Nov. 26, 1968 N. A. MacLEOD 3,412,730

MEANS AND METHOD TO PROMOTE BLOOD AND LYMPH CIRCULATION IN PRESSURIZED SUITS

Filed Dec. 8, 1965 2 Sheets-Sheet 1

Fig. 1.

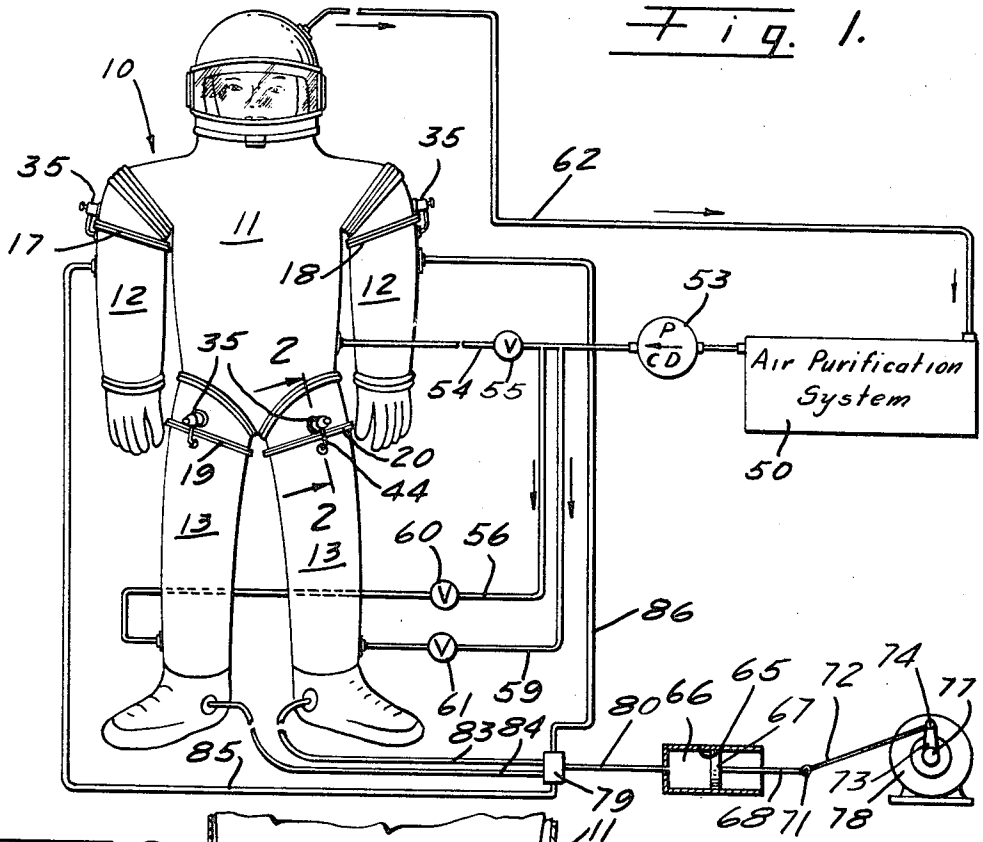
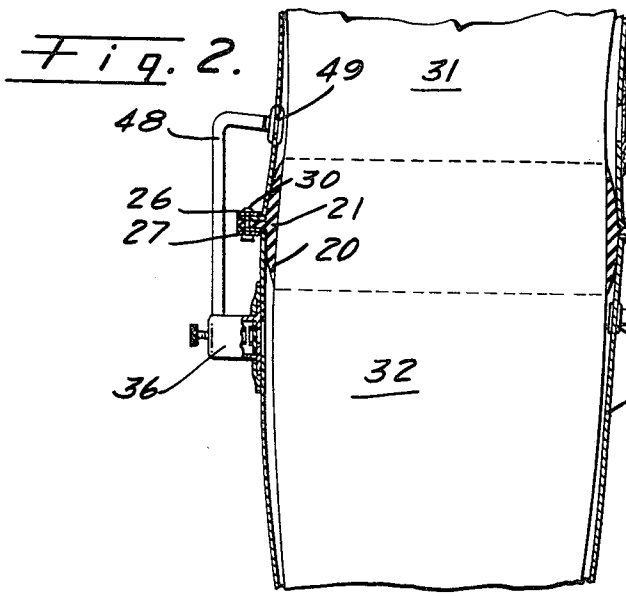


Fig. 2.



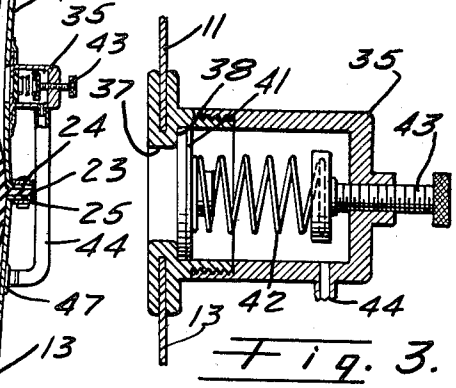


Fig. 3.

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Filed Dec. 8, 1965 2 Sheets-Sheet 2

Fig. 4.

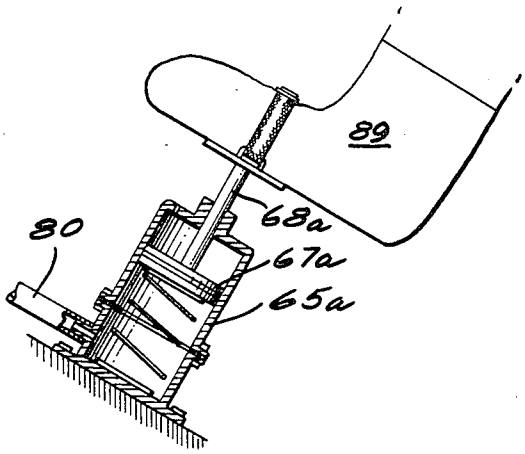


Fig. 5.

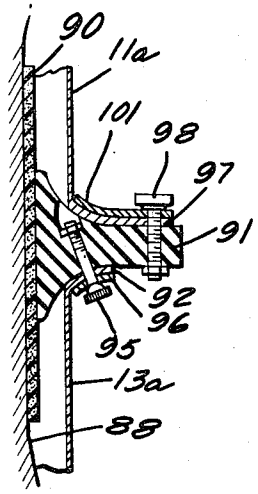


Fig. 6.

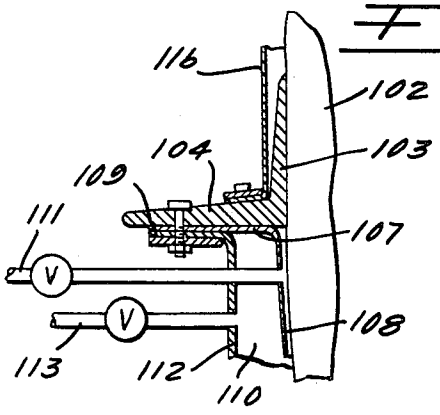


Fig. 7.

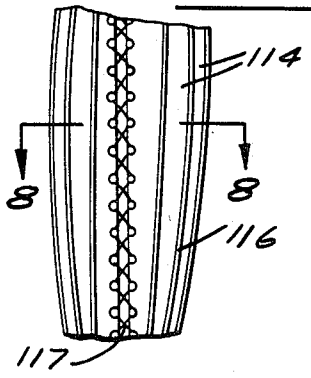


Fig. 8.

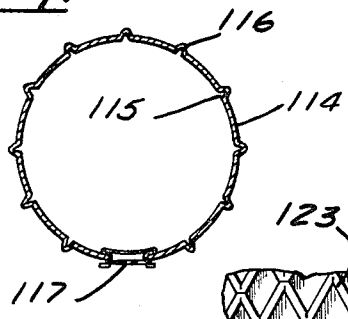


Fig. 9.

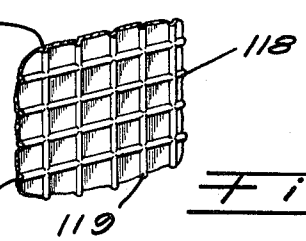
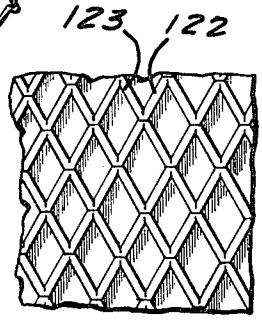


Fig. 10.



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3,412,730

MEANS AND METHOD TO PROMOTE BLOOD AND LYMPH CIRCULATION IN PRESSURIZED SUITS

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Filed Dec. 8, 1965, Ser. No. 512,403
10 Claims. (Cl. 128—40)

This invention relates to a means and method for increasing blood and lymph circulation in astronauts wearing pressurized suits.

The enforced inactivity during space travel accompanied by the loss of gravitational loading on the body tends to produce a condition in a man on a long space flight similar to that of the condition produced by a prolonged confinement in bed. During such prolonged muscular inactivity, there is a loss of calcium and a serious circulatory impairment in a human body.

The circulation of blood and lymph can be assisted by varying the pressure on the body from positive to negative in rapid sequences. These may be done ordinarily by enclosing the limbs in a rigid pressure tank, as disclosed in my United States Letters Patent No. 3,094,983, for Blood Circulation Device and Method. An astronaut, however, must have a continuous freedom of movement even when wearing a space suit and such prior means and method are not applicable to a space suit which must be flexible.

Although space suits are flexible, they can easily sustain a positive pressure up to 15 lbs. per square inch, but if they are completely flexible, negative pressure cannot be used in the suit in that it would cause it to collapse against the body of the wearer. Thus, for example, when a limb is enclosed in a flexible container only positive pressure pulses can be applied and these act against the arterial blood flow into the limb.

It is an object of this invention to produce all of the beneficial effects of positive and negative pressure cycling on the limbs, and even the lower torso, of an astronaut wearing a pressurized space suit so as to cause healthy tissue movement and to assist blood and lymph circulation.

It is another object of the invention to provide an improved pressurized suit.

It is still another object of the invention to provide a space suit which is divided into two or more portions, one of which completely encloses the upper torso and head, and the other of which encloses the limbs. The latter portion may also enclose the lower torso. If a space suit is pressurized to generally, for example, 10 lbs. per square inch, this can be maintained in the upper torso and head portion, but that portion containing the limbs and/or lower torso can have the pressure varied above and below 10 lbs. per square inch as, for example, from 13 lbs. per square inch to 7 lbs. per square inch. This would cause the limbs to be subjected to an alternating pressure cycle of plus or minus 3 lbs. per square inch with respect to the upper torso and head.

It is a further object of the invention to provide a pressurized suit, as described in the preceding paragraphs, for bed-rest patients. In such a suit the general pressure may be maintained at several pounds higher than that of atmospheric pressure. The suit will be of value in treating emphysema, a condition of the lungs in which the ability to perform the normal functions of oxygen absorption and carbon dioxide emission is adversely affected. Concomitant with this is a reduction in the victim's ability to exercise his body, and a lowering of circulatory efficiency thereby results. By raising the pressure in the suit to several pounds per square inch above atmospheric pressure, the rate of oxygen absorption by the lungs will

be increased. Varying the pressure in the limb portion of the suit above and below the pressure in the head and upper torso will cause tissue movement and promote blood and lymph circulation.

General suit pressures as high as 10 lbs. per square inch above atmospheric pressure could be used in such treatments although pressures of only 2 to 4 lbs. per square inch would produce significant results.

Such a method of treatment would also be beneficial to patients having heart disease and those suffering from the general debility of old age.

Further objects and advantages of the invention may be brought out in the following part of the specification wherein small details have been described for the competence of disclosure, without intending to limit the scope of the invention which is set forth in the appended claims.

Referring to accompanying drawings, which are for illustrative purposes:

FIG. 1 is a front elevational view of a pressurized suit according to the invention;

FIG. 2 is a fragmentary cross-sectional view, taken substantially as indicated by line **2—2** in FIG. 1;

FIG. 3 is an enlarged cross-sectional view of the valves shown in FIG. 2;

FIG. 4 is a fragmentary view, partially in cross-section, of an alternate means to vary the pressure in the limb portions of the suit shown in FIG. 1;

FIG. 5 is a fragmentary cross-sectional view of a means to seal one portion of the suit in FIG. 1 from another;

FIG. 6 is a fragmentary cross-sectional view of an alternate embodiment of the limb portion of the suit shown in FIG. 1;

FIG. 7 is a fragmentary view of an alternate type of limb portion of the suit shown in FIG. 1;

FIG. 8 is a cross-sectional view, taken as indicated by the line **8—8** in FIG. 7;

FIG. 9 is a view of a type of flexible material usable for the limb portions of the suit; and

FIG. 10 is a fragmentary view of a variation of the material shown in FIG. 9.

Referring again to the drawings, there is shown in FIG. 1 a space suit generally designated as **10**. Space suits may be made of rubberized cloth so that a pressure seal may be maintained or the suit may be made of similar elastomeric materials to provide flexibility and ease of movement for the wearer. They also may be made using varying amounts of metal which may be imbedded in elastomeric materials for ease of sealing and for flexibility.

The space suit shown has an upper torso and head portion **11** and two limb portions **12** and **13**, for the arms and the legs, respectively. Each of the arms and legs and the inside of the portions of the suit covering them are sealed from the torso and head and the inside of the portion of the suit covering them. The seals are shown at **17**, **18**, **19** and **20** in FIG. 1, and in an enlarged view of the seal **20** in FIG. 2. Each of the seals, as indicated in FIG. 2, is made of an annular band **21** of elastomeric material such as adapted to snugly fit on the leg or arm on which it is intended to be used. Extending radially outwardly from the seal's outer circumferential surface is an annular flange **23**. In the case of the seal **20**, the upper side of the flange abuts an annular flange member **24**, integral with the torso portion of the suit above the seal, and the lower face of the flange **23** abuts a flange **25** integral with the leg portion **13** of the suit. Above the flange **24** and below the flange **25** are relatively rigid metal rings **26** and **27**. The rings and the three flanges are sealingly secured together by a plurality of circumferentially spaced bolts **30**.

Space suits generally have other layers of material, additional to the outer sealing layer, shown in FIG. 2, as

the torso portion **11** and the leg portion **13**. Irrespective of the layers of material, other than the outer layers shown, the skin of the upper leg **31** and of the lower leg **32** is effectively proximate to the sealing layer of the suit so that there is relatively little air space between the skin and the suit, as indicated in FIG. 2.

Between each of the portions of the suit and portions of the body which are sealed from each other, such as an arm and the torso or a leg and the torso, there are a pair of oppositely closing, spring loaded check valves, as **35** and **36**, as shown in FIG. 2. An enlarged view of the valve **35** is shown in FIG. 3, the valves **35** and **36** being identical. The valves **36** are not shown on the suit in FIG. 1 in that they are somewhat rearwardly of the valves **35** but are positioned for comfort so that the astronaut may sit down and lean backwardly without pressing against them.

The valve **35** is open to the torso portion of the suit by means of an aperture **37**. Inwardly of the aperture **37** is an annular seat **38** upon which the valve disc **41** is held in closed position by means of a spring **42** and an adjusting screw **43**. The valve **35** is set to open against the force of the spring when the pressure in the torso portion of the suit is, for example, 3 lbs. per square inch greater than the pressure in the limb portion of the suit. The air, or other life-sustaining gas used, in the torso will then flow into the limb portion of the suit through a tube **44**, sealingly secured to the latter at **47**. Each of the other valves **35** is positioned and set to operate in the same way with respect to the torso and adjoining limb.

The other valves **36** are reversely positioned and each is set to open when a respective limb portion has a desired pressure, for instance, 3 lbs. per square inch greater than that in the suit portion surrounding the torso. The gas in the limb portion will then flow through a tube **48** which has one end connected to the valve and has its other end sealingly secured to the torso portion of the suit at **49** in FIG. 2. Under such settings of the valves **35** and **36**, the torso pressure would normally be approximately 8 lbs. per square inch.

An air purification system **50** supplies purified air or other oxygen mixtures to the pressurized suit **10** by means of a constant delivery pump **53**. Air is supplied directly to the torso and head portion **11** through a tube **54** having a shut-off valve **55**. Fresh air is also supplied to the leg portions of the suit through tubes **56** and **59** having shut-off valves **60** and **61**, respectively. The supply of air to the leg portions is generally for flushing purposes, and air may be moved from the leg portions to the torso by opening the valves **35** or **36**. In the same manner irrespective of the pressure, air may be moved through the latter valves into the leg portions from the torso when they are opened by means of the adjusting screws. Any unused air and the carbon dioxide is returned from the head and torso portion to the air purification system through tube **62**.

To promote blood and lymph circulation, the pressure is varied in the limb portions **12** and **13** by means of a piston pump **65**, having a cylindrical chamber **66** sealed at one end by a piston **67**. A connecting rod **68** is secured at one end to the outer end of the piston and the other end of the rod is pivotally connected at **71** to a rod **72**. The other end of the rod **72** is pivotally connected to an arm **73** at **74**, the arm being rotated about its end **77** by a motor **78**. The length of the stroke of the piston is determined by the position of the pivot point **74** on the arm **73**. To provide a pressure variation from a normal of 5 lbs. per square inch in the limb portions to a decreased pressure of 2½ lbs. per square inch and an increased pressure of 7½ lbs. per square inch, the piston travel volume on suction must be equal to the volume of air in the limb portions plus the connections and the volume of the cylinder in front of the piston. Similarly on the compression stroke, the piston travel volume must equal one-third of the volume of air in the limb portions plus the connections and the volume of the cylinder in front of the piston to produce an overpressure of 2½ lbs. per square inch or an overall pressure of 5 lbs. per square inch.

If the piston travel is in excess of these limits, then the valves **35** and **36** will open if set at pressure limits of 2½ lbs. per square inch and 7½ lbs. per square inch, thus preventing undesirable pressure variations.

The chamber of the pump is connected to a four-way discharge block **79** by means of a tube **80**, the block being connected to the leg portions by tubes **83** and **84** and being connected to the arm portions by tubes **85** and **86**.

In the operation of the space suit, there is a constant delivery of purified air to the torso and head portion by means of the pump **53** and at a constant pressure, for example, 10 lbs. per square inch. If the valves **60** and **61** are open, then the pressure to the leg portions would also be 10 lbs. per square inch. If it is desired, similar conduits may be connected to the arm portions so that the same pressure may be established in them. Where there is no direct connection to the arm portions from the air pump **53**, the pressure can be developed in the arms by opening the valves **35** and closing them before the pump **65** is started. Similarly, when the pump **65** is started, the valves **60** and **61** are also closed.

Thus, to promote circulation of blood and lymph in the arms and legs, the same starting pressure may be caused to exist in the limb portion as in the torso and head portion. Then, if the pressure in the entire suit is 10 lbs. per square inch and the legs and arms are sealed from the head and torso portion, actuation of the pump **65** will increase and decrease the pressure in the arm and leg portions. For example, on the increase, the pressure of the limb portions may have a maximum of approximately 13 lbs. per square inch so as to tend to cause venous circulation to increase from the legs toward the heart. When the pressure is decreased in the limb portions to 7 lbs. per square inch, for example, the arterial flow from the heart to the limb portions is increased because the resisting pressure on the limbs is decreased. The cycling of the pressure variation need not be rapid since the pressure differential in the limb portions from that in the head and torso portion causes increased blood and lymph flow in one direction or the other. The desirable rate for pressure variation is from 10 to 60 cycles per minute.

Since astronauts are extremely healthy people, they normally have very good blood and lymph circulation, and it is probably necessary or desirable that the pressure be varied in the limb portions to promote circulation for about only a few minutes each hour. Experience will dictate the actual length of the period or periods that it will be desirable or necessary to vary the pressure in the limb portions to promote blood and lymph circulation.

The same kind of operation can be used on a bed-rest patient, especially where the patient has heart disease or emphysema and it is desirable to supply air or oxygen-enriched air directly to the lungs at an increased pressure. Under such an increased pressure, the absorption of the oxygen by the blood stream is greatly increased and the patient's lungs can more readily absorb the necessary oxygen for healthy body conditioning. At the same time, as indicated above, variation of the pressures in the limb portions would increase the circulation in the limbs.

In FIG. 4 there is shown a pump **65***a*, equivalent to the pump **65**, and having a piston **67***a* connected to a rod **68***a*. The rod **68***a* is secured to an astronaut's foot **89** so that the astronaut may obtain exercise at the same time the pump is increasing and decreasing pressures in the limb portions to promote circulation. The pump is connected to the tube **80** in the same manner as shown in FIG. 1.

In FIG. 5 another type of seal is shown and which may be used to seal the limb portions from the head and torso portion in the same manner as do the seals **17**, **18**, **19** and **20**. The seal here is comprised of an annular elastomeric member **90**, surrounding a limb portion **88** and in contact

with the skin thereof. Sealingly secured to the annular member **90** is an annular flange **91** extending radially outwardly therefrom. A leg portion **13***a* has a flange **92** at its upper end and which is held in sealing engagement with the flange **91** by a plurality of spaced bolts **95** in contact with an annular ring **96**. At the upper side of the flange **91** a torso portion **11***a* has a flange **97** sealingly secured to the flange **91** by a plurality of spaced bolts **98** and a metal ring **101**.

In FIG. 6 there is an embodiment of the invention which is particularly adaptable to increase the circulation in the limbs of a bed-rest patient. The torso portion **11***b* is shown to be sealingly secured to an elastomeric annular sealing member **103**, formed as a right angle in cross section and having a radially extending flange **104** at the lower end. Sealingly secured to the lower side of the flange **104** is a flange **107** of an inner layer **108** snugly fitted on the leg **102**. The material of the inner layer may be elastomeric so as to seal the leg and must be flexible so as to fit snugly on it. Also, sealingly secured to the lower side of the flange **104** is a flange **109** of an outer layer **112**. The outer layer must be inelastic and must be adapted to hold the liquid under pressure. Between the two layers is a space **110** forming an enclosed chamber **110** about the leg. Extending through the inner layer and outer layers is a valved conduit **111**. When the valve is opened pressure on the outer side of the inner layer will force air from between the skin and the inner layer to permit the inner layer to fit in direct and complete contact with the leg. The outer layer has a valved conduit **113** which is used to fill the chamber **110** with a liquid, generally water. It also may be used to empty the chamber.

In operation, a pump **65** is connected to each of the chambers **110** on the limbs and, since the layer **112** is inelastic, the pressure on all of the water therein, as well as the connections thereto, may be rapidly cycled as described in my U.S. Letters Patent No. 3,094,083, mentioned above. Such rapid cycling of pressure impulses in all of the liquid is particularly conducive to vary the pressures on the limbs through the layers **108** so as to greatly stimulate the arterial flow toward the legs when the pressure is decreased and to similarly stimulate the flow of blood toward the heart through the capillaries and veins when the pressure is increased.

In FIGS. 7 and 8, layers of generally flexible material are shown and which may be tightened on the limbs as a substitute for the relatively loose material as shown in the arm and leg portions **12** and **13** in FIG. 1. Here the material may be elastomeric and has a series of circumferentially spaced portions **114** which are adapted to be in snug fitting contact with the limb. Spaced between the portions **114** are grooves **115** formed by elongated, stiffened protrusions **116**. In this structure, the grooves **115** provide passages for the air or gas within the limb portions of the suit and, when the pressure is increased or decreased within the limb portions, the gases will flow through the grooves so as to make the pressure changes within the limb portions effective upon the limbs to promote circulation. The material is tightened so as to be in contact with the limbs by means of the lacings **117**.

In FIGS. 9 and 10 alternate embodiments of limb portion materials are illustrated. Each of these materials are flexible and adapted to seal the limb as a part of the suit. The material shown in FIG. 9 has protrusions **118** and **119** at right angles to each other and forming grooves **120** and **121** to face the skin and provide air passages. In the same manner the material shown in FIG. 10 has protrusions **122** and crossing protrusions **123** which similarly permit the formation of grooves on the inside of the material for the air or gas passage around the limbs.

The invention and its attendant advantages will be understood from the foregoing description and it will be apparent that various changes may be made in the form, construction and arrangement of the parts of the invention without departing from the spirit and scope thereof or sacrificing its material advantages, the arrangement hereinbefore described being merely by way of example. I do not wish to be restricted to the specific form shown or uses mentioned except as defined in the accompanying claims, wherein various portions have been separated for clarity of reading and not for emphasis.

I claim:

1. In a pressurizable suit for enclosing a human body:
(a) a first part of a suit for sealingly enclosing the torso and head;
(b) a second part of said suit for sealingly enclosing at least one pair of the limbs;
(c) means within said suit to seal the suit parts and the respective body parts therein from each other;
(d) means connected to said first and second parts to supply a constant supply of life-sustaining gas to said parts at a predetermined positive life-sustaining pressure; and
(e) means connected to said second part to alternately increase and decrease pressure therein so that when the pressure is increased it is greater than the pressure in the first part and the blood flow to the heart is increased and when the pressure is decreased it is less than the pressure in the first part and the blood flow into the limbs is increased.

2. The invention according to claim **1** including:
(a) a plurality of separate valved conduits between said parts, at least one of said valves in one of said conduits being set to open at a predetermined pressure to permit said gas to flow from the first part to the second part,
(b) at least one of said valves in another of said conduits being set to open at a predetermined pressure to permit said gas to flow from the second part to the first part.

3. The invention according to claim **1** in which:
(a) said second part of said suit has substantial portions thereof in snug relationship with surfaces of said limbs,
(b) said portions being spaced by elongated passages to permit the flow of said gas along said surfaces of said limbs.

4. The invention according to claim **1** in which:
(a) said means to alternately increase and decrease the pressure in said second part includes a manually operable piston pump.

5. The invention according to claim **1** including:
(a) valve means to shut off said supply of life-sustaining gas to said second part for periods when the pressure therein is being increased and decreased.

6. The invention according to claim **5** in which:
(a) said second part is comprised of an inner and an outer layer having a sealed space therebetween adapted to be filled with water through a valved conduit,
(b) said inner layer being flexible and having a substantial part thereof being adapted to be snugly fitted on said limbs,
(c) means to vent any fluid from between said inner layer and the limbs,
(d) said means connected to said second part to alternately increase and decrease pressure therein being connected to said sealed space between said inner and outer layers so as to be adapted to vary the pressure on said limbs through said inner layer.

7. A method of promoting blood and lymph circulation in the limbs of a human being sealingly enclosed within a pressurizable suit:
(a) providing a constant supply of life-sustaining gas to the suit at a predetermined positive life-sustaining pressure;
(b) sealing the portions of the suit containing at least two of the limbs from a portion of the suit containing the head and torso so as to seal said limbs from the head and torso;

(c) alternately increasing and decreasing pressure surrounding said limbs to make it greater and less than said predetermined pressure so that the blood flow to the heart is increased when said pressure on said limbs is increased and the blood flow into said limbs is increased when said pressure on said limbs is decreased.

8. The invention according to claim **7** including the step of shutting off said constant supply of gas to said limb portions after said portions are sealed and before said pressure is increased and decreased.

9. The invention according to claim **7** including:

(a) snugly fitting said limb portions of said suit on said limbs;

(b) applying a layer of sealing material outwardly of said suit on said limb portions to provide a sealed chamber outwardly of said suit and said limbs;

(c) filling said chamber with liquid; and

(d) applying said increase and decrease of pressure to said liquid to effect said pressure changes on said limbs, said inner layer being flexible.

10. The invention according to claim **7** in which:

(a) said pressure is increased and decreased by the reciprocal pumping action of one of said limbs on a piston pump connected to said limb portion,

(b) the pressure increase occurring on movement of the piston in one direction and the decrease occurring on movement of the piston in the reciprocal direction.

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L. W. TRAPP, *Primary Examiner.*