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I.A.M. Report No. 160

A PHILOSOPHY OF PRESSURE SUITS

by

Squadron Leader J. Ernsting, O.B.E.

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Farnborough, Hants.

November 1960

The crew of aircraft flying at high altitude must be protected against the low environmental pressure and low temperature which characterise the upper regions of the atmosphere. In modern military aircraft this protection is afforded primarily by pressurisation of the crew compartment. Since at high altitude preservation of the artificial environment of the pressure cabin is necessary for the well-being and in many circumstances, the survival of its occupants, the principle of duplication of essential systems is normally applied to cabin pressurisation. Whilst this principle can be applied to the pressure control mechanisms it is impractical to apply it to the structure of the cabin itself. Experience has shown that even in modern aeroplanes the reliability of the pressure cabin is less than that of other essential structures such as the main spar of the wings or the tail plane. Further, in military aircraft there is always the possibility that enemy action may destroy the integrity of the pressure cabin whilst the aircraft remains an effective weapon. Thus a secondary system of protection for the crew against the effects of exposure to the environmental conditions existing at high altitude is necessary. Various forms of emergency protective systems may be envisaged ranging from personal oxygen equipment to a pressurised escape capsule. Whilst the pressure capsule is an interesting engineering concept, no fully tested device of this type is available as yet, and the fitting of such a device to existing aircraft types would entail major structural modifications.

Protection against the effects of exposure to the low pressure and temperature existing at high altitude following failure of the pressure cabin is commonly provided by personal pressurised equipment. Many forms of pressure clothing have been developed and considerable confusion exists as to the degree of protection afforded by and the operational acceptability of various assemblies. The purpose of this paper is to present a rational philosophy of pressure clothing based upon physiological and operational considerations.

The conditions to which the occupants of a cabin may be exposed by failure of pressurisation depend in part upon the nature of the failure. The pressurisation of the cabin may fail because of an insufficient flow of air into it, or an excessive loss of air from it through the normal air outlet system or a defect in the wall of the cabin. The commonest cause of an inadequate inflow of air is engine failure and this cause occurs principally in single-engine aircraft. Whilst failure of supply of air will result in a gross reduction of cabin pressure differential and of the supply of heat to the cabin, it is generally associated in single engined aircraft with the rapid descent of the aircraft. It is usually a design requirement for a pressure cabin that the time taken for the cabin pressure differential to fall to zero after complete cessation of flow of air into the cabin must exceed the time taken for the aircraft to descend from its ceiling to below 40,000 feet[1]. Where this requirement is met the occupant will not be exposed to conditions in which pressure clothing is required by a failure of cabin air supply. In some

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[1] All altitudes quoted in this paper are pressure-equivalent altitudes based upon the I.C.A.N. scale.

military aircraft, however, the cabin leak rate is high and the absolute pressure in the cabin following engine failure may fall to such a level that emergency pressure clothing is necessary even through the aircraft is descending rapidly. Since in these situations the duration of exposure will be short it is unlikely that the temperature to which the occupant will be exposed will be intolerably low.

One of the most common causes of loss of cabin pressurisation is a malfunction of the system controlling the flow of air out of the cabin. Thus the cabin outlet valves may become fixed in the fully open position and inspite of a very high rate of flow of air into the cabin the cabin pressure differential will fall to a negligible value. Whilst a failure of this type results in an absolute pressure within the cabin approaching that of the immediate environment around the aircraft it may or may not result in a serious reduction in the cabin temperature. The cabin temperature following such a failure depends upon a number of factors, including the cabin temperature before failure, the temperature around the aircraft, the temperature, mass and pressure of air flowing into the cabin, the relative sites at which air enters and leaves the cabin, the size of the cabin, the thermal capacity of its walls and the amount of radiant heat entering the cabin through transparencies. There would appear to be a considerable variability in the rate at which the cabin temperature will fall and in the final value which may be reached between one aircraft and another, and in the same aircraft under various circumstances. Thus the cabin temperature following failure of the cabin outlet valves may rapidly approach the temperature of the atmosphere around the aircraft or it may only fall slowly to a value considerably greater than that of the aircraft environment

Various types of defect can occur in the walls of the pressure cabin of an aircraft. Since military aircraft are fitted with mechanical escape systems which require suitable apertures in the cabin wall there is a greater chance of a failure of the cabin wall in this type of aircraft. Likely causes of failure in this group are deflation of the seal round a canopy or hatch, inadvertent release of a canopy or hatch or structural failure of part or of the whole of a transparency. Structural damage due to enemy action may also result in loss of cabin pressurisation. The reduction in the cabin pressure differential caused by a defect in the cabin will depend primarily upon the size of the defect. The site of the defect is also of importance in this connection as in certain positions the flow of air over a defect in the aircraft skin may reduce the absolute pressure within the cabin to a value less than that of the atmosphere around the aircraft. This phenomenon of aerodynamic suck can result, for example, in a pressure altitude within the cabin of 50,000 feet in an aircraft flying at a pressure altitude of 40,000 feet. A further feature of this type of failure is that the fall in cabin pressure differential may occur very rapidly. In addition, when the area of cabin wall which is lost is large, for example a canopy, considerable air movement and turbulence may be created within the cabin. The crew may be subjected to severe buffeting by this air movement. The rate at which the cabin temperature will fall and the final value reached in this type of failure is influenced by the same factors when the defect is in the cabin wall as when loss of cabin pressurisation is due to faulty outlet valves.

Thus various defects can arise in the integrity of the pressure cabin or in the associated pressure control system that will result in the absolute pressure within the cabin falling towards, or even becoming less than the atmospheric pressure around the aircraft. The rate at which the cabin pressure approaches that of the environment can vary over a very wide range, the duration of the pressure change varying between about 0.1 sec. and several minutes. A reduction in the cabin pressure differential may or may not be associated with a significant reduction in the temperature within the cabin. It may be possible to define more closely the conditions to which the crew of a particular type of aircraft may be exposed, particularly if the effects of battle damage are excluded. Thus experience with a particular type of aircraft may show that the pilot's canopy does not come separated inadvertently and that the canopy itself does not shatter. In these circumstances the possibility that the crew may be exposed to very low temperatures when cabin pressurisation fails may not be worth taking into account. It is difficult, however, to see how certain types of failure can be definitely excluded and it is much more logical to suppose that aircrew may be exposed to low pressure and low temperature following failure of the cabin or its associated pressurisation system.

Whenever possible, failure of cabin pressurisation at high altitude is followed immediately by descent to an altitude at which flight with an unpressurised cabin is safe. Before a pilot can initiate such a descent he must be aware that there has been a failure. In most circumstances it should be possible for descent to be initiated within 30 seconds of a serious failure of pressurisation of the cabin. Occasionally the flight path may be such that descent cannot be initiated until a minute or more has passed, e.g. if failure occurs during the ascent in a ballistic type flight path. Whilst rapid descent following failure is highly desirable, there may be aerodynamic and structural reasons for descending fairly slowly. Immediate descent in the sense expressed here may, however, be impractical for reasons of fuel economy or the nature of the mission. Thus the amount of fuel remaining in the aircraft when the emergency arises may be adequate for the return to base only if the flight is continued at high altitude. Operationally it may be essential that an aircraft should remain at high altitude following failure of the pressure cabin. Thus failure may occur deep in enemy territory and the safety of the aircraft and its crew may depend upon the maintenance of height for several hours. Thus the time for which protection is required following loss of cabin pressurisation may be either restricted to several minutes or extended to several hours. When escape from an aircraft is made at high altitude the duration of exposure to high altitude is, of course, limited to only a few minutes.

In order that the protection required against the effects of loss of cabin pressurisation can be considered, the physiological effects of this situation must be discussed. The physiological effects of loss of cabin pressurisation at high altitude may be divided into two groups. The first group of effects is related to the sudden fall in pressure around the occupants of the cabin. The second group is related to the low barometric pressure and low temperature to which the crew are exposed following the failure.

Within the body, the fluid systems will not be directly affected by a fall in barometric pressure (unless the pressure becomes so low that the fluid is close to boiling point or gas comes out of solution). Gases contained in body cavities will tend to expand. Wherever the internal gases cannot escape to the exterior there will be a rise in pressure in the organ relative to the external surface of the body. The gas containing cavities are the intestinal tract, the nasal sinuses, the middle ear cavities and the lungs. Expansion of the intestinal gases may give rise to discomfort, pain and very occasionally circulatory and respiratory embarrassment. There is considerable individual variation as to the degree of discomfort or pain produced by a given change in pressure. Although in a few individuals the expansion of intestinal gas can cause incapacitation due to abdominal pain, distension of abdominal gas will not cause any serious disturbance in the majority of normal healthy aircrew. The gases contained within the cavities of the skull (sinuses and middle ear) generally do not give rise to any disturbance on decompression since the volumes of gas concerned in relation to the size of the ventilating passages to the exterior are small. If, however, these passages are blocked due to, for example, an upper respiratory tract infection, serious pain and haemorrhage may arise. The lungs differ from the other gas containing cavities in the body in that they normally contain a large volume of gas relative to the size of the ventilating passage to the exterior and because the lungs themselves are relatively fragile. Over a very wide range of rates of decompression the expanding gases within the lungs can escape and no disturbance of these organs will occur. If, however, the rate of decompression of the cabin is very fast the expanding gas in the lungs cannot escape rapidly enough and in certain circumstances damage will be done to the lungs. The limits of human tolerance to rapid decompression are determined primarily by the behaviour of the lungs.

The effects of rapid decompression upon the lungs may be modified by the personal oxygen equipment used because the equipment may impede the free flow of gas from the respiratory tract. The flow of gas from the lungs can be impeded by two mechanisms. The first is related to the resistance to gas flow offered by the expiratory port and valve in the oxygen mask. The second is related to the fact that in all pressure demand systems the outlet valve of the oxygen mask is of the compensated type. The compensating mechanism will hold the expiratory valve shut during a rapid fall in cabin pressure and so prevent any egress of gas from the lungs.

Exposure to low barometric pressures can give rise to three distinct physiological effects, viz:- anoxia, decompression sickness and vaporisation of tissue fluids. Anoxia arises when the partial pressure of oxygen within the alveolar gas falls below its normal sea level value of 100 mmHg. Significant anoxia does not arise, in this context, however, until the alveolar oxygen tension falls below 60 mmHg. At altitudes of up to 40,000 feet anoxia may be prevented in the steady state by delivering 100% oxygen to the respiratory tract. At altitudes above 40,000 feet even if 100% oxygen is breathed a significant degree of anoxia will arise since the total barometric pressure is inadequate to maintain an alveolar oxygen tension of greater than 60 mmHg. The degree of anoxia which ensues on exposure to altitudes above 40,000 feet increases rapidly with increasing altitude. Even a short exposure to altitudes of greater than 45,000 feet leads rapidly to unconsciousness (figure 1). Above 50,000 feet unconsciousness ensues within 15 seconds of the exposure. The actual time for which the total lung pressure must be reduced below 90 mmHg absolute for impairment of consciousness to follow is only 5 seconds.

Prolonged exposure to altitudes in excess of 25,000 feet will cause one or more of the symptoms of decompression sickness (bends, chokes and circulatory and neurological disturbances) in the vast majority of subjects Very occasionally decompression sickness occurs on exposure to altitudes between 20,000 feet and 25,000 feet. The incidence of incapacitating decompression sickness increases with increase in altitude and with an increase in the duration of the exposure. Thus whilst exposure to an altitude of 35,000 feet for one hour leads to incapacitating decompression in only 8% of seated subjects, a similar exposure to 37,000 feet will cause incapacitating decompression sickness in 34% of seated subjects (figure 2). Even moderate exercise greatly increases the incidence of decompression sickness as compared with the incidence in the same group of subjects under identical conditions but at rest (figure 3). It is very rare, however, for decompression sickness to arise immediately on exposure to reduced barometric pressure. Incapacitating decompression sickness is seen only very seldom following rapid decompression until at least 5 minutes have elapsed (personal observation). Beyond this time as has been seen the incidence increases with duration of exposure. The incidence of decompression sickness in a group of aircrew can be modified by either the selection of relatively unsusceptible subjects or by denitrogenation. In order that complete protection may be given by denitrogenation the pre-oxygenation must be rigorous. Pure oxygen must be delivered to the respiratory tract for a considerable period of time at low altitude if effective protection is to be given following exposure to high altitude. For example in order to provide 15 minutes protection at altitudes above 35,000 feet 100% oxygen must be breathed for at least one hour at sea level. Denitrogenation at intermediate altitudes up to 25,000 feet is less effective than denitrogenation for the same period at sea level.

When the total barometric pressure is less than the vapour pressure of tissue fluid at body temperature, vaporisation of the fluid will occur. Thus the lungs of animals exposed to pressure altitudes in excess of 63,000 feet become filled with water vapour and vapour locking of their circulation occurs. Such extreme effects do not occur in practical aviation since protection against anoxia alone demands that the absolute pressure within the respiratory tract and circulation be maintained at a value greater than 120 mmHg. Exposure of peripheral regions of the body, for example the hands, to barometric pressures of less than the vapour pressure of the tissue fluids at tissue temperature leads to vaporisation of these fluids with no apparent impairment of performance over short periods of time.

As has already been discussed exposure to low barometric pressure following loss of cabin pressurisation is usually associated with exposure to low temperature. The effects of low temperatures on the body can be divided into two groups, local and general. The local effects which generally arise first in the exposed regions of the body, such as face and the hands, consist of impaired function and eventual tissue damage (frost bite). The general effects which do not occur until the exposure has been of a certain duration consist of progressive impairment of performance followed by unconsciousness and eventually death. An aircrew member wearing normal flying clothing including an oxygen mask and gloves will not suffer any serious damage during an exposure limited to 10 minutes to the lowest temperature conditions which may be encountered at high altitude. Exposure beyond this time will, however, lead to more severe peripheral cold injury and progressive impairment of performance.

It is apparent from the foregoing that the nature of the effects of exposure to low barometric pressure and temperature depend not only upon the absolute pressure and temperature but also upon the duration of the exposure. However extreme the altitude and temperature conditions, provided that the duration of exposure is relatively short, the only serious physiological effect will be anoxia. If however the exposure is prolonged then both decompression sickness and cold injuries will occur. Experience has shown that any exposure may be considered of short duration if the time spent above 40,000 feet does not exceed 5 minutes and that descent to lower altitudes is carried out as rapidly as possible. Even if the exposure to altitudes above 40,000 feet is as long as 10 minutes that the incidence of decompression sickness and cold injury is relatively small. Thus the physiological problems which arise following loss of cabin pressurisation differ widely depending upon whether immediate descent to low altitude is undertaken or whether the exposure to high altitude is prolonged. This difference in physiological effects can be linked logically with the differing operational requirements of immediate descent and prolonged maintenance of altitude following loss of cabin pressurisation.

Protection against the effects of rapid decompression can only be provided by artificially reducing the rate at which the gas pressure around the body falls when the cabin pressurisation fails and thus limiting the pressure differential developed between the lungs and the surface of the chest. It is possible to achieve this form of protection with those types of full pressure suit in which the man is enclosed in an airtight bag before decompression occurs. Under these circumstances as the cabin pressure falls the suit will rapidly inflate and whilst the pressure within it will fall slightly only a small fraction of the sudden reduction in cabin pressure will be transmitted to the man. With a suitable pressure control system the pressure in the suit can then be reduced at a safe rate to the desired absolute pressure. In other types of oxygen equipment possibly the best that can be achieved with respect to rapid decompression is to ensure that the equipment does not add any resistance to the outflow of gas from the respiratory tract. There is a likelihood that in partial pressure suit assemblies some positive protection may be afforded by rapidly inflating a bladder around the trunk to prevent overdistension of the lungs.

In order to prevent significant anoxia at altitudes greater than 40,000 feet 100% oxygen must be delivered to the respiratory tract and the absolute pressure within the lungs maintained at a value of at least 141 mmHg. In certain situations where the duration of exposure is extremely short (and the breathing pressure is relatively low) an intrapulmonary pressure as low as 120 mmHg absolute is acceptable.

In order to prevent decompression sickness following loss of cabin pressurisation at high altitude the pressure of the immediate environment around each aircrew member must not fall below 282 mmHg absolute.[1] In order to be effective this absolute pressure must be applied to the whole of the body. Even if the absolute pressure is not greater than 225 mmHg the incidence of serious decompression sickness in exposures of several hours duration will probably be low. The incidence of incapacitating decompression sickness over this length of time will, however, increase rapidly as the pressure is reduced below 225 mmHg absolute. This physiological requirement is related to unselected aircrew. It is possible to select, by test procedures, subjects who are relatively unsusceptible to decompression sickness. When, however, the duration of exposure is prolonged the proportion of aircrew excluded by such a test procedure will be very significant. For example, in one series of selection tests 50% of the subjects developed serious decompression sickness during a 4 hour exposure to 35,000 feet.

As has been mentioned already protection may also be provided against decompression sickness by denitrogenation. Thus in one group of subjects in order to provide effective protection for a 4 hour exposure at altitudes above 30,000 feet preoxygenation had to be carried out for 4 hours at sea level. Thus unless the selection of unsusceptible subjects with its inherent high wastage rate is accepted or prolonged, preflight preoxygenation is used, the only effective method of providing long duration protection against decompression sickness after failure of the pressure cabin is to maintain the pressure immediately around the subject at or greater than 225 mmHg absolute.

Vaporisation of tissue fluids only occurs when a portion or the whole of the body is exposed to an absolute pressure of less than 47 mmHg. As has been pointed out already the need to protect against anoxia demands that the absolute pressure within the respiratory tract and therefore the circulation is maintained at a value greater than 120 mmHg. Thus vaporisation of tissue fluid can only occur as a local phenomenon on exposure to altitudes in excess of 63,000 feet. Since the high breathing pressures required to prevent anoxia at these altitudes demand that most of the body should be covered, the regions which may be exposed directly to very low pressure are limited. Experimental work exposing the hands to simulated altitudes in excess of 70,000 feet demonstrated that for short duration exposures vaporisation of tissue fluids causes no significant impairment of performance and no deleterious after effects. If the exposure to altitudes above 63,000 feet is to be prolonged then other considerations demand that no part of the body should be exposed directly to the very low barometric pressure.

When, following loss of cabin pressurisation, aircrew are exposed to low ambient temperatures for longer than 10 minutes, protection against the effects of these low temperatures must be provided. Protection entails the provision of insulating material between the skin and ambient air and the supply of heat to the body. If the exposure is to be of long duration then sufficient heat must be supplied in order to maintain the aircrew member in thermal comfort. The distribution of the heat supplied must be such that hands and feet are protected efficiently and the normal temperature controlling mechanism of the body must not be interfered with. A further important point is that heating must be supplied to any valves or ports through which moist gases pass.

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[1] Even at this pressure an occasional case of decompression sickness will occur. The incidence at greater absolute pressures is, however, insignificant in this context.

Thus, to summarise, the physiological requirements for protection following loss of cabin pressurisation may be divided clearly on a time basis into two groups. In situations where immediate descent following loss of cabin pressurisation can be carried out and exposure to altitudes in excess of 30,000 feet does not exceed 10 minutes, it is only necessary to prevent anoxia by providing 100% oxygen to the respiratory tract at an absolute pressure of at least 140 mmHg. If, however, the duration of the exposure exceeds 10 minutes theh not only must protection against anoxia be provided but also against decompression sickness and the effects of low temperature. In order to give protection against these factors the absolute pressure around the body must be maintained at at least 282 mmHg and sufficient heat supplied to maintain thermal balance.

The physiological requirements which have been outlined in previous paragraphs can be met relatively simply by means of a bag encasing the wearer which is pressurised to the desired absolute value and to which oxygen and heat are supplied. The principal difficulty, however, arises when the practical requirements concerned with flight are considered. Thus any personal equipment developed to protect an aircrew member following loss of cabin pressurisation should not in principle reduce his routine flying efficiency. The ideal in this context is that he should wear no specialised personal equipment. Thus a compromise has to be struck between a minimal reduction in routine flying efficiency and adequate protection following loss of cabin pressurisation. Further considerations which have to be borne in mind in the design of pressure clothing is that it must allow the man adequate mobility and the ability to use his special senses so that he can perform the task required of him after depressurisation of the cabin at high altitude. Further this personal equipment must be integrated with the escape and survival systems which are provided in the aircraft. In many details the demands of full routine flying efficiency and of integration with escape and survival systems oppose directly the physiological requirements which have already been outlined. Thus in practice and particularly in the development of operational pressure clothing there must be a compromise between these two conflicting demands. In the end the success of any pressure clothing system will depend on the correctness of this compromise.

As has been described, the ideal physiological solution to the problems of protection following loss of cabin pressurisation is the full pressure suit. It is possible by means of this garment to provide protection against the effects of a sudden reduction in cabin pressure, against anoxia, decompression sickness and the cold. To date, however, no flexible garment has been constructed which, whilst fulfilling the physiological requirements, also meets the practical operational needs. Further, although a full pressure suit will obviously provide protection for short duration exposures, it actually gives more physiological protection than this situation demands. It is important, therefore, to examine the nature of the personal equipment which is necessary for short duration protection at high altitude, i.e. which will prevent anoxia at altitudes in excess of 40,000 feet.

It has been seen that anoxia may be prevented at altitudes of greater than 40,000 feet by delivering 100% oxygen to the respiratory tract and maintaining the pressure within the lungs at a value of at least 141 mmHg absolute. The manoeuvre whereby the absolute pressure within the respiratory tract is maintained at a value greater than that of the environment is known as positive pressure breathing. Positive pressure breathing of itself induces a number of physiological disturbances and, depending upon the altitude to which protection is required, counterpressure must be applied to various parts of the body. Thus at altitudes up to 56,000 feet oxygen under the necessary pressure may be delivered by means of an oronasal mask. The disturbances induced in the head and neck at higher pressures demand that counterpressure should be applied to the fact and upper part of the neck, i.e. at altitudes above 56,000 feet some form of pressure helmet is necessary. Again at altitudes of up to 50,000 feet no body counterpressure is necessary but at the breathing pressures required at altitudes above 50,000 feet support must be given to the respiratory tract by applying counterpressure to the trunk. The circulatory disturbances induced by positive pressure breathing are such that at altitudes in excess of 50,000 ft counterpressure must also be applied to the lower limbs. The combination of counterpressure to the trunk and lower limbs will provide adequate protection at altitudes up to 70,000 ft for short duration exposures. At greater altitudes counterpressure must also be applied to the upper limbs. Thus where short duration protection against anoxia at altitudes above 40,000 feet is all that is required, large regions of the body may be left unencumbered by pressure clothing.

The practical advantages of the philosophy outlined in the previous paragraphs are well demonstrated by the assemblies of partial pressure clothing developed for the Royal Air Force. The basic components of this series of garments are a high pressure sealing oronasal mask, a partial pressure helmet, the pressure jerkin, a bladder by means of which counterpressure is applied to the whole trunk, and the standard Royal Air Force anti-G suit. These components are combined in various ways to provide adequate physiological protection against the effects of sudden exposure to various altitudes for long enough to allow rapid descent to below 40,000 feet (Table I and figure 4).

TABLE I. Royal Air Force Partial Pressure Assemblies

	Assembly	Ceiling of protection (maximum cabin altitude)
A.	Oronasal mask	50,000 feet
B.	Oronasal mask Pressure Jerkin Anti-G suit	56,000 feet
C.	Partial pressure helmet Pressure Jerkin Anti-G suit	70,000 feet
D.	Partial pressure helmet Arm Jerkin* Anti-G suit	110,000 feet

* Pressure jerkin fitted with sleeves which pressurise the upper limbs.

Each of these assemblies with its appropriate pressure demand oxygen regulator has been fully evaluated in an extensive physiological test programme which included the exposure of considerable numbers of subjects to reduced pressure in a decompression chamber. The actual simulated altitude - duration curves for which it has been proved that a given assembly will provide sure protection are shown in figure 4. These curves do not necessarily represent the limits of protection afforded by the various assemblies. In some instances it is known that an assembly will provide protection for a longer period than is shown in figure 4. Directly however the duration of exposure to altitudes in excess of 30,000 feet exceeds 10 minutes the incidence of decompression sickness will become significant. The protective efficiency of these various assemblies has been confirmed by the results of training aircrew in their use. The total number of aircrew presented for training in these assemblies and the incidence of unsuccessful field training are summarised in Table II (unpublished data of Ernsting and Wagner).

TABLE II. Summary of results of training aircrew in the use of R.A.F. partial pressure assemblies

Assembly	Number of aircrew undergoing training	Incidence of unsuccessful training
Oro-nasal mask Pressure Jerkin Anti-G suit	80	1.2%
Partial pressure helmet Pressure jerkin Anti-G suit	136	2.2%
Partial pressure helmet Arm jerkin Anti-G suit	76	1.3%

In many pressure helmets oxygen at the required pressure is applied not only to the respiratory tract but also to the entire surface of the head and the upper part of the neck. The application of pressure by means of such a helmet gives rise to a force which tends to lift the helmet off the head. This force is opposed by tying the helmet down on the trunk portion of the pressure garment. The need for a connection between the helmet and the trunk garment reduces the mobility of the head upon the trunk and requires a complicated mechanical device around the neck. In Royal Air Force partial pressure helmets this problem is overcome by not applying pressure to a region over the crown of the head equal in area to the cross-sectional area of the neck. This partial pressurisation of the head prevents lift of the helmet on inflation and thus eliminates the need for any connection between the helmet and the trunk garment. With this form of helmet no restriction of head movement exists and very little restriction is produced by pressurisation of the equipment.

The simple design of the basic pressure garment of this series of assemblies, the pressure jerkin, ensures that sizing, fitting and donning of the assembly is also simple and rapid. Such an assembly is comfortable to wear during routine flight and does not impose an unacceptable heat load provided that cabin conditioning is adequate. Mobility of the head and upper limbs is unrestricted when the garments are not pressurised since neither the neck nor the upper limbs are encased by the pressure clothing. In full cover garments the most severe restriction of movement caused by inflation occurs at the neck and the shoulder joints. In the R.A.F. series of partial pressure assemblies these effects are avoided by not applying counterpressure to the neck and the shoulder. At altitudes of up to 70,000 feet experience has proved that, for short duration protection, it is unnecessary to apply counterpressure to the neck and to the upper limbs. Even at 70,000 feet there is no restriction of movement of the upper limbs when the pressure jerkin is worn. Although counterpressure must be applied to the upper limbs at altitudes in excess of 70,000 feet it is unnecessary to apply counterpressure to the shoulder itself so that adequate shoulder movement may be retained whilst counterpressure is applied to the arms themselves. Whilst pressure gloves are desirable at altitudes above 70,000 feet no serious impairment of manual dexterity and no permanent damage will ensue if the bare hands are exposed to greater altitudes for a limited period of time.

The relative simplicity of this series of partial pressure assemblies has enabled complete integration with the R.A.F. escape systems to be carried out successfully. The use of a robust multi-services connector has greatly reduced the labour of routine entry to and exit from the ejection seat and has also reduced the incidence of anoxic incidents due to inadvertent disconnection of the oxygen supply. Since the pressure jerkin is the outermost garment the flotation stole has been attached directly to it, reducing the number of separate garments which have to be worn. Extensive flying by both test pilots and squadron pilots has proved that these partial pressure assemblies induce very little impairment of routine flying efficiency in those crew positions for which they were designed. The body garments cause virtually no reduction of trunk or limb mobility. The present partial pressure helmets whilst still some way from the ideal helmet represent a reasonable compromise between the practical and physiological requirements.

In these partial pressure assemblies the pressure jerkin and the mask or pressure helmet are inflated by a pressure demand oxygen regulator. Whilst, in order to achieve protection to the maximum possible altitude, each assembly must be used with a specific type of oxygen regulator, all the assemblies can be used with the same type of regulator. Thus any of the assemblies may be used in an aircraft fitted with a regulator delivering oxygen at an absolute pressure of 141 mmHg at altitudes in excess of 40,000 feet. The limitations to the protection afforded by each of the assemblies when used with such a regulator are given in Table III.

TABLE III. Limitation of protection of partial pressure assemblies when used with a regulator delivering oxygen at 141 mmHg absolute

	Assembly	Ceiling of protection (maximum cabin altitude)
A.	Oronasal mask	45,000 feet
B.	Oronasal mask Pressure Jerkin Anti-G suit	52,000 feet
C.	Partial pressure helmet Pressure Jerkin Anti-G suit	70,000 feet
D.	Partial pressure helmet Arm Jerkin Anti-G suit	110,000 feet

Thus it is possible to provide short duration protection against the effects of exposure to high altitude with a series of assemblies which employ the same aircraft installation. Connection between the assemblies and the aircraft (or seat) mounted regulator is made by way of a single standard personal equipment connector. It is possible for the aircrew to be encumbered with the minimum of pressure clothing consistent with the maximum altitude of the sortie to be flown. The versatility of such an aircraft installation may be extended even further by modifying the panel (or seat) mounted main regulator so that by manual adjustment it will deliver oxygen at any absolute pressure between 282 and 141 mmHg in addition to automatically delivering oxygen at 141 mmHg absolute at altitudes in excess of 40,000 feet. With a modified regulator of this type a full pressure suit may be used in addition to the full range of partial pressure assemblies described above. The full pressure suit will of course also require an air supply for ventilation and pressurisation of the body part of the garment. Such a supply should be available however even when partial pressure assemblies are used.

SUMMARY

Operationally two distinct requirements may be distinguished with respect to the use of pressure clothing following loss of cabin pressurisation at high altitude. On the one hand immediate descent to a safe altitude will be undertaken following loss of cabin pressurisation, so that the length of time for which protection against the effects of exposure to high altitudes will be short, not longer than 5 minutes above 40,000 feet. On the other hand it may be necessary for the aircraft and its occupants to remain at high altitude for some time after failure of the pressure cabin has occurred, the actual time varying from 10 minutes to several hours. Physiological considerations lead to the conclusion that if the duration of the exposure to altitude in excess of 40,000 feet is limited to five minutes then protection against the effects of anoxia alone is required, whilst if the duration of the exposure is greater the aircrew must be protected not only against anoxia but also against decompression sickness and the effects of exposure to low temperature. Adequate long duration protection can only be provided by a full pressure suit in which oxygen is delivered to the respiratory tract, the absolute pressure at the surface of the body is not allowed to fall below 282 mmHg and thermal balance is maintained by supplying heat. Whilst such a suit will also provide adequate protection for a short duration exposure with present designs the wearer is encumbered unnecessarily by a garment covering his whole body when only partial coverage will provide sufficient protection. Thus short duration protection can be afforded by assemblies which cover only part of the body and which therefore allow greater mobility and cause less reduction of flying efficiency than a full pressure suit. Proceeding on these lines a series of partial pressure assemblies have been developed for use by the Royal Air Force, so that the aircrew members can wear the minimum of pressure clothing consistent with the altitude and nature of the sortie he is to undertake. This philosophy has been adopted in order to maintain routine flying efficiency in face of the need for pressure clothing owing to the higher operating altitudes of service aircraft.

REFERENCES

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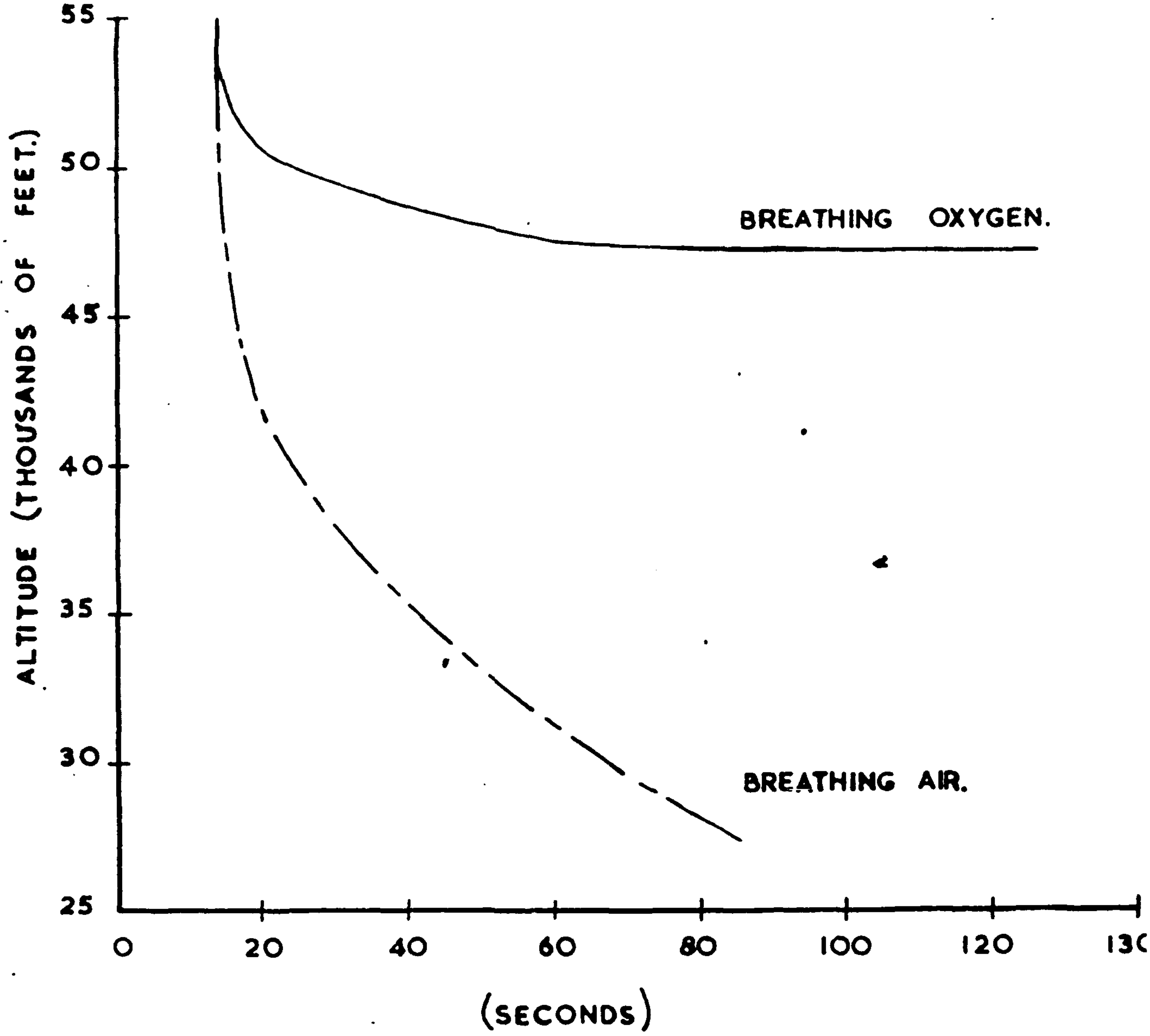
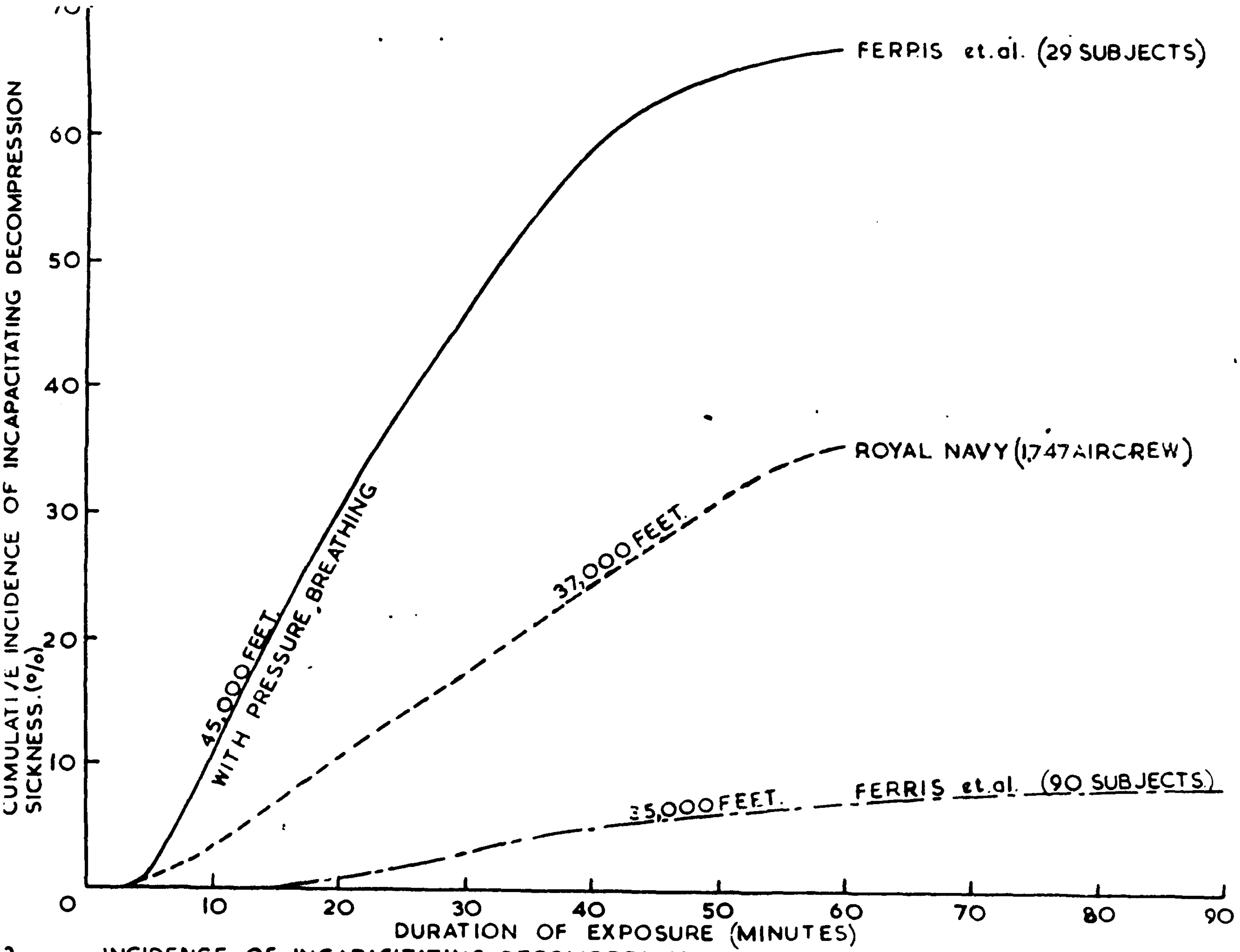


DURATION OF USEFUL CONSCIOUSNESS FOLLOWING RAPID DECOMPRESSION FROM (a) 8,000 ft WHILST BREATHING AIR AND (b) 30,000 ft WHILST BREATHING OXYGEN.

FIGURE. 1.



2. INCIDENCE OF INCAPACITATING DECOMPRESSION SICKNESS IN FIT SEATED SUBJECTS.

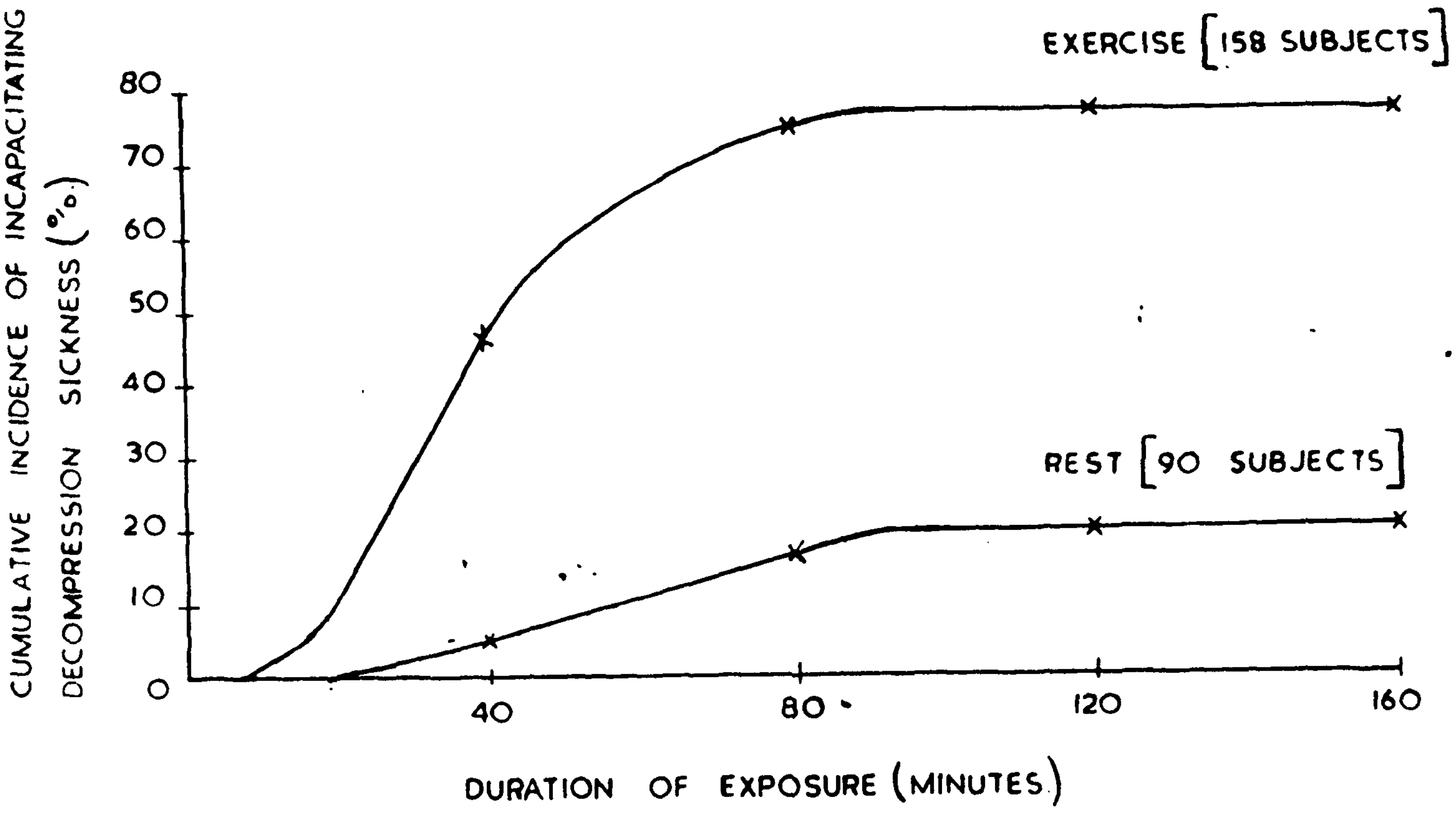
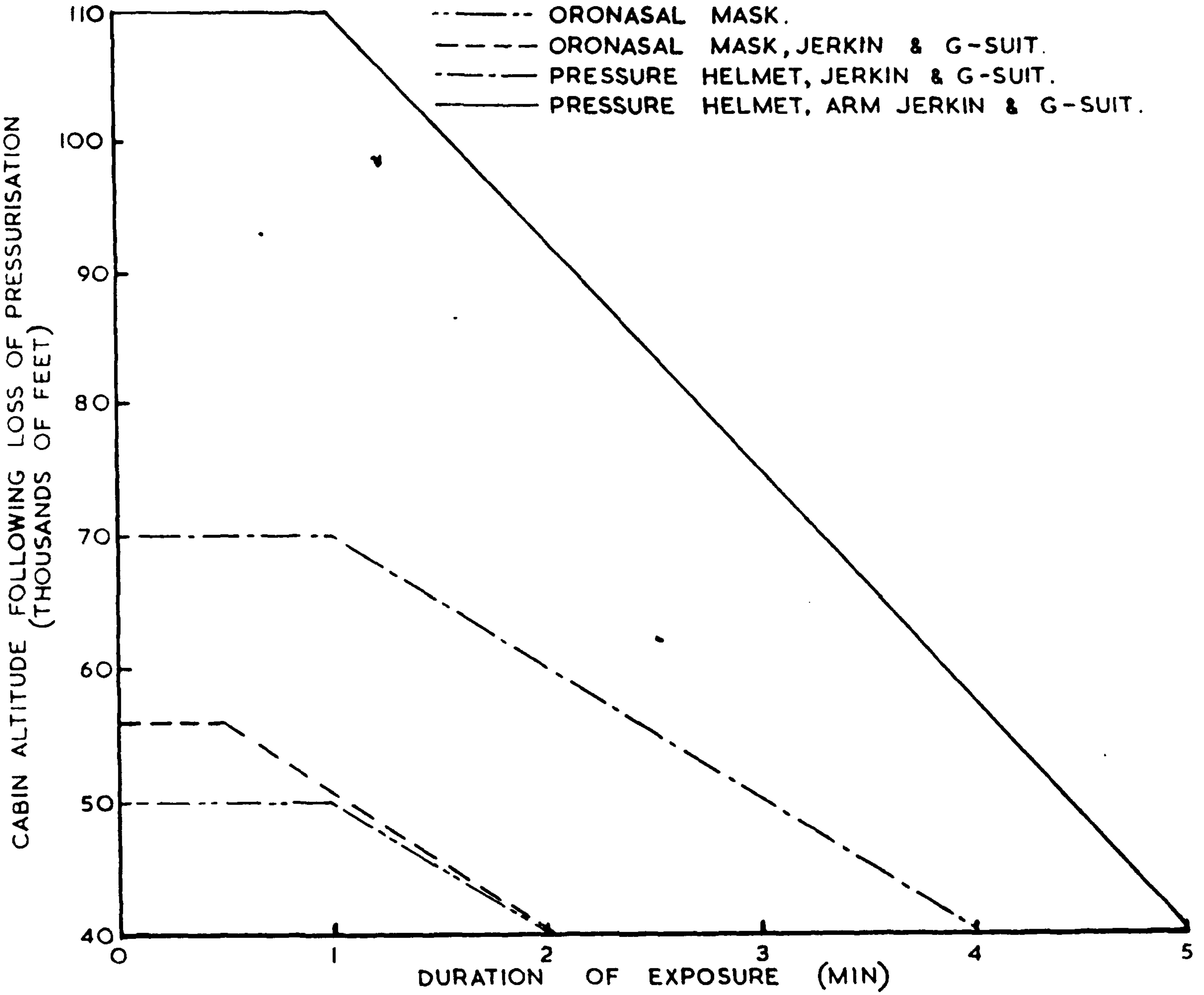


FIGURE 3. THE EFFECT OF EXERCISE [5 KNEE BENDS EVERY 3 MINUTES] UPON INCIDENCE OF INCAPACITATING DECOMPRESSION SICKNESS AT 35,000 feet [FERRIS et al]



DURATION OF PROTECTION AFFORDED BY R.A.F. PARTIAL PRESSURE ASSEMBLIES FIGURE 4