**Chapter 51
Effects of flight**

**David P. Thomson**

**Introduction**

For humans to fly, they must adapt to a very dynamic environment. The Wright brothers were successful because they understood that stability was not possible. To stay in the air, the pilot and aircraft had to be able to adjust to the changing conditions [1]. To care for critically ill and injured patients in this setting requires a basic knowledge of both the forces affecting an aircraft and the forces that affect humans within that aircraft. There are the classic forces of aerodynamics: lift, gravity, thrust, and drag. The forces affecting humans also include vibration, barometric pressure, acceleration, spatial disorientation, and thermal stresses, among others.

**Aerodynamic forces**

In order to understand how the flight environment affects patients and air medical providers, the EMS physician must have a basic understanding of aerodynamic forces and terminology.

For an aircraft to fly, there must be a source of lift. For the fixed wing airplane, that source is the wing. In the helicopter, the rotor blade supplies the lift. In both cases, the wing or rotor passing through the air encounters two phenomena. Bernoulli’s principle states that when air is accelerated, it has a lower pressure. A wing with a curved upper surface and a straight lower surface causes air traveling over the upper surface to speed up to catch its counterpart moving beneath the wing. The pressure on the upper surface is reduced compared to that of the lower surface, producing lift.

Helicopters often have essentially symmetrical airfoils for their rotors; thus the speed of the air relative to the rotor is the same for the upper and the lower surface. For these rotors, and for the wings of many aerobatic aircraft, lift depends on the angle of attack. This is the angle that develops between the chord line (the imaginary line formed between the most forward point in the leading edge and the farthest aft point in the trailing edge) and the direction of the air. Children who put their hands outside the car window and feel the air move their arm up and down take advantage of this phenomenon.

The density of air determines how much lift a given wing or rotor can generate. Hot air does not have as much density as does cold air. Air pressure also decreases with altitude. The combination of the actual altitude above sea level and the effect of the temperature is expressed as the density altitude. Thus an aircraft that might be able to generate enough lift to take off in the winter at JFK airport (at sea level) might not be able to take off in Denver, the Mile High City, in August.

Gravity, or weight, is the force that opposes lift. For aircraft, the weight of the aircraft, its fuel, and its passengers or load determines the effects of gravity. An aircraft that is too heavily loaded cannot overcome the effects of gravity with the effects of lift. Aircraft are tested to determine their useful load, which is the remainder when the weight of the aircraft and its necessary supplies (e.g. fuel, oil) is subtracted from the amount of lift that can be generated.

Thrust is the ability of the engine, or the main rotor, to move the aircraft through the air. A propeller, or a jet engine, provides the thrust for airplanes. For helicopters, the main rotor provides this thrust.

The Wright brothers were among the first to understand that an aircraft propeller is essentially a rapidly spinning wing. The term airscrew has been used to describe how a propeller pulls the aircraft through the air. Just as a screw pulls itself through a piece of wood, the propeller bites into the air and pulls the airplane forward through the air. This pulling allows the wing to pass through the air and generate lift.

Drag is the force that opposes the aircraft’s movement through the air. Thin, smooth, gradually curved shapes move through a fluid more easily than boxy shapes. If one has rowed a jon boat, with its squared bow and flat bottom, then paddled a long, slender kayak, it is easy to appreciate the effects of drag. A slender, tapered business jet experiences much less drag than a biplane.

**Effects on humans**

The first recorded ascents of humans into the air occurred in the 1780s, with the French balloonists, Montgolfier, Charles, and de Rosier. Charles, using a hydrogen-filled balloon, was the first to note that when he ascended rapidly he became exceptionally cold and that when he descended he developed ear pain. Others ascended even higher, with Glaisher and Coxwell noting the effects that occurred when they climbed to 9,450 meters, nearly perishing in the attempt. Even before powered flight was achieved, the effects of altitude on the organism had become apparent [2].

**Atmospheric effects**

The atmosphere has a significant effect on humans in flight. Temperature decreases with altitude at a rate of about 2 ºC (3.5 ºF) per 1,000 feet – the adiabatic lapse rate [3]. For patients and medical crews this phenomenon can become important, as even in helicopters an ascent to 5,000 feet above ground level is not uncommon, resulting in an uncomfortable temperature change. While the Commission on Accreditation of Medical Transport Systems (CAMTS) standard 02.05.15 requires “climate control [4],” knowing the extent of the changes that may occur during a flight is an important consideration in patient packaging.

Barometric pressure at 18,000 feet/5,500 meters is half of that found at sea level, resulting in a doubling of the gas volume, in accordance with Boyle’s law [5]. The most familiar manifestation of this phenomenon is the ear discomfort that many people experience as an airliner descends for landing. Barotitis media and barosinusitis may occur because of these gas volume changes and should be taken seriously as they can incapacitate crew members during critical phases of flight [6]. Although the middle ear and the sinuses are dramatic examples, any gas-filled structure or device can be affected. A pneumothorax or an endotracheal balloon may expand or contract depending on the pressure/altitude change.

While common sense might suggest that any patient transported by air with a pneumothorax should have a thoracostomy, the research is not as clear. A case series from Somalia is illustrative: two patients, treated with needle thoracostomy, survived a trip at 3,000 meters without difficulty. A third patient, who was transported at a lower cabin altitude, also survived his trip but later succumbed to his wounds. The latter patient had extensive adhesions secondary to tuberculosis, making thoracic drainage more difficult [7]. Although they caution the reader against air transport of a pneumothorax, the writers of another case report note that the patient underwent a 2-hour airplane flight without complication, the pneumothorax being discovered incidentally after her arrival at the receiving burn center [8].

Placing a needle or a tube in a patient’s chest is not without risk in itself. In an elegant study from the University of Oklahoma, an experimental model of pneumothorax was flown in a helicopter and the volume changes measured at 1,000 and 1,500 feet above ground level (AGL), altitudes commonly encountered in helicopter EMS (HEMS) transport. The authors noted a 1.5% increase in pneumothorax size per 500 ft increment. They also suggest that the use of oxygen may mitigate some of the effects [9]. It appears that prophylactic placement of a tube, even in a known pneumothorax, may not be needed. Pneumocephalus and penetrating eye trauma also produce worries regarding pressure changes, but there is little literature surrounding the effects of flight on these [10].

Concerns have been raised about endotracheal tube cuff pressures exceeding 30 cmH2O and producing tracheal mucosal injury. A Swiss group adjusted the pressure of the cuff prior to departure, and then measured the pressures during flight, noting that almost all of their patients’ cuff pressures exceeded 30 cmH2O during flight [11]. A group from France notes that it is their practice to fill the cuff with saline when treating intubated patients in a hyperbaric chamber, suggesting that this may be useful for helicopter transfers [12]. However, few follow this practice in air medical transport. On descent, the converse problem can become apparent: the cuff can contract and the patient may develop an air leak [13]. Regular monitoring of cuff pressures with a manometer is recommended.

The pressure decrease associated with altitude also produces hypoxia, with its obvious effects on both the patient and providers (see Volume 1, [Chapter 50](https://jigsaw.vitalsource.com/books/9781118990827/epub/OPS/c50.xhtml#c50)). Pulse oximetry and routine use of supplemental oxygen can be employed to mitigate these effects, but providers should be particularly cautious in managing patients with cardiovascular compromise or anemia.

**Aircraft effects**

The type of aircraft can have a significant effect on both patient and crew. A smooth flight in a newer jet aircraft may produce little fatigue for the passengers. A helicopter flight, even through smooth air, subjects the passengers to constant vibrations of several different frequencies [14], which can have a pronounced effect on crew fatigue [15]. Some have postulated that back pain, a common problem among helicopter pilots, is in part due to vibration [16]. Vibration may affect the spinal muscles [17–19], as well as the vertebrae, depending on the frequencies produced by the individual aircraft type [20]. Vibration may also affect monitors, pumps, and other patient care devices. These devices, and the cables and wires associated with them, must be inspected regularly.

In addition to the issue of vibration is the problem of noise. From the perspective of human physiology, these are closely related [21]. Aircraft engines, propellers, transmissions, and rotors generate significant levels of noise in many different frequency bands [22]. In commercial transport airplanes the engines are at a distance from the cabin, and the pressure hull of the fuselage tends to attenuate engine and wind noise. Modern high-bypass jet engines also tend to produce less noise [23]. Most helicopters, however, have little structure to attenuate the noise, and the engines, transmission, and rotor system are located directly above the passenger cabin [24]. Vibration and noise contribute to fatigue and may be part of the accident chain [21]. Helicopter companies have recognized the importance of this problem and have embarked on studies to better address this issue [25]. At the present time, the best solution is the use of headphones or helmets. Helmets are required by CAMTS for helicopter operations [4]. Both the HGU-56/P and the HGU-86/P helmets, worn by the US military and many HEMS programs, provide substantial hearing protection [26]. Testing of other helmets has yielded similar results [27].

Aircraft motion may have significant effects on patients and crew members. Most medical aircraft are not flown in a manner that produces substantial G forces [28]. The one notable exception to this may occur during takeoff and landing in fixed wing aircraft, where the acceleration may cause patients, crew, and, most importantly, equipment to shift. Crews must package patients and secure equipment accordingly. If the patient has a condition that is likely to be affected by the aircraft movement (e.g. fractures), the crew should discuss this with the pilot to see if the takeoff or landing profile can be modified.

Motion sickness is the most commonly reported side-effect of aircraft travel. Unusual head positions, unexpected turbulence, and the need to concentrate on tasks in the aircraft cabin contribute to this phenomenon. Patients, especially those with conditions that preclude their ability to look out a window or who have nauseogenic medications or conditions, may benefit from prophylactic administration of antinausea medications prior to departure. Crew members may occasionally require antiemetics in order to remain functional. Sedating medications such as the phenothiazine-based antiemetics or antihistamines such as dimenhydrinate should be avoided if at all possible by crew members. Ondansetron, especially in its quick-dissolving form, may be useful for crew members. Other motion sickness remedies, such as ginger root or Sea Bands (Sea-Band Ltd, [www.sea-band.com](http://www.sea-band.com/)) are used by many who seek natural remedies for this malady. Some crew members may be able to overcome motion sickness by looking outside when patient care duties permit.

The conflict between what the instruments say and what the pilot’s vestibular system is experiencing produces spatial disorientation, a sensation that is difficult to overcome. Spatial disorientation is a particular problem for pilots. The most profound and deadly manifestation of spatial disorientation occurs during inadvertent or unexpected flight into instrument conditions. Dark night conditions can produce this same problem, in which the pilot cannot distinguish ground from sky. General Jimmy Doolittle, best known for the “Doolittle Raid” on Tokyo in 1942, demonstrated that aircraft could be flown solely with reference to instruments in September 1929 [3]. Since that time thousands of pilots have become “instrument rated.” Nevertheless, pilots who crash after unexpectedly encountering instrument flight conditions remain a serious problem [29]. Repetitive practice, either in a simulator or with a safety pilot acting as a lookout for the hooded training pilot, allows a pilot to safely manage spatial disorientation. Pilots must keep “instrument current” by performing a series of instrument procedures every 6 months.

Flicker vertigo is a problem that primarily affects helicopter crews. Most noticeable on a sunny day, the rotors produce a visual flicker as they spin. Helicopter rotor systems often produce flicker within a range that produces vertigo (4–20 Hz) [30]. When motion detected by the eyes is in conflict with that perceived by the vestibular system, nausea, or at least a sopite syndrome, can be induced [31–34]. Flicker vertigo produces nausea and disorientation; in rare cases seizures have been reported. Visors or other headgear that limit the view of the rotor system may be helpful in preventing flicker vertigo. Night vision goggles do not appear to enhance or decrease this problem [30].

**Other concerns in the flight environment**

Many HEMS services in the United States use night vision goggles (NVGs) when operating after dark, a practice encouraged by the National Transportation Safety Board [35]. NVGs enhance the available light and present what is essentially a black and white picture in front of the crew member’s eyes. Although NVGs improve the ability of pilots and crews to see at night, they are not without their problems. They have a markedly reduced field of view, and their visual acuity is equivalent to approximately 20/200 [36]. The ANVIS goggles weigh about 800 grams including their mount [37]. When a counterweight is added to the occiput, the NVG, helmet and counterweight weigh about 3.7 kg [38]. This results in neck pain being a common complaint among helicopter crews [39]. Because of these concerns, it is important that helmets fit the crew member well [40].

The air medical service has been described as one of the most dangerous jobs in the United States [41]. In order to mitigate risks, crews wear helmets, flame-retardant uniforms, and boots. Like many other forms of personal protective garb, this flight equipment can make it difficult for individuals to cool during hot and humid operations. Attention must be paid to fluid intake to prevent heat injuries.

Conversely, cold weather operations can pose a threat as many cold weather garments are made of synthetic materials that melt when exposed to a heat source. Flight crew members should wear natural fiber underwear and socks (i.e. cotton, wool, silk). Boots and outerwear should be made of leather or flame-retardant fabrics, such as Nomex®.

**Conclusion**

The provision of emergency care in the aerospace environment poses a number of challenges. Providers must be mindful of the unique characteristics of the airplane or helicopter in which they are caring for their patient. Pressure and temperature changes can significantly affect the patient and the crew. Noise, vibration, and other aircraft effects will alter the way in which care can be delivered. Special consideration must be given to protect the patient and the crew from the environment and the emergencies that can arise as the result of flight.

## References

1. 1 Culick FEC, Dunmore S. *On Great White Wings: The Wright Brothers and the Race for Flight*. New York: Hyperion, 2001.
2. 2 DeHart RL. The historical perspective. In: *Fundamentals of Aerospace Medicine*, 2nd edn. Baltimore, MD: Williams & Wilkins, 1996, pp.3–22.
3. 3 Sanderson J. *Aviation Fundamentals*. Englewood Cliffs, NJ: Jeppesen Sanderson Inc, 1991.
4. 4 Commission on Accreditation of Medical Transport Systems. *Commission on Accreditation of Medical Transport Systems*, October 2012. Available at: <http://camtsshelley.homestead.com/Approved_Stds_9th_Edition_for_website_2-13.pdf>
5. 5 Hart KR. The passenger and the patient in flight. In: DeHart RL (ed) *Fundamentals of Aerospace Medicine*, 2nd edn. Baltimore, MD: Williams & Wilkins, 1996, pp.667–83.
6. 6 Rayman RB. Otolaryngology. In: Rayman RB (ed) *Rayman's Clinical Aviation Medicine*, 5th edn. New York: Castle Connolly Graduate Medical Publishing, 2006, pp.297–307.
7. 7 Haid MM, Paladini P, Maccherini M, et al. Air transport and the fate of pneumothorax in pleural adhesions. *Thorax* 1992;47:833–4.
8. 8 Hurren JS, Dunn KW. Spontaneous pneumothorax in association with a major burn. *Burns* 1994;20:178–9.
9. 9 Knotts D, Arthur AO, Holder P, et al. Pneumothorax volume expansion in helicopter emergency medical services transport. *Air Med J* 2013;32:138–43.
10. 10 Milligan JE, Jones CN, Helm DR, Munford BJ. The principles of aeromedical retrieval of the critially ill. *Trends Anaesthes Crit Care* 2011;1:22–6.
11. 11 Bassi M, Zuercher M, Erne JJ, Ummenhofer W. Endotracheal tube intracuff pressure during helicopter transport. *Ann Emerg Med* 2010;56:89–93.
12. 12 Bessereau J, Coulange M, Jacquin L, et al. Endotracheal tube intracuff pressure during helicopter transport: letter to the editor. *Ann Emerg Med* 2010;56:583.
13. 13 Miyashiro R, Yamamoto L. Endotracheal tube and laryngeal mask airway cuff pressures can exceed critical values during ascent to higher altitude. *Pediatr Emerg Care* 2011;27:367–70.
14. 14 Pearson JT, Goodall RM, Lyndon I. Active control of helicopter vibration. *Comput Control Engine J* 1994;5:277–84.
15. 15 Bateman RP, White RP Jr. Helicopter crew evaluations on the effects of vibration on performance. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 1985;29:550–3.
16. 16 Bongers PM, Hulshof CT, Dijkstra L, et al. Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics* 1990;33:1007–26.
17. 17 De Oliveira CG, Simpson DM, Nadal J. Lumbar back muscle activity of helicopter pilots and whole-body vibration. *J Biomech* 2001;34:1301–15.
18. 18 De Oliveira CG, Nadal J. Back muscle EMG of helicopter pilots in flight: effects of fatigue, vibration, and posture. *Aviat Space Environ Med* 2004;75:317–22.
19. 19 Bazrgari B, Shirazi-Adl A, Kasra M. Seated whole body vibrations with high-magnitude accelerations – relative roles of inertia and muscle forces. *J Biomech* 2008;41:2639–46.
20. 20 De Oliveira CG, Nadal J. Transmissibility of helicopter vibration in the spines of pilots in flight. *Aviat Space Environ Med* 2005;76:576–80.
21. 21 Von Gierke HE, Nixon CW. Vibration, noise and communication. In: DeHart RL. *Fundamentals of Aerospace Medicine*, 2nd edn. Baltimore, MD: Williams & Wilkins, 1996, pp.261–308.
22. 22 Mucchi E, Vecchio A. Acoustical signature analysis of a helicopter cabin in steady-state and run up operational conditions. *Measurement* 2010;43:283–93.
23. 23 Pike AC. Helicopter noise certification. *Acoustics* 1988;23:213–30.
24. 24 Padfield RR. *Learning to Fly Helicopters*. New York: TAB Books, 1992.
25. 25 Caillet J, Marrot F, Unia Y, Aubourg PA. Comprehensive approach for noise reduction in helicopter cabins. *Aero Sci Technol* 2012;23:17–25.
26. 26 Gordon E, Ahroon WA, Hill ME. *Sound Attenuation of Rotary-Wing Aviation Helmets with Oregon Aero Earcup Replacement Products*. Ft Belvoir, VA: US Army Aeromedical Research Laboratory, 2006.
27. 27 Pääkkönen R, Kuronen P. Noise attenuation of helmets and headsets used by Finnish Air Force pilots. *Appl Acoust* 1996;49:373–82.
28. 28 Holleran RS. *ASTNA Patient Transport Principles and Practice*, 4th edn. St Louis, MO: Elsevier Mosby, 2010.
29. 29 AOPA Air Safety Institute. *22nd Joseph T. Nall Report*. Frederick, MD: AOPA Air Safety Institute, 2010.
30. 30 Rash CE. Awareness of causes and symptoms of flicker vertigo can limit ill effects. *Human Fact Aviat Med* 2004;51:1–6.
31. 31 Bubka A, Bonato F, Urmey S, Mycewicz D. Rotation velocity change and motion sickness in an optokinetic drum. *Aviat Space Environ Med* 2006;77:811–15.
32. 32 Bos JE, Bles W. Motion sickness induced by optokinetic drums. *Aviat Space Environ Med* 2004;75:172–4.
33. 33 Johnson D. *Introduction to and Review of Simulator Sickness Research*. Arlington, VA: US Army Research Institute for the Behaviorial and Social Sciences, Rotary Wing Aviation Research Unit, 2005.
34. 34 Kiniorski ET, Weider SK, Finley JR, et al. Sopite symptoms in the optokinetic drum. *Aviat Space Environ Med* 2004;75:872–5.
35. 35 Sumwalt RL. *National Transportation Safety Board*. Available at: [www.ntsb.gov/doclib/speeches/sumwalt/sumwalt050411.pdf](http://www.ntsb.gov/doclib/speeches/sumwalt/sumwalt050411.pdf)
36. 36 Salazar G, Temme L, Antonio JC. Civilian use of night vision goggles. *Aviat Space Environ Med* 2003;74:79–84.
37. 37 Own the Night. Available at: [www.ownthenight.com/catalog/i105.html](http://www.ownthenight.com/catalog/i105.html)
38. 38 Harrison MF, Neary JP, Albert WJ, et al. Physiological effects of night vision goggle counterweights on neck musculature of military helicopter pilots. *Mil Med* 2007;172:864–70.
39. 39 Parush A, Gauthier MS, Arseneau L, Tang D. The human factors of night vision goggles: perceptual, cognitive, and physical factors. *Rev Human Fact Ergonom* 2011;7:238–79.
40. 40 Van den Oord MH, Steinman Y, Sluiter JK, Frings-Dresen MH. The effects of an optimised helmet fit on neck load and neck pain during military helicopter flights. *Appl Ergonom* 2012;43:958–64.
41. 41 Blumen IJ. National Transportation Safety Board. Available at: [www.ntsb.gov/news/events/2009/hems\_public\_hearing/presentations/NTSB-2009-8a-Blumen-revised-final-version.pdf](http://www.ntsb.gov/news/events/2009/hems_public_hearing/presentations/NTSB-2009-8a-Blumen-revised-final-version.pdf)