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Hypobaric Training Issues for High Altitude Agile Aircraft

Wing Commander DP Gradwell BSc PhD MB ChB DAvMed FRAeS RAF
RAF Centre of Aviation Medicine, Henlow, Bedfordshire, SG16 6DN. UK.

Introduction

Over the next few years the inventory of many western air forces will change with the introduction into front line service of new high performance aircraft. Such so-called fourth generation combat jets offer enhanced capabilities in terms of speed, agility and altitude, and in particular the potential for these attributes to be combined on a single platform. In Sweden the JAS Grippen has entered service, the development of the F22 Raptor proceeds rapidly in USA and in at least four European countries the introduction of Eurofighter is awaited eagerly. The introduction of these aircraft must be matched by training of the aircrew destined to fly them. Appropriate aeromedical training will, of necessity, be based on the capabilities of the aircraft and thus it will result in a sudden increase in the requirement for more advanced, and more complex hypobaric training.

Aircraft performance

Whilst elements of the capabilities of specific aircraft may remain classified the fundamental performance of this group of aircraft is well known. Indeed the broad requirements for high altitude flight, high agility and survivability are common to all of the aircraft of the next generation. Thus we can expect that the man or woman flying this aircraft will be achieving altitudes of 60,000 ft, fly at speeds up to mach 2 and be exposed to accelerations of up to $+9G_z$. The onset rate of the G loading will be high, perhaps 15G/s, and having achieved peak G it will be sustainable for relatively prolonged periods.

The further complexities of performances include the potential for the application of G in more than one axis and the interaction of elements of the aircraft performance. For example, the aircraft will be capable of very high rates of ascent, and having achieved high altitude will retain much of its high G capability. This will inevitably have consequences for the operation of life support systems and, in the event of a breaching of the integrity of the cockpit, to a potentially significant additional hazard to the pilot.

Life support systems

Taking Eurofighter as an example of these new aircraft types, the primary source of breathing gas for the pilot will be a molecular sieve oxygen concentrator, controlled in such a manner as to deliver to the pilot's mask a gas containing an adequate fractional concentration of oxygen to prevent hypoxia. To avoid the risk of acceleration atelectasis the sieve will operate well below its maximum concentrating capacity, unless higher oxygen content is necessary to prevent hypoxia. However, with high rates of ascent the response of the MSOC control system must be rapid to ensure that it maintains an appropriate FiO_2 in the face of rapidly falling cabin altitudes.

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The requirements for altitude protection up to at least 55,000-60,000 ft were identified early in the development programme for the Eurofighter. At such aircraft altitudes, with an intact cabin, the pilot would be exposed to an altitude no more than 22,500 ft (300 mm Hg). Loss of cabin pressurisation, however, would result in the aviator being exposed to an ambient pressure of perhaps as little as 54 mm Hg. To afford protection against the worst consequences of hypoxia positive pressure breathing is provided, with mask cavity pressures of approximately 70 mm Hg (9.3 kPa). This short duration protection against hypoxia is not, of course, without its own adverse physiological consequences, making it essential that an efficient counter-pressure assembly is worn. In the case of Eurofighter that counter-pressure assembly consists of a chest counter-pressure waistcoat, incorporated in to the aircrew Flight Jacket, and full coverage anti-G trousers.

With pressure breathing used as an element of the G protection system (PBG) it is desirable that the two components of physiological protection operate in a complementary fashion (1). In the case of Eurofighter the roles of the breathing regulator and the anti-G valve are integrated elements of the aircrew services package (ASP), which also serves as the route for the connections between aircraft services, the ejection seat and the man. The inter-linkage between the breathing regulator and the G valve allows the use of anti-G trouser inflation as a part of the altitude counter-pressure assembly. The inflation of the anti-G trousers is performed in accordance with a ratioed relationship with breathing pressure, to provide enhanced lower body counter-pressure. The ASP has therefore two gas supplies, one bringing MSOC product gas to provide the pilot's breathing gas, and the other delivering compressed air for anti-G trouser inflation.

Current high altitude training

The Royal Air Force has operated aircraft at altitudes in excess of 55,000 feet over many years. These aircraft included the Lightning interceptors and the V-force bombers such as Vulcan and Victor. Although these types are no longer in service there is a continuing need to train crews to operate very high altitude reconnaissance aircraft. It has been the established philosophy of RAF aeromedical training that all aircrew should first experience potential physiological challenges such as high altitude under the controlled conditions of hypobaric training in a suitable chamber.

Although the details of the training given to these crews has been described in detail elsewhere (2) it is worth outlining current practice. Aircrew selected to operate high altitude photo-reconnaissance Canberras have previously received aeromedical training which will have included exposure to positive pressure breathing, up to 30 mm Hg (4 kPa), and a rapid decompression to 45,000 ft. Prior to flying the Canberra they are required to experience decompression in a hypobaric chamber, over 3 seconds, from 25,000 ft to 56,000 ft. To prevent severe hypoxia at this altitude they are provided with 100% oxygen at a breathing pressure of 70 mm Hg (9.3 kPa) above ambient.

To prepare the crew for this type of chamber training they are given an intensive, individual course in the use of their specific counter-pressure assembly. This assembly consists of a partial pressure jerkin, covering the whole of the trunk, including the hernial orifices, and a pair of anti-G trousers. Since the bladders of the garments are supplied with gas from the panel mounted pressure demand breathing regulator in the aircraft the mask cavity pressure will be mirrored equally by the pressure in the garments.

To be able to tolerate breathing pressures of this order, however, it is essential that the aircrew are given training in the breathing technique to be adopted. Theoretical training on pressure breathing and the use of counter-pressure garments, appropriate ground level pressure breathing training and physiological assessments are all conducted on the first day of a two-day course. At the end of that first day the crew must be able to tolerate 70 mm Hg PPB for a period of 30 seconds, followed by a progressive decay in the mask cavity pressure to 0 mm Hg over the next 90 seconds.

The following day, after a medical examination, they dress in their normal Aircrew Equipment Assembly (AEA), including counter-pressure garments, helmet and mask, before carrying out a 30 minute period of preoxygenation to reduce the risk of decompression illness at altitude. They are then decompressed breathing 100% oxygen, at a rate of 4,000 ft.min^{-1} to a base altitude of 25,000 ft. When all necessary safety precautions and monitoring are satisfactory they are rapidly decompressed, in 3 seconds, to an altitude of 56,000 ft.

The chamber is held at that altitude, during which time the aircrew subject maintains pressure breathing at 70 mm Hg (9.3 kPa). Descent of the chamber, at a rate of 10,000 ft.min^{-1} is matched by a progressive reduction in breathing pressure, so that after 90 seconds, when the chamber has descended to an altitude of 40,000 ft, the mask cavity pressure is no more than normal safety pressure. The descent rate is maintained until the chamber has been recompressed to 25,000 ft, at which point descent is slowed to 4,000 ft.min^{-1}. On return to ground level the subject leaves the chamber, but subsequently receives a thorough debrief on his performance at altitude. Each subject is decompressed individually and to conduct this training requires the co-ordinated efforts of a team of at least six staff, including specialist medical officers, pressure chamber operators and monitoring technicians.

Subject monitoring

Since high breathing pressures are a physiological challenge in themselves the aircrew undergoing training are medically examined before beginning the ground level training and are monitored both during these positive pressure breathing (PPB) exercises and when undergoing hypobaric exposure to 56,000 ft. For the ground level PPB training the variables observed are: ECG, heart rate, blood pressure, respiratory rate, inspiratory and expiratory flow, and mask tube pressure. A display of inspiratory and expiratory flow is overlaid on a suitable moving sinusoidal trace to assist the subjects to learn to adopt the correct breathing pattern and frequency. This measure is valuable in minimizing the potential for hyperventilation during pressure breathing. Breathing gas pressure is measured from the mask tube, rather than the cavity, to avoid disturbing the subjects own oro-nasal mask.

During the subsequent decompression to high altitude the variables measured are similar, but flow measurements are omitted and haemoglobin saturation added.

Eurofighter hypobaric training

The Director General Medical Services (RAF) established a working party in 1998 to examine the aeromedical aspects of the introduction of Eurofighter into service (3). One of the conclusions of that working group report was that

Eurofighter aircrew should have the benefit of hypobaric training analogous to that given to our existing Canberra aircrew. Therefore it is planned that at least one, and perhaps two hypobaric chambers at RAF CAM will be modified to accept the Eurofighter ASP, mounted on a representative ejection seat.

Cockpit depressurization in agile military aircraft is always possible but the rate at which such an event occurs would depend on the mechanism of its causation. A slow leak of cabin pressure would be detected and can be acted upon by the aircrew in a timely manner but loss of canopy will induce a very rapid decompression. In such an event the rate of decompression can be as fast as 0.1 seconds. Fortunately such events are rare at high altitude, but they do occur. It is not considered necessary, however, to subject aircrew in training to such a fast decompression. Instead they are taught an appropriate, safe breathing pattern to adopt when the countdown to the RD is called. This ensures that their lungs are at end-tidal volume at the time of the decompression. Lung gas expansion will not then result in a significant hazard of pulmonary barotrauma. (4)

To reflect accurately the operation of the normal cabin pressurisation differential, and thus pressure changes in the event of its loss, the base and final altitudes for hypobaric training will be set in accordance with the performance of the environmental control and life support systems. Therefore, as described above, aircrew undergoing training would be decompressed slowly to a base altitude representative of the intact cockpit and then undergo a rapid decompression to a final altitude of, for example 55,000 ft. Although Eurofighter is more manoeuvrable at high altitude than is the Canberra, we anticipate remaining at the final altitude for 30 seconds, before initiating a descent to below the altitude at which pressure breathing is required. Such training would continue to be conducted on an individual basis, with full physiological monitoring. This does, of course, have consequences in terms of the requirement to have available staff trained and experienced in this type of hypobaric exercise.

Further hypobaric considerations

In the training scenario described above the decompression will be conducted as if the aircraft was in straight and level flight. However Eurofighter is an agile aircraft, capable of sustained high G levels at altitude which will be associated with the operation of PBG in the intact cabin. Indeed even if PBG were not used, aircrew would be carrying out anti-G straining manoeuvres which have the effect of raising intra-thoracic pressure. Sudden decompression, in the presence of elevated lung pressure carries a risk of lung barotrauma. Fortunately such events have been rare, to date. However, the more widespread use of high G at higher altitudes must carry an increased risk. Moreover, this risk occurs at any altitude at which cabin pressurisation begins to operate and becomes maximal at the point at which full cabin differential pressures are reached.

Some investigation into this problem has already been conducted (5,6). In two series of experiments subjects were rapidly decompressed whilst already pressure breathing. In the first group decompressions were carried out in 2 seconds between altitudes of 8,000 and 25,000 ft, and in the second group the rapid decompression time was reduced to 1 second. In both groups the subjects tolerated the decompressions well, with no adverse physiological incidents. However, the faster the rate of decompression the greater the risk of an unacceptable increase in intra-thoracic pressure during the change in ambient pressure. Whilst such decompression profiles are perhaps not a suitable training goal it is an area where further research is needed to determine what degree of risk exists and how it may be mitigated.

Conclusion

When the next generation of high performance aircraft enter service there is a need to ensure that the aircrew destined to fly them have received the best possible training, to allow them to cope with the potential significant physiological hazards that are associated with this type of flying. We believe the RAF is well placed to build on many years experience in high altitude training to apply smoothly the lessons learned to the training of aircrew on Eurofighter. It is important to remember however, that in training some of the hazards of loss of cabin pressurisation are significantly reduced and there are areas that require further physiological study, to ensure that we can continue to give appropriate training and timely advice to our aircrew.

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