the manner shown in Fig. 14. The strap element 72 is in sliding engagement with the wall of the suit at the central junction region 67 of the hip coverings 31, 32 and the torso covering 21, and when the hip coverings are flexed or bent with respect to the torso covering and with respect to each other, for example, when the hip covering 32 is flexed to the position 68 and the hip covering 31 is flexed to the position 69, such sliding engagement compensates for the extension and contraction of the respective hip coverings during such flexure.

However, since the strap element 72 is disposed at the inner region of the hip coverings, it is desirable to provide a compensating tension member 73, 74 inside the suit at the outer region at 67a of each of the hip coverings and extending from the lower portion of the torso covering 21 to the lower margins 31c and 32c of the hip coverings for additionally restraining separating movement of the leg coverings with respect to the torso covering. For the construction shown especially in Figs. 11 and 12, each tension member 73, 74 includes strip elements 75, 76 and 77 of flexible material such as woven fabric tape arranged in a forked arrangement, the junction of which is preferably positioned at substantially the pivotal axis of the hip of the wearer and the respective remote ends of the strip elements suitably secured to the torso covering 21 and secured at the respective lower margins 31c and 32c to the detachable connector structures 66 as by the slotted aperture and looped arrangement described hereinabove for the ends of the strap 72, whereby these strip elements cooperate in withstanding the tension load under inflation conditions when the hip covering is bent forwardly and rearwardly relative to the torso covering. These strip elements at the junction thereof may be attached as by end loops in sliding engagement with a swivel ring 78 of stiff material such, for example, as steel, to facilitate the cooperation of the respective strip elements 75, 76 and 77 during such bending movement.

Each strip element 75 may be attached at its remote end to a connector structure 66 as de-



scribed hereinabove and shown especially in Fig. 14. Each strip element 77 may be secured at its remote end as by a suitable adhesive to the front wall of the torso covering and the strip element 76, which may extend continuously between the swivel rings 78 of the respective compensating tension members 73, 74 and along the back wall of the torso covering as shown especially in Figs. 11 and 12, may be attached to an intermediate portion of such back wall as by a suitable adhesive. A portion of the strip elements 76 and 77, adjacent the swivel ring 78 are not secured to the torso covering but are free for relative movement with respect to each other and to the strip element 75, whereby desirable cooperation is secured between such elements. When the hip covering 32 is in the position 68, the strip elements 75 and 76 cooperate in withstanding the tension stresses; when the covering 32 is in the intermediate position, as shown especially in Fig. 12, the elements 76, 77 mutually cooperate with the strip element 75; and when the covering 32 is in the position 69 the strip elements 75 and 77 cooperate in withstanding the tension load. Such an arrangement of the hip coverings as described hereinabove facilitates flexing of the leg coverings at the region of the hips while preventing objectionable bulging of the torso covering which bulging definitely restricts freedom of movement by the wearer, especially when in a sitting position.

We have found that such an arrangement of hip coverings and flexible joints at the knees, described hereinabove, cooperate effectively in providing maximum free flexible swinging movement of the legs relative to the torso covering without undue expenditure of human energy despite the internal pressure therein. The rubber and fabric parts of the suit are united integrally by vulcanization.

In the shoulder joint 26, illustrated in Fig. 13, the torso covering 21 may be adhered and sealed to the exterior surface of an annular ring element 80 by means of rubber cement, for example, and secured firmly in place thereto by a suitable clamping band or strap 81, the annular ring element having an inwardly extending flange to provide for a bearing race element 82. In like manner the upper part 60 of the arm covering 22, 23 may be secured by means of a strap 84 and by cementing to an annular element 83 having an outwardly extending flange to provide for a bearing race element 85 in overlapping relation with the other bearing element 82. The annular elements 80 and 83 are maintained in assembled relationship by means of a metal snap ring or retainer element 86 seating in an annular recess 87 in the interior surface of the element 80 adjacent the bearing element 85 and by means of a rubber sealing ring 88 including a metal insert 89 which, as shown in Fig. 13, limits movement of the element 83 including the bearing race element 85 toward the sealing ring 88, the sealing ring having a face contiguous with the retainer element 86 and having an inwardly extending flange portion contiguous with the flange portion of the annular element 83 to provide an air seal.

For the arrangement of the torso covering 21 and the rotatable connector 26, as shown in Fig. 13, the spacing of the respective shoulder joints of the suit may be of lesser extent whereby the overall width of the suit at the region of the shoulders is less than would otherwise be the case were the torso covering 21 to be attached to the rotatable connector 26 from the opposite end of

the annular ring element 80. A snubbing action upon the torso covering adjacent the neck results from the reverse bend of the flexible material which action restricts spreading movement of the respective rotatable connectors while preventing upward movement of the headpiece 35. An annular element 90, generally trapezoidal in section, may be attached as by a suitable adhesive to the margin of the neck aperture in the torso covering, which annular element is disposed in an annular groove in a suitable neck ring structure 91. The torso covering 21 including the annular element 90 may be secured detachably to the neck ring 91 by means of a suitable clamping band 92 which band 92 may be sheathed in a suitable fabric cover 93 adhered to the torso covering. The head piece 35 may be detachably engaged with the neck ring 91 in any suitable manner, such, for example, as shown in the copending application of Carroll P. Krupp, Serial No. 453,175, filed August 1, 1942. For separating the space in the head piece from the space in the inflatable suit to aid in preventing fogging of the headpiece, a suitable diaphragm 94 of resilient rubber-like material having an aperture for the head may be provided and may be attached to the neck ring 91 by a suitable adhesive and a metal ring 95, which metal ring may be held in place by a plurality of spaced-apart screws 96.

For providing relative rotating movement between the upper part 60 of the arm covering 22, 23 and the flexible joint 27, 28, and for interconnecting the same a detachable connector structure 61 shown especially in Fig. 15 may be used. A structure identical with structure 61 may be used for interconnecting the knee joint 29, 30 and the hip covering 31, 32 to provide extensive relative rotating movement between such knee joint and hip covering. The connector 61 includes a sleeve structure 100 to which may be secured the end 59, for example, of the tubular member 45 of the flexible joint 27, 28 by means of a suitable adhesive and a clamping band 63, which structure includes a bearing race 101 at the outer face thereof intermediate the ends of the structure 100 providing an extension 102. The sleeve structure 100 also includes a ring element 103 mounted at the outer face thereof and overlapping the bearing race 101, which element includes a bearing race 104 adjacent and in register with the bearing race 101. A plurality of rotatable elements 105 is disposed between the bearing races for providing relative full-circle rotation therebetween and for securing the element 103 to the structure 100.

The lower margin of upper part 60 of the arm covering may be secured to a second sleeve structure 106 by a suitable adhesive and the clamping band 62, the structure 106 being in telescopic engagement at the extension 102 of the sleeve structure 100 and in overlapping relation with the latter structure. Where the detachable connector structure 61 is to be used at the knee joint 29, 30, the attachment of the strap 72 and the element 75 of the compensating tension member 73, 74 to the sleeve 106 may be made in the manner shown in Fig. 14 at the sleeve 118. The second structure 106 is also provided with a depression 107 adjacent the face of the ring element 103 opposite the bearing race 104 and in register with a depression 108 in the element 103. An expansible-contractible annular member 109 is disposed in these depressions 107 and 108 between the element 103 and the structure 106 for detachably engaging the sleeve struc-

tures 100 and 106. A suitable sealing ring 110, preferably of resilient rubber or other rubber-like material, is disposed between the structures 100 and 106 in an annular depression 111 in the structure 106 and may be held in place by pressure of the material against the walls thereof and by a metal snap ring 112. The sealing ring 110 is provided with a sealing lip 113 which engages the extension 102 of the structure 100, thereby preventing air leakage through the connector structure 61.

Since extensive relative rotating movement between the flexible joint 29 and 30 and the hip covering 31 and 32 is not required for providing the desired freedom of movement, the detachable connector structure 66, as shown especially in Fig. 14, may be used for interconnecting these parts of the suit; although the connector structure 61 (Fig. 15) may be used, if desired, for providing such extensive relative rotating movement. The end 59 (Fig. 14) for example, of the tubular member 45 of the flexible joint for the knee may be secured to a sleeve structure 115 as by a suitable adhesive and the clamping band 63, which structure includes a depressed portion 116 at the outer face and intermediate the ends of the structure providing an extension 117. The lower margin 31c, 32c of the hip covering 31, 32 may be secured to a second sleeve structure 118 as by a suitable adhesive and the clamping band 62, which structure is in telescopic engagement with the structure 115 at the extension 117 and in overlapping relation with the structure 115.

The second sleeve structure 118 includes a depressed portion 119 at the inner face and in register with the depressed portion 116. An expansible-contractible annular member 120 is disposed in the depressed portions 116 and 119 for detachably engaging the structures 115 and 118. A sealing ring 121 of suitable rubber-like material is disposed between the structures 115 and 118 at the extension 117 and is disposed in an annular depression 122, which may be dove-tailed in section, in the structure 118. The sealing ring 121 may be held in the depression 122 by pressure of the material against the walls thereof and by a metal snap ring 123. The ring 121 is provided with a sealing lip 124 engaging the extension 117 for preventing air leakage through the detachable connector structure 66.

Normal use of the inflatable suit shown in Fig. 1 requires frequently the raising and lowering of the arm in combination with bending of the elbow of the wearer. In operation under such a condition each arm covering 22, 23 may be freely raised or lowered by means of relative full-circle rotation between the arm covering and the torso covering 21 through the turning movement of the rotatable connector 26. Extensive and free flexible bending at the elbow is permitted by the flexible joint 27, 28, which bending in the forward and rearward direction is attained through flexure of the series of outwardly bulged portions along a substantial extent of the arm covering. Further freedom of movement is provided by the detachable connector structure 61 which permits relative rotating movement between the flexible joint and the upper part 60 of the arm covering.

The hip coverings 31 and 32 cooperate with the flexible joints 29 and 30 at the knees of the wearer in providing extensive and free flexible swinging movement of the leg coverings 24, 25. When the leg covering 25, for example, is bent in the manner shown in Fig. 1 the flexible joint 30 at the knee provides extensive bending at this

region through flexure of the series of outwardly bulged portions as described hereinabove while the hip covering facilitates free movement at the region of the hips through the pivoting action thereof at substantially the pivotal axis of the hip of the wearer. The outwardly bulged annular portions 32a and 32b of the hip covering 32 flex substantially throughout their length circumferentially and longitudinally, while the strap element 72 being in sliding engagement with the wall of the suit at the central junction 67 of the torso 21 and the leg coverings 24, 25 compensates for variation in hip covering length at the inner region thereof and cooperates with the compensating tension member 74 in preventing longitudinal separating movement of the torso covering and the lower portions of the leg coverings. With the leg covering 25 in the position shown in Fig. 1 the tension load stresses are taken by the strip elements 75 and 76 of the tension member 74 disposed in the hip covering 32, which arrangement also prevents longitudinal separating movement of the leg portion 25 and the torso portion 21 at the outer region of the hip covering 32.

Another embodiment of the flexible joint for the limb covering is shown in Figs. 7 to 10, inclusive, which joint may be used at the region of the elbow or the knee and which joint may be of greater longitudinal extent along the limb covering than the flexible joints 27 to 30 shown in Fig. 1. Under some conditions it may be desirable to provide a flexible joint 125 intermediate the upper and lower parts of the limb coverings which extends substantially the full length of the limb coverings and which is arranged to tend to assume a bent condition conforming to the natural curve of the arm or leg of the wearer when, for example, the wearer is seated and manipulating the controls of the aircraft.

The flexible joint 125 shown in Fig. 7 is especially adapted for such use and is shown as applied to the arm covering which covering includes an upper part 126, a lower part or glove 127 and the flexible joint 125. This flexible joint comprises a tubular member comprising flexible material such, for example, as square-woven fabric impregnated or coated with resilient rubber or other rubber-like material and having substantial fullness at spaced-apart positions along the tubular member in opposite portions in the direction of forward and rearward swinging movement for providing a series of outward bulges 128, 129 in the opposite portions. Sidewall portions 130, 131, each of similar construction at opposite sides of the joint 125, interconnect such bulged portions and are restrained from outward bulging as compared to the bulged portions 128, 129 to promote swinging movement of the upper 126 and lower 127 parts of the arm covering in the forward and rearward direction by flexure of the series of bulged portions over a substantial extent of the arm covering. For restricting outward bulging of the tubular member to the bulged portions and for additionally restraining outward bulging of the sidewall portions, band elements 132 of suitable flexible material are disposed circumferentially between adjacent bulged portions of the tubular member. These band elements 132 each, desirably, include one or more cords of cotton material, for example, and a suitable fabric covering strip, the cords and covering strip being adhered to the wall of the tubular member as by a suitable adhesive.

For further restraining outward bulging of the

sidewall portions and for restraining longitudinal separating movement of the upper and lower parts of the arm covering, tension elements 133, 134 of flexible material such, for example, as twine extend along the tubular member at the side-wall portions. For maintaining the bent position of the flexible joint under inflation conditions the tension elements extend along the tubular member at a determinate distance from the longitudinal axis thereof and are spaced from the sidewall portions. The details of construction at the tension element 133 are shown especially in Figs. 7 to 10 and the construction at the tension element 134 at the opposite sidewall portion of the joint is of similar construction. These tension elements are supported in the desired position by means of flexible hinge structures 135 including ring elements 136 which structures are attached to the sidewall portions at substantially the respective central regions longitudinally thereof as shown especially in Fig. 7. Each flexible hinge structure 135 includes an attaching patch 137 of suitable woven fabric which is adhered to the sidewall by a suitable adhesive and a hinged portion 138 also of suitable woven fabric which is adhered in a similar manner to the attaching patch 137, which hinge portion 138 includes the ring element 136. The tension elements 133 and 134 extend through the ring elements 136 of the flexible hinged structures, as shown especially in Figs. 9 and 10, and being spaced from the sidewall portions by the hinged portions 138, flexure of the hinged structures is thereby facilitated during the swinging movement of the flexible joint. During such swinging movement the hinge portion 138 may assume several positions in coaction with the tension element such, for example, as positions 139 and 140, as shown by the broken lines in Figs. 9 and 10. The arrangement of the flexible joint 125 provides for free flexible movement of the adjacent parts of the limb covering in the direction of forward and rearward swinging movement, the respective components thereof cooperating with one another in obtaining this result.

Variations may be made without departing from the scope of the invention as it is defined in the following claims.

We claim:

1. An inflatable suit including a torso portion and a limb portion for incasing a body and providing free flexible movement of the limb, said portions comprising a torso covering of flexible wall material and a limb covering of flexible wall material including a flexible joint intermediate the length of said limb covering and interconnecting adjacent parts of the latter covering to provide for forward and rearward bending thereof, said flexible joint comprising a tubular structure comprising flexible material having substantial fullness at spaced-apart positions along said structure in opposite front and back portions in the direction of forward and rearward swinging movement to provide a series of outward bulges in said opposite front and back portions and having sidewall portions extending longitudinally along side regions of said tubular structure coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness as compared to said bulged portions to promote swinging movement of said adjacent parts of said limb covering in said direction by flexure of said series of bulged portions over a substantial extent of said limb covering while lateral compactness of the joint

is maintained under inflation of the suit and joint and means restraining longitudinal separating movement of said adjacent parts of the limb covering and restraining outward bulging of said sidewall portions.

2. An inflatable suit including a torso portion and an arm portion for increasing a body providing free flexible movement of the arm, said portions comprising a torso covering of flexible wall material, an arm covering of flexible wall material including a flexible joint to provide for forward and rearward bending of said arm covering, and an ax-ular rotatable connector interconnecting said torso and said arm coverings and providing full-circle relative rotating movement between said coverings, said flexible joint comprising a tubular structure comprising flexible material having substantial fullness at spaced-apart positions along said structure in opposite front and back portions to provide a series of outward bulges in the direction of forward and rearward swinging movement, said bulges being contiguous with one another in each of said opposite portions, and having sidewall portions extending longitudinally along side regions of said tubular structure coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness and substantially restrained from outward bulging as compared to said bulged portions to promote swinging movement of adjacent parts of said arm covering in said direction by flexure of said series of bulged portions over a substantial extent of said arm covering while lateral compactness of the joint is maintained under inflation of the suit and joint, and means restraining longitudinal separating movement of adjacent parts of the arm covering and restraining outward bulging of said sidewall portions.

3. An inflatable suit including a torso portion and a limb portion for incasing a body providing free flexible movement of the limb, said portions comprising a torso covering of flexible wall material and a limb covering of flexible wall material including an upper part, a lower part, a flexible joint intermediate said parts, and a detachable connector structure interconnecting said upper part and said flexible joint, said joint comprising a tubular member comprising flexible material having substantial fullness at spaced-apart positions along said member in opposite front and back portions to provide a series of outward bulges in the direction of forward and rearward swinging movement, said bulges being contiguous with one another in each of said opposite portions, and said tubular member having sidewall portions extending longitudinally along side regions of said tubular member coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness and substantially restrained from outward bulging as compared to said bulged portions to promote swinging movement of said upper and lower parts of the limb covering in said direction by flexure of said series of bulged portions over a substantial extent of said limb covering while lateral compactness of the joint is maintained under inflation of the suit and joint, means disposed circumferentially of said tubular member between adjacent bulged portions for restricting bulging to the latter said portions, and means comprising strip elements of flexible material extending along said tubular member at said sidewall portions for restraining longitudi-

nal separating movement of said upper and lower parts and for additionally restraining outward bulging of said sidewall portions.

4. An inflatable suit as defined in claim 3 in which said detachable connector structure includes rotatable means providing substantially full-circle relative rotating movement between said flexible joint and said upper part of the limb covering.

5. An inflatable suit including a torso portion and a leg portion for incasing a body providing substantially free flexible movement of the leg, said portions comprising a torso covering of flexible wall material and a leg covering including a hip covering of flexible wall material, said hip covering comprising a series of outwardly bulged substantially annular contiguous portions each tapering from the outer region of the hip to the inner region thereof at the central junction of the leg covering and the torso covering, means disposed circumferentially, between adjacent annular portions for restraining outward bulging of said hip covering to said annular portions and for promoting swinging movement of the leg covering in a forward and rearward direction by limiting flexure of said hip covering to said annular portions, and means at said hip covering for restraining longitudinal separating movement of said torso and said leg coverings and for promoting flexure of said hip covering at substantially the pivotal axis of the hip of the wearer.

6. An inflatable suit comprising a torso covering of flexible wall material, a pair of leg coverings each including an upper part of flexible wall material, each said upper part having a lower margin and comprising a hip covering comprising a series of outwardly bulged substantially annular portions tapering from the outer region of the hip to the inner region thereof at the central junction of the leg covering and the torso covering, band elements of flexible material disposed circumferentially between adjacent annular portions for restricting outward bulging of said hip covering to said annular portions and for promoting swinging movement of the leg covering in a forward and rearward direction by limiting flexure of said hip covering to said annular portions, and means for restraining longitudinal separating movement of said leg coverings and said torso covering, said means comprising a strap element of flexible material extending continuously along said upper parts of the leg coverings inside said suit at the inner region of said leg coverings and extending between the respective said lower margins of said upper parts, said strap element being in sliding engagement with said wall material at substantially the central junction of said leg coverings and said torso covering for permitting adjusting the length of said upper parts during swinging movement of said leg coverings in said direction and said means comprising a pair of compensating tension members, each said tension member being disposed inside said suit at the outer region of each of said leg coverings and extending from said torso covering to said lower margin of said upper part of the leg covering along said hip covering and each said tension member comprising strip elements of flexible material arranged in a forked arrangement, the junction of which being positioned at substantially the pivotal axis of the hip of the wearer and the remote ends of said strip elements being secured to said torso covering and said lower margin of said upper part whereby said strip elements cooperate in withstanding the tension load under

inflation conditions when the leg covering is bent forwardly and rearwardly relative to the torso covering.

7. An inflatable suit comprising a torso covering of flexible wall material and a pair of leg coverings including hip coverings of flexible wall material arranged to assume under inflation conditions a position intermediate a position at right angles to said torso covering and a position along the longitudinal axis of said torso covering and said leg coverings being arranged for swinging movement in a forward and rearward direction relative to said torso covering by pivoting substantially at the pivotal axis of the hips of the wearer whereby undue bending and bulging of the torso covering is prevented, each of said hip coverings having a lower margin and comprising a series of outwardly bulged substantially annular contiguous portions each tapering from the outer region of the hip to the inner region thereof at the central junction of the leg covering and the torso covering, means disposed circumferentially between adjacent annular portions for restricting outward bulging of said hip coverings to said annular portions and for promoting swinging movement of the leg coverings in said direction by limiting flexure of said hip coverings to said annular portions, parts of said annular portions bulging to a lesser extent than other parts thereof during said swinging movement of the leg coverings, and means at the inner and outer regions of each of said leg coverings and extending from said torso covering to each said lower margin of said hip coverings for restraining longitudinal separating movement of said torso covering and said leg coverings and for promoting flexure of said hip coverings at substantially the pivotal axis of the hips of the wearer.

8. An inflatable suit comprising a torso covering of flexible wall material and a pair of leg coverings of flexible wall material arranged to assume under inflation conditions a position intermediate a position at right angles to said torso covering and a position along the longitudinal axis of said torso covering, each said leg covering comprising an upper part having a lower margin, a lower part and a flexible joint intermediate said upper and lower parts and detachably secured to said lower margin for providing relative swinging movement in a forward and rearward direction between the latter said parts, said upper part including a hip covering comprising a series of outwardly bulged substantially annular portions tapering from the outer region of the hip to the inner region thereof at the central junction of the leg covering and the torso covering, band elements of flexible material disposed circumferentially between adjacent annular portions for restricting outward bulging of said hip covering to said annular portions and for promoting swinging movement of the leg covering in said direction by limiting flexure of said hip covering to said annular portions, and means extending from said torso covering to said lower margins along said hip coverings for restraining longitudinal separating movement of said torso and said leg coverings and for promoting flexure of said hip coverings at substantially the pivotal axis of the hips of the wearer, said flexible joint comprising a tubular member comprising flexible material having substantial fullness at spaced-apart positions along said member in opposite front and back portions in the direction of forward and rearward swinging movement to provide a series of outward bulges in said oppo-

site portions and having sidewall portions extending longitudinally along side regions of said tubular member coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness as compared to said bulged portions to promote swinging movement of adjacent parts of the leg covering in said direction by flexure of said series of bulged portions over a substantial extent of said leg covering while lateral compactness of the joint is maintained under inflation of the suit and joint, means restraining longitudinal separating movement of the adjacent parts of the leg covering and restraining outward bulging of said sidewall portions, and a detachable connector structure interconnecting said tubular member to said lower margin of said upper part of the leg covering.

9. A flexible joint for connecting adjacent parts of a limb covering of an inflatable high-altitude suit for maintaining the wearer under air pressure substantially greater than the surrounding air pressure while providing for relative swinging movement of said parts forwardly and rearwardly, said joint comprising a tubular member comprising flexible material having substantial fullness at spaced-apart positions along said member in opposite front and back portions in the direction of forward and rearward swinging movement to provide a series of outward bulges in said opposite portions, said bulges being contiguous with one another in each of said opposite portions, and said tubular member having sidewall portions extending longitudinally along side regions of said member coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness as compared to said bulged portions to promote swinging movement of said adjacent parts in said direction by flexure of said series of bulged portions over a substantial extent of said covering while lateral compactness of the joint is maintained under inflation of the suit and joint, band elements of flexible material disposed circumferentially between adjacent bulged portions for restricting bulging of said member to said bulged portions and for restraining outward bulging of said sidewall portions, flexible hinge structures including ring elements attached to said sidewall portions between said band elements at substantially the respective central regions longitudinally of said sidewall portions and oppositely disposed along said tubular member at a determinate distance from the longitudinal axis of said tubular member, and tension elements of flexible material for restraining longitudinal separating movement of said adjacent parts and for restraining outward bulging of said sidewall portions, said tension elements extending along said tubular member through said ring elements at and spaced from said sidewall portions for permitting flexing of said hinge structures during said swinging movement, said tubular member tending to assume a bent position under inflation conditions by virtue of the arrangement and cooperation of said hinge structures and said tension elements.

10. A joint for connecting adjacent parts of an inflatable suit for relative rotating movement of said parts, said joint comprising a sleeve structure secured to one of said parts and including a bearing race at a face thereof and intermediate the ends of said structure providing an extension thereof and including a ring element mounted at said face and overlapping said bearing race,

said element having a bearing race adjacent and in register with the first said bearing race and having a depression in a face thereof opposite the second said bearing race, and rotatable elements disposed in said bearing races for securing said ring element to said sleeve structure and for providing relative full-circle rotation between said ring element and said structure, a second sleeve structure secured to the other of said parts and being in telescopic engagement at said extension and in overlapping relation with the first said sleeve structure and having a depression in a face thereof adjacent the opposite face of said element and in register with the first said depression, expansible-contractible ring means disposed in said depressions between said ring element and said second sleeve structure and adapted to be contracted inwardly relative to said sleeve structures for detachably engaging said structures, and sealing means between said structures at said extension.

11. A flexible joint for connecting adjacent parts of an inflatable high-altitude suit for maintaining the wearer under air pressure substantially greater than the surrounding air pressure while providing for relative swinging movement of said parts forwardly and rearwardly, said joint comprising a tubular member comprising flexible material having substantial fullness at spaced-apart positions along said member in opposite front and back portions in the direction of forward and rearward swinging movement to provide a series of outward bulges in the front and back portions, said bulges being contiguous with one another in each of said front and back portions, and said tubular member having sidewall portions extending longitudinally along side regions of said member coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness and substantially restrained against outward bulging as compared to said bulged portions to promote swinging movement of said adjacent parts in said direction by flexure of said series of bulged portions while lateral compactness of the joint is maintained under inflation of the suit and joint, said side walls restraining longitudinal separating movement of said adjacent parts.

12. A flexible joint for connecting adjacent parts of an inflatable high-altitude suit for maintaining the wearer under air pressure substantially greater than the surrounding air pressure while providing for relative swinging movement of said parts forwardly and rearwardly, said joint comprising a tubular member comprising flexible material having substantial fullness at spaced-apart positions along said member in opposite front and back portions in the direction of forward and rearward swinging movement to provide a series of outward bulges in the front and back portions, said bulges being contiguous with one another in each of said front and back portions, and said tubular member having sidewall portions extending longitudinally along side regions of said member coextensive with the front and back bulged portions and between and interconnecting such bulged portions and being of lesser fullness and substantially restrained against outward bulging as compared to said bulged portions to promote swinging movement of said adjacent parts in said direction by flexure of said series of bulged portions while lateral compactness of the joint is maintained under inflation of the suit and joint, and means including restraining

means at said sidewall portions for restraining longitudinal separating movement of said adjacent parts and outward bulging of said sidewall portions and for confining bulging of said member to said bulged portions.

13. A flexible joint for connecting adjacent parts of an inflatable high-altitude suit for maintaining the wearer under air pressure substantially greater than the surrounding air pressure while providing for relative swinging movement of said parts forwardly and rearwardly, said joint comprising a tubular member comprising flexible material having substantial fullness at spaced-apart positions along said member in opposite front and back portions in the direction of forward and rearward swinging movement to provide a series of outward bulges in the front and back portions, said bulges being contiguous with one another in each of said front and back portions, and said tubular member having sidewall portions extending longitudinally along side regions of said member coextensive with the front and

back bulged portions and between and interconnecting such bulged portions and being of lesser fullness and substantially restrained against outward bulging as compared to said bulged portions to promote swinging movement of said adjacent parts in said direction by flexure of said series of bulged portions while lateral compactness of the joint is maintained under inflation of the suit and joint, band elements of flexible material disposed circumferentially of said tubular member between adjacent bulged portions for confining bulging of said member to said bulged portions and for restraining outward bulging of said sidewall portions, and strip elements of flexible material extending along said tubular member at said sidewall portions and secured directly thereto for restraining longitudinal separating movement of said adjacent parts and for additionally restraining outward bulging of said sidewall portions.

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**Certificate of Correction**

Patent No. 2,410,632.

November 5, 1946.

**RUSSELL S. COLLEY ET AL.**

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Column 14, line 7, claim 2, for "increasing" read *incasing*; column 15, line 22, claim 5, for "restraining" read *restricting*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 18th day of March, A. D. 1947.

[SEAL]

**LESLIE FRAZER,**  
*First Assistant Commissioner of Patents.*