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Quick Response by Pilots Remains Key to Surviving Cabin Decompression

The immediate donning of oxygen masks by the flight crew is the essential first step after an airplane loses cabin pressure at a high altitude.

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When an airplane undergoes rapid decompression above 30,000 feet, the time of useful consciousness (TUC) for flight crewmembers (and passengers) may be 30 seconds or less[1] (Table 1, page 2). But crewmembers' surprise and — in some instances, their lack of familiarity with decompression — may sometimes contribute to delays in responding correctly to the emergency. Research by the U.S. Air Force showed that eight pilots out of 10 who have no prior experience with decompression wait as long as 15 seconds to respond with proper corrective actions to a loss of cabin pressure.[2]

A U.S. Air Force training film of a rapid decompression to 43,000 feet in an altitude-chamber exercise showed several participants who had been informed that decompression was imminent. They had been instructed to respond to the "bang," which signaled the onset of the decompression, by donning an oxygen mask, grabbing a device that resembled a control stick and giving a "thumbs-up" signal to indicate that they were feeling fine.[3] Nearly all the participants needed assistance from the chamber technician to don their masks.

United Airlines pilots have viewed a similar film about the effects of a loss of cabin pressure at different altitudes, said Capt. Jeffrey Bayless, the airline's director of flight safety.[4]

In that film, he said, "a trained individual who knew what was going to happen (decompression) couldn't get the mask on. … The idea of the film was to show that [pilots] can get disoriented very quickly."

Like other airlines, United does not include time in an altitude chamber as part of its decompression training but uses a simulator to instruct pilots on how to respond to cabin decompression; the training includes a simulated loss of cabin pressure and a simulated emergency descent to a safe altitude. Decompression training in a simulator is included as part of a pilot's initial type rating; after that, a simulated decompression typically is part of a pilot's proficiency check every two or three years.[5]

Capt. Robert W. Howard, manager of flight standards at United, said that the airline's emphasis is on ensuring that pilots can meet the requirement by the U.S. Federal Aviation Administration (FAA) that they be able to don an oxygen mask with one hand within five seconds.[6] The Joint Aviation Authorities has a similar requirement.[7]

"The training in donning the mask is the important issue," Howard said. "Avoiding the effects of hypoxia or other causes of respiratory incapacitation is among the highest-emphasis items for pilots and their training. … The emphasis for us is if there's any hint of any problem, you put on the oxygen mask. … We're not taking any chances."[5]

Donning the mask and other elements of decompression training — including mastering emergency descent procedures

Table 1
Time of Useful Consciousness (TUC)
By Altitude

Altitude (feet above sea level)	TUC
40,000	15 seconds
35,000	20 seconds
30,000	30 seconds
28,000	1 minute
26,000	2 minutes
24,000	3 minutes
22,000	6 minutes
20,000	10 minutes
15,000	Indefinite

Source: Adapted from *Fundamentals of Aerospace Medicine*

Sheffield, Paul; Heimbach, R. "Respiratory Physiology." Chapter 5 in *Fundamentals of Aerospace Medicine*, edited by DeHart, Roy. University of Oklahoma, Oklahoma City, Oklahoma, U.S.: Williams and Wilkins, 1996.

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— are accomplished in the classroom and the simulator, he said. United does not require altitude-chamber experience because effective training can be accomplished by other means and because government agencies and aircraft manufacturers have never required — or even recommended — altitude-chamber training for airline pilots, he said.

Capt. Erik Reed-Mohn, manager of governmental and external affairs for the Scandinavian Airlines System Flight Academy — where pilots also receive decompression training in a simulator rather than an altitude chamber — said that his experience in an altitude chamber when he was a Royal Norwegian Air Force pilot in the 1970s convinced him of the benefits of altitude-chamber training.[8]

"You could feel your own mind go," Reed-Mohn said, recalling how he and his colleagues had been assigned to perform simple tasks, such as reciting numbers, during decompression exercises. "You never noticed that you were about to pass out. … They asked questions, and the answers were hard to find. … 'What's the number after 19?' You didn't care. If you encounter that feeling, you're in trouble."

Daniel M. Izard, president and CEO of Associated Aviation Underwriters, an aviation insurance company, said that the company encourages "the highest level of training and recurrent training" for pilots — including decompression training — but does not define what the training should include and does not specify whether altitude-chamber experience should be involved.[9] The type of decompression training that pilots receive does not affect the amount of the insurance premium, Izard said.

Durwood J. Heinrich, director of aviation and chief pilot at Texas Instruments, said that the eight pilots in his corporate flight department receive most of their decompression training in simulators but that, about every five years, they undergo training in an altitude chamber.[10]

Why?

"Two words: Payne Stewart," Heinrich said, referring to an Oct. 25, 1999, accident in Aberdeen, South Dakota, U.S., in which all six people on a chartered Learjet 35, including professional golfer Payne Stewart, were killed.

Preliminary reports from the U.S. National Transportation Safety Board (NTSB) said that the airplane's cockpit voice recorder contained no voices but that there were "sounds consistent with various alarms (cabin altitude/low pressure; stall warnings), plus engine noises and other sounds that may provide useful information for investigators."[11] (As of Feb. 14, 2000, NTSB had made public no conclusions about the cause of the accident.)

Speculation has centered on the possibility that the accident may have been related to decompression early in the flight and that the pilots and passengers may have been incapacitated by the low level of oxygen.[12] Pilots of military aircraft, who were assigned to follow the Learjet after the Learjet crew stopped responding to air traffic control (ATC) transmissions and after the airplane climbed above its assigned altitude of 39,000 feet and deviated from its planned course to Dallas, Texas, said that the airplane's windows were covered with ice and that there was no sign of flight-control movement. The flight ended when the airplane dived into the ground at the time the Learjet's fuel supply would have been exhausted.

Even flight crewmembers with altitude-chamber training may have difficulty recognizing cabin decompression and understanding the importance of speed in donning their oxygen masks, the U.K. Air Accidents Investigation Branch (AAIB) said in a report on an Aug. 13, 1998, decompression incident involving a Boeing 737 (B-737) on a night flight from Dubrovnik, Croatia, to London (England) Gatwick Airport.[13] Both the captain, who had nearly 19,000 hours of flight experience, and the first officer had received altitude-chamber training during their previous military careers.

The first officer was preparing the airplane for descent from Flight Level (FL) 350 to FL 280, as requested by ATC, when he "felt pressure in his ears and therefore checked the cabin pressurization panel above his head," the report said. "He observed that the cabin rate of climb indicator was at the top of its scale" and drew the captain's attention to the indicator. At the same time, the senior flight attendant felt pressure in her ears, heard a "bang" and felt "misting" and a rush of air.

A "bang" is characteristic of an *explosive decompression*, which is defined by NTSB as "a violent expansion and noise from cabin air released under pressure."[14] A *rapid decompression* is one in which cabin pressure increases by 7,000 feet (2,134 meters) per minute or more, generally accompanied by "misting" — or the formation of a cloud in the cabin as the temperature and the dew point in the cabin converge and water vapor condenses into visible droplets. A *slow decompression* occurs if the cabin altitude rises at a rate of a few hundred feet per minute or less.

The B-737 first officer attempted to control the cabin rate of climb by switching to the standby pressurization system, the AAIB report said.[13] When use of the standby system failed to improve the situation, he donned his oxygen mask. The captain, who had been talking with a passenger who was visiting the flight deck, told the visitor to return to her seat and observed that the cabin altitude indicator showed that cabin altitude had climbed to 20,000 feet.

"He therefore attempted to don his oxygen mask, but in doing so, it became entangled with his spectacles and knocked them to the floor," the report said. "He tried to retrieve them but lost consciousness and slumped forward."

The first officer attempted to help the captain but was unable to do so. He initiated a descent, then transmitted several MAYDAY emergency calls to ATC, requesting an immediate descent to a lower altitude, and after one instance of a blocked transmission and another instance in which he received clearance to descend to FL 250, the first officer was assigned a radar heading and cleared for descent to any altitude. The first officer then asked the senior flight attendant to assist the captain.

"To enter the flight deck, [the flight attendant] had to remove her oxygen mask, and although she knew that a portable oxygen set was stowed above row 8, she decided against the delay in retrieving the set and went straight onto the flight deck," the report said. "The first officer pointed to the [captain] and indicated that she should try to assist him. However, before she was able to do so, she collapsed onto the floor."

The first officer attempted again — this time, successfully — to put on the oxygen mask for the captain. Soon afterward, the captain regained consciousness.

"His [the captain's] first action was to deploy the speed brake to increase the rate of descent," the report said. "He then attempted to communicate with the first officer through the flight interphone but was in fact transmitting to ATC. … [H]e could not hear ATC … because of background noise as a result of his inadvertent selection of [automatic direction finder] identification on his audio selector."

Later, as the first officer flew the airplane through 11,000 feet during the descent, the captain assumed responsibility for ATC communications, the report said. The approach and landing were uneventful, but after landing, the captain and four passengers were taken to a hospital. The captain was unaware that he had been unconscious — a typical reaction from a victim of hypoxia — until after the airplane had been landed and the situation was explained to him. An investigation revealed that "the lower aft corner of the aft cargo door was seen to gape open by about half an inch [1.27 centimeters]" and that there was a barely visible crack in the doorframe.

In analyzing the incident, the AAIB report said that, because an experienced captain and an experienced flight attendant had lost consciousness during the decompression, "it is … possible that neither fully appreciated the nature of hypoxia."

"The term 'time of useful consciousness' may lead crewmembers to assume that a longer time is available for performance of tasks than is actually the case," the AAIB report said. "The timescale 'window of opportunity' for donning oxygen [masks] and securing personal safety, and thereby that of the aircraft, can be very limited and must take overriding precedence."

Bayless said that the training given by United and other airlines stresses the limitations that pilots face in responding to an occurrence of decompression — and stresses that those limitations require that pilots don their oxygen masks and initiate oxygen flow before determining the cause of decompression and that they initiate an emergency descent, if necessary, then notify ATC of their actions as soon as possible.[4,15]

Flight operations manuals outline other decompression-related procedures, including specific routes and altitudes to be flown in an emergency descent if a loss of cabin pressure occurs during flight over high terrain and specific fuel considerations if the pressure loss occurs during an extended overwater flight with distant diversion airports.

United's manual, for example, directs pilots who are determining the minimum altitude for operation after an emergency descent to "ensure two factors are considered: terrain separation and fuel remaining. Do not descend below an altitude that provides adequate terrain separation and assures a diversion airport is within range of the airplane."[15]

In events involving long overwater flights, the manual said that fuel for flight after loss of pressure at a critical point en route (a point farthest from an airport suitable for landing) is calculated at 14,000 feet. The manual advises pilots, "[I]f conditions permit, remain at an altitude no lower than 14,000 feet until it is determined that sufficient fuel remains for continued flight at a lower altitude."

Statistics compiled by the U.K. Civil Aviation Authority showed that 77 occurrences of decompression were reported in all types of pressurized aircraft from 1990 through 1999.[16] From 1985 through 1999, 164 decompression occurrences were reported to the Transportation Safety Board of Canada,[17] and from 1990 through 1999, the Australian Bureau of Air Safety Investigation recorded five decompression occurrences.[18]

Hypoxia Defined

The following definitions customarily have been used to describe various types of hypoxia[1]:

- Hypoxic hypoxia: "Hypo" means "low," and this term defines a low level of oxygen in the blood. The hemoglobin molecule in the red blood cells is responsible for bringing oxygen from the lungs to the brain and other parts of the body. If the inhaled air contains insufficient oxygen, the red blood cells cannot perform their duty adequately, and a state of hypoxic hypoxia is said to exist;

- Stagnant hypoxia: If a "plus-G" maneuver is performed so that blood is pulled from the brain, a state of stagnant hypoxia is said to exist. Loss of consciousness caused by the forces of gravity has been known in aviation since the World War I era;

- Histotoxic hypoxia: Certain substances, for example, cyanide and ethyl alcohol, interfere with cellular use of oxygen. In this situation, although the lungs may oxygenate the blood adequately and the heart initially may circulate the blood adequately, body cells begin losing their ability to use oxygen. Death often follows soon afterward, depending on the amount of the toxic agent in the body; and,

- Hypemic hypoxia (also known as anemic hypoxia): Carbon monoxide has a 200-fold greater tendency than oxygen to attach to hemoglobin, and if carbon monoxide binds with the red blood hemoglobin so that insufficient oxygen is being carried, the condition is called hypemic hypoxia. Loss of red cells (because of anemia or hemorrhaging) is also in this category.

In older literature, the term "anoxia" may be found. The literal meaning is "without oxygen," and the term rarely is used today because most oxygen deficiencies occur along a scale of decreasing levels of oxygen in the body, rather than a total absence of oxygen.♦

— Stanley R. Mohler, M.D.

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In the United States, statistics compiled by the FAA Civil Aeromedical Institute (CAMI) showed that 355 occurrences of aircraft decompression were reported from 1974 through 1983, an average of about 35 a year,[19] and less than half were classified as "significant." CAMI classifies an occurrence of decompression as significant if the cabin pressure exceeds 14,000 feet, if the passenger oxygen masks are deployed or if the occurrence results in any injuries.

NTSB described the sudden onset of the explosive rapid decompression on an Aloha Airlines B-737 soon after departure from Hilo, Hawaii, U.S., during a flight in visual meteorological conditions on the afternoon of April 28, 1988.[14] "No unusual occurrences were noted by either crewmember during the departure and climbout. As the airplane leveled at 24,000 feet, both pilots heard a loud 'clap' or 'whooshing' sound, followed by a wind noise behind them. The first officer's head was jerked backward, and she stated that debris, including pieces of gray insulation, was floating in the cockpit. The captain observed that 'there was blue sky where the first-class ceiling had been.' The captain immediately took over the controls of the airplane. He described the airplane attitude as rolling slightly left and right and [said] that the flight controls felt 'loose.'"

The cockpit was so noisy that the pilots initially could communicate with each other only by using hand signals, and the first officer was unsure whether ATC could hear her radio transmissions. The crew declared an emergency and landed at Kahalui Airport, Maui, Hawaii.

One person, a flight attendant who was standing in the aisle when the decompression occurred, was killed when she was swept out of the cabin through a hole in the fuselage, and eight people received serious injuries. The airplane was damaged beyond repair. The report said that the probable cause of the accident was the failure of the airline's maintenance program to detect disbonding and fatigue damage that ultimately led to failure of a lap joint and the separation of part of the fuselage.

Six years later, on April 4, 1994, the pilot of a Skywest Airlines Fairchild Metro III heard a loud "bang" as he flew the airplane through 19,800 feet on what was to have been a climb to FL 210 near Ontario, California, U.S.[20]

The NTSB report on the incident said, "The captain was partially sucked through the broken left side window. After about four seconds, he was able to pull himself back into the aircraft unassisted. He declared an emergency and landed the aircraft without further incident."

The captain received minor injuries; the 11 other people on the airplane were not injured. The report said that the probable cause of the occurrence was the failure of maintenance personnel to detect a windscreen crack that exceeded operational limits for pressurized flight.

The crew of an American Trans Air Boeing 727 experienced what began as a slow decompression on a night flight that departed from Midway Airport, Chicago, Illinois, U.S., on May 12, 1996. The NTSB report said that the cabin-altitude warning horn sounded as the airplane reached cruise altitude at FL 330.[21]

"The captain noticed the right air conditioning pack was off, and he, along with the flight engineer, attempted to reinstate the pack without using a checklist," NTSB said. "The cabin altitude continued to climb to 14,000 feet, at which time the warning lights illuminated and the oxygen masks deployed in the [passenger] cabin. While attempting to correct the cabin altitude, the flight engineer inadvertently opened the outflow valve."

The result was a rapid loss of cabin pressure.

"The captain, the flight engineer and the lead flight attendant all subsequently became unconscious due to hypoxia," NTSB said. "The captain had delayed donning his oxygen mask. The flight engineer became unconscious after reviving the flight attendant. The first officer, who had only 10 hours of flight time in the airplane, had donned his oxygen mask when the warning horn first sounded, maintained consciousness, and was able to initiate an emergency descent. During the descent, the captain, the flight engineer and the attendant regained consciousness, and an emergency landing was made at Indianapolis, Indiana."

Eleven people, including three flight attendants and eight passengers, received minor injuries; no injuries were reported among the 101 other people on the airplane, including the three-member cockpit crew. The report said that the probable cause of the occurrence was the failure of the captain and the flight engineer to use a checklist to troubleshoot the pressurization system problem and the flight engineer's improper control of the pressurization system.

Physiologically, the major effect of cabin decompression is the reduction of the amount of oxygen available for bodily functions. As cabin pressure decreases and pressure altitude increases, there is a decrease in oxygen in any given volume of cabin air — and less oxygen is in each inhaled breath. To compensate for decreasing oxygen levels, people breathe faster and their pulse rates increase; euphoria and a tingling sensation in the fingers may develop, along with blurred vision, light-headedness, muscle spasms, sinus pain and gastrointestinal discomfort. All of these reactions may be symptoms of hypoxia.[19]

The effects of hypoxia may vary from one person to the next, depending on the person's health, state of fatigue, state of physical fitness and how much activity an individual must perform. (Pilots and flight attendants require more oxygen during an emergency than typical, healthy, seated passengers.) Because the eyes and the brain have a high metabolism and cannot store oxygen, they are most sensitive to oxygen depletion; the first measurable decline in the body's functioning occurs in sight, with some loss of night vision at altitudes as low as 5,000 feet.[22] After several hours at 10,000 feet, many people experience a "measurable deterioration" of their mental abilities and physical dexterity. At 18,000 feet, the mental deterioration may be followed by unconsciousness; the TUC at that altitude is about 15 minutes. At 25,000 feet, the TUC may be as little as three minutes, and in some situations, exposure to cabin altitudes of more than 25,000 feet without supplemental oxygen for more than two minutes might result in permanent brain damage. At higher altitudes, the TUC decreases rapidly; at 40,000 feet, for example, the TUC may be 15 seconds or less.

Other physical effects of decompression include the painful expansion of gases in body cavities — the stomach and intestines, the joints, diseased areas beneath the teeth and inside decayed teeth — and pain in the middle ears and the sinuses as the body adjusts to the pressure change.[19] If the decompression is slow, one of the early symptoms of hypoxia is a blue tinge on the lips and under the fingernails; the color change is a result of the reduction of oxygen in the hemoglobin of red blood cells.[23]

Military pilots began receiving training in altitude physiology in the 1920s. By World War II, physiological training had become widespread in military flight operations. Today, military flight officers and other crewmembers usually receive physiological training, which includes periodic refresher courses. Physiological training encompasses an instruction phase for discussion of the human circulatory system, the human brain, the lungs and other physiological systems, including the sense of balance. Crewmembers receive information on the oxygen-carrying capacity of blood, the physiology of circulation and the hazards of hypoxia to consciousness. The instruction includes discussion of symptoms that may be experienced by individuals as they become hypoxic.

Altitude-chamber training allows pilots to experience the effects of hypoxia and decompression at high altitudes in a carefully controlled environment. As the pressure altitude in the chamber increases, each participant learns which symptoms he or she experiences with the onset of hypoxia: Some feel a tingling in the fingers; others feel a general warmth or a sort of euphoria.

In the United States, Federal Aviation Regulations Part 61 requires anyone who serves as pilot-in-command of a pressurized aircraft to receive ground-school training on physiological aspects of high-altitude flight, including hypoxia and other high-altitude sickness; gas expansion; and duration of consciousness without supplemental oxygen.[24] There is no requirement for civilian pilots to have altitude-chamber experience, but FAA has said that a pilot's ability to recognize hypoxia "can be greatly improved by experiencing and

Table 2
Reactions* Among Participants in U.S. Federal Aviation Administration Altitude-chamber Training, 1965–1992

Students' Symptoms	Total Reactions
Aerotitis media	992
Aerosinusitis	219
Abdominal gas	23
Aerodontalgia	21
Hyperventilation	18
Suspected decompression sickness	4
Apprehension	9
Claustrophobia	3

* Reactions observed among 15,412 participants in altitude-chamber training at the U.S. Federal Aviation Administration Civil Aeromedical Institute in Oklahoma City, Oklahoma, U.S.

Source: U.S. Federal Aviation Administration

witnessing the effects of hypoxia during an altitude-chamber 'flight.''"[25] FAA offers civilian pilots aviation physiology training, including altitude-chamber training, at CAMI in Oklahoma City, Oklahoma, U.S., or at participating military bases.[26]

Typical altitude-chamber training for civilian pilots includes experience at the 25,000-foot-altitude level, a hypoxia demonstration and a decompression from 8,000 to 18,000 feet.

Critics have said that altitude-chamber training for civilian pilots unnecessarily puts participants at risk of decompression sickness and other altitude-related ailments and that alternative methods — including training films and classroom instruction — sufficiently educate pilots about decompression.[27] (In cases of decompression sickness, an individual's exposure to low barometric pressure causes nitrogen and other inert gases that normally are dissolved in body fluids and body tissues to form bubbles; this can occur in different parts of the body.[28] The most frequent symptom is pain in the joints, known as "the bends," but numerous other symptoms may occur, including confusion, headache, blurred vision, dizziness, nausea, tingling in the lower chest and back, abdominal pain, chest pain, muscle weakness, and mottled skin. The most severe cases of decompression sickness can result in death.)

FAA has defended the altitude-chamber training as superior to "mere movies and lectures" and said that, among 15,412 participants in altitude-chamber training between 1965 and 1992, there were four instances of suspected decompression sickness; 1,285 participants experienced other reactions, including ear blocks, sinus blocks, tooth problems, abdominal gas, hyperventilation, claustrophobia, apprehension and pulmonary gas expansion during rapid decompression (Table 2).[29] None of the reactions was classified by FAA as serious.

FAA also said that some of the criticism was based on data gathered from military altitude-chamber training that showed that there was about one case of decompression sickness for every 1,000 participants. The statistic referred to military pilots who receive repeated altitude-chamber training, with career military personnel who serve as observers inside the altitude chambers and with altitude-chamber experiences at altitudes of more than 25,000 feet.

Military altitude-chamber training also involves rapid decompressions from 8,000 feet to 22,000 feet in 1.5 seconds, compared with FAA rapid decompressions, which take participants from 8,000 feet to 18,000 feet in from three seconds to five seconds. The lower altitude and the longer time for the onset of the decompression explain why no cases of pneumothorax were observed among participants in FAA altitude-chamber exercises, FAA said. (Pneumothorax is a leak of air from the lungs into the chest, which can be caused when an altitude-chamber trainee holds his or her breath during rapid depressurization, causing a tear in the lung.)

Regardless of whether the training is conducted in an altitude chamber or a flight simulator, the message is the same: The first step for any flight crewmember faced with a loss of cabin pressure is the immediate donning of an oxygen mask.♦

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Mohler received the 1998 Cecil A. Brownlow Publication Award for journalism that enhances aviation-safety awareness.

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"Racing Balloon Is Shot Down by Air Force Attack Helicopter in Belarus." *Accident Prevention* Volume 53 (July 1996): 1–8.

"A Sudden High-altitude Cabin Decompression Immediately Threatens Safety of Aircraft Crew and Passengers." *Human Factors & Aviation Medicine* Volume 41 (November–December 1994): 1–4.

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