Physiological hazards of flight at high altitude

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The US Air Force U-2 reconnaissance aircraft flies at 72 000 feet almost every day for many hours. The world's fastest manned aircraft, the SR-71, flew for many years at 80 000 feet and higher. Because of the very hostile low pressure conditions, such excursions into the high altitude environment can only take place with specialised life-support equipment such as pressure suits and oxygen systems to protect against the potential loss of cabin pressure.

On Aug 16, 1960, US Air Force test pilot Joe W Kittinger Jr stepped out of an unpressurised gondola attached to a helium-filled balloon at 102 800 feet above the earth and became the first man to fly supersonic without an aircraft. He also set the world's altitude parachute record, which stands to this day. The potential physiological hazards that Kittinger could have suffered were it not for his life-support equipment include hypoxia, hypocapnia, trapped gas expansion, decompression sickness, ebullism (vaporisation of body fluids), and extreme cold. Furthermore, he had to contend with conditions such as spatial disorientation, flailing of the extremities, opening parachute shock, and spinning. This high altitude environment Kittinger experienced by balloon, free fall, and parachute is also visited by various aircraft, both powered and unpowered (soaring). The environment is simulated in hypobaric chambers used for research and training. Finally, shuttles and other spacecraft traverse this region to reach space. Three physiological hazards associated with the high altitude aviation environment are described below.

Hypoxia associated with altitude exposure happens when oxygen partial pressure in the lung falls below the sea level equivalent of 100 mm Hg, but is not relevant until alveolar oxygen tension falls below 60 mm Hg. At 10 000 feet, reduced ability to learn new tasks can be measured. For that reason, civilian and military regulations state that supplemental oxygen should be used above 10 000 feet of aircraft or cabin altitude. As the partial pressure of oxygen in inspired air continues to drop with increasing altitude, signs and symptoms of hypoxia become more evident, and include loss of peripheral vision, skin sensations (numbness, tingling, or hot and cold sensations), cyanosis, euphoria, and eventually unconsciousness at higher altitudes. Up to an altitude of 34 000 feet, sea level oxygen equivalent can be attained by increasing the percentage of oxygen in the breathing gas. Above 40 000 feet, positive pressure breathing with 100% oxygen is required. Without positive pressure breathing, even very short exposure to altitudes greater than 43 000 feet leads rapidly to unconsciousness.

Aircraft cabin pressurisation systems were developed mainly to prevent hypoxia. Although most modern aircraft are pressurised, there are still a substantial number of civilian and military aircraft that do not have pressurisation systems. Some general aviation aircraft fly as high as 30 000 feet unpressurised. Furthermore, very high altitudes are reached for record-setting attempts in gliders and parachuting from balloons. Oxygen equipment for hypoxia protection for such aircraft ranges from simple nasal cannulas at lower altitudes to highly sophisticated regulators and masks at the higher levels. Large civilian and military aircraft—such as passenger and cargo planes—maintain cabin pressure equivalent at 4000–8000 feet altitude. Because of the air volume in these large planes, accidental loss of cabin pressure usually takes several minutes, allowing the aircraft time to descend to lower altitude. On the other hand, military aircraft such as fighter and reconnaissance aircraft have higher cabin altitudes and smaller cabin volumes that can lose cabin pressure very rapidly. Thus, in high altitude flight, structural failure in a pressurised cabin or loss of cabin pressure control would be catastrophic without hypoxia protection for the crew. Unlike previous

US Air Force

High altitude low opening (HALO) parachute jump

aircraft, the new generation of fighter aircraft is expected to operate up to 60 000 feet or higher. Pilots of these new fighters will be equipped with partial pressure suits, pressure demand regulators, and positive pressure breathing oxygen masks that deliver up to 70 mm Hg in the event of decompression at high altitude. Even with this positive pressure breathing level, oxygen saturation will be about 60%, with the partial pressure of oxygen at about 35 mm Hg while at 60 000 feet. This level is very marginal and will keep the pilot conscious just long enough to descend to a lower altitude.

Exposure to reduced environmental pressure leads to decompression sickness. It can arise in divers returning to sea level pressure from the increased pressure at depth, or in aviation because of exposure to decreased pressures of altitude. In general, decompression sickness is the result of nitrogen evolving from tissues during exposure to reduced pressure. This gas forms bubbles that directly or indirectly cause symptoms of the disease, ranging from mild joint pain to serious neurological manifestations. However, the symptoms of altitude decompression sickness are generally accepted to be less severe than those noted in diving. As a result, several military high-altitude operations are undertaken despite an inherently high risk for the disease. For example, U-2 reconnaissance aircraft have been flying for many years with a risk for decompression sickness of about 75%.

Primary countermeasures to reduce risk of altitude decompression sickness include cabin or pressure suit pressurisation to increase ambient pressure and denitrogenation. This procedure is accomplished by breathing 100% oxygen—referred to as preoxygenation or prebreathing—before and during altitude exposure. This process results in reduced nitrogen concentrations in tissues and thus less evolved gas during exposure. Other ways to reduce the risk of decompression sickness at altitude include good hydration, short exposures, and low levels of exercise. Present treatments for altitude decompression sickness include descent to sea level, breathing 100% oxygen for 2 h or more at ground level, and in serious cases, hyperbaric oxygen therapy.

Ebullism is defined as effervescent evaporation of body fluids at barometric pressure equal to or below saturated vapour pressure at body temperature. Armstrong's line defines the onset of ebullism at 63 000 feet of altitude or 47 mm Hg ambient pressure. Effects noted in animals exposed to these high altitudes include severe tissue anoxia, doubling of body volume, unconsciousness within about 10 s, freezing of secretions by evaporation, circulatory arrest, and total flaccid paralysis in about 30 s.

Although all systems are involved, pulmonary atelectasis is the most important pathological finding in ebullism. Reversal of collapsed lungs is critical to survival. Both high frequency ventilation and hyperbaric oxygen therapy have been suggested. Although fatal for long periods, short exposures (less than 5 min) to low pressure in animals and human beings have happened. In separate hypobaric chamber accidents, two people were exposed to near vacuum conditions; both survived. The first walked out of the chamber with only minor barotrauma, and long-term follow-up suggested no lasting sequelae. The second had substantial pulmonary and cerebral injuries but was functioning at baseline levels within 2 years of the accident. Pressure suits designed for use in high altitude aircraft and in the space programme are the main countermeasure for ebullism.

The medical practice associated with protection of aviators from the physiological hazards of high altitude is highly dependent on doctors' education and ongoing development of new technologies to keep pace with expanding operational demands.