Chapter 1

The History and Development of Aviation Medicine

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The development of aviation medicine can only be understood in the context of the scientific advances and technical innovations that made flying possible, with balloons in the 18th century, with gliders in the 19th century, and with powered aircraft in the 20th century. The forerunner of aviation medicine was the study of high mountain physiology. The Jesuit priest J. A. de Acosta described the hypoxia symptoms he experienced during his stay in the Andes in the 16th century and thereby coined the term "mountain sickness." Chinese tradesmen also suffered from the symptoms of mountain sickness on their journeys through the Hindukush and the Karokorum mountains and reported these 1600 years before de Acosta did so in 1590.[1–3] Evangelista Torricelli (1608–1647) made an important contribution to altitude physiology with the development of the mercury barometer in 1643. Additionally, he coined the term "air-pressure" and was the first to perform animal experiments under negative pressure conditions.

Otto von Guericke (1602–1686) developed the air pump in 1650 and was thereby the first person to create a "vacuum" (1654). Only a few years later, in 1659, Robert Boyle (1627–1691) constructed an air pump. With the help of his colleague Robert Hooke (1635–1703), he operated the prototype of a vacuum chamber in 1677 (Fig. 1). By

[a] Paul Bert, 1878, includes 264 references about mountain sickness.[10]

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Figure 1. First altitude chamber used by Robert Hooke in 1677. In: Gazenko, 1987.

means of a self-experiment, he was able to form the first conclusions about altitude physiology after spending 15 minutes in the vacuum chamber at an equivalent altitude of about 2400 m (7875 ft). Another significant contribution was presented by Joseph Priestley (1733–1804), who discovered oxygen in 1774. Antoine Lavoisier (1743–1794) shortly afterwards recognized its meaning for oxidation.[2,4–6] By now, the fundamental knowledge for the understanding of altitude physiology had been established.

On November 1, 1783 the first manned flight took place when the French physicist Jean Francois Pilâtre de Rozier (1756–1785) and the officer François Laurent, Marquis d´Arlandes (1742–1809) undertook an ascent with a balloon, built by the Montgolfier brothers, reaching an altitude of 2700 feet (900 m). This date is known as the day aviation was born. de Rozier entered the annals again only two years after his first flight, but this time as the first victim of an aviation accident. In

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Figure 2. First flight-surgeon John Jeffries (1745–1819). In: Crough, 1983.

1785 the Frenchman Jean Pierre François Blanchard (1753–1809) and the American physician John Jeffries (1745–1819) crossed the British Channel in a balloon (Fig. 2), carrying out meteorological experiments. The development of the hydrogen balloon by the French physicist Jacques Alexandre César Charles (1746–1823) allowed greater heights to be reached, which raised serious medical problems: during his first ascent on December 1, 1783 Charles reached a height of over 8200 feet (2700 m) and in doing so experienced ear pain caused by the pressure change, hypothermia and the symptoms of mild hypoxia.[3,6,7]

In 1803, close to Hamburg in Germany, the French physicist, magician and balloonist Etienne-Gaspar Robert, better known as "Robertson," together with M. Lhoest reached a height of over 21 000 feet (7000 m) and reported a general apathy and an acceleration of the pulse[8]: "Our chest seemed expanded and lacked resilience, my pulse was hurried; that of M. Lhoest was less so; like

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mine, his lips were swollen, his eyes bloodshot; all the veins were rounded out and stood up in relief on my hands. The blood had rushed to my head so much that I noticed that my hat seemed too small."[b]

During the ascent by the Italians Andreoli, Brasette and Zambeccary in 1804 up to an altitude of more than 18 000 feet (6000 m), the limit of endurance for further altitude ascents became evident: the aeronauts suffered from frostbites in the upper and lower extremities, nausea and dizziness. However, all of them survived this adventure into the heights. Just over half a century hereafter, on September 5, 1862, the ascent of "Zenith" took the English scientists James Glaisher (1809–1903) and Henry Tracey Coxwell (1819–1900) within just under an hour to a height of over 26 800 feet (8800 m). They, too, fainted. Already at a height of 17 200 feet (5640 m) they noticed tachycardia, difficulties in breathing, and palpitation. Their lips and hands became cyanotic and they experienced difficulties in reading their instruments. 3000 feet (1000 m) higher, Glaisher felt clearly "seasick," and at 26 500 feet (8700 m) they were overpowered by exhaustion and slackness.[1–3,8,9] A scientific dealing with the most urgent high altitude physiological questions was therefore a condition sine qua non.

In his laboratory, the French physiologist Paul Bert (1830–1886) undertook a comprehensive investigation of the physiological effects of air-pressure, often using himself as a subject. His experiments laid the foundation for modern altitude physiology and explained the causes of altitude and decompression sickness: His publication *"La pression barométrique; recherches de physiologie expérimentale"* (1878) was a milestone, not just in the area of altitude physiology but also of experimental medicine in a broad sense. Bert used the altitude chamber in order to establish the physiological effect of pressure change and collected experimental results up to an altitude of 8800 m. This chamber was also used by the balloonists Joseph E. Crocé-Spinelli (1843–1875) and H. Theodore Sivel (1834–1875) for preparation of their altitude ascents (Fig. 3). In this connection they recognized

[b] Citation after P. Bert, 1878: 175.

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Figure 3. Ascent of H. T. Sivel and J. E. Crocé Spinelli on March 22, 1874. In: Paris, Bibl. des Arts décoratifs.

the advantage of extra oxygen at high altitude; nevertheless, on April 15, 1875, a tragic incident occurred: despite Bert's warning that they were carrying an insufficient supply of oxygen, together with the meteorologist Gaston Tissandier (1843–1899) they conducted a balloon ascent from Paris up to over 8000 m (26 250 ft); only Tissandier survived.[11]

On July 31, 1901, in Berlin, the meteorologists Arthur Berson (1859–1943) and Reinhard Süring reached a height of 32 000 feet (10 500 m) with their balloon "Preussen." While Süring lost consciousness at this altitude, Berson was able to start the lifesaving descent. After the landing both scientists reported that after using extra oxygen, the difficulties in breathing and the feeling of fear ceased; however, a leaden fatigue, exhaustion, a weakness to the stomach and, to a lesser degree, a headache continued. In fact, oxygen was provided through glass-tube mouthpieces instead of the recommended face-fitting oxygen masks.[10,11]

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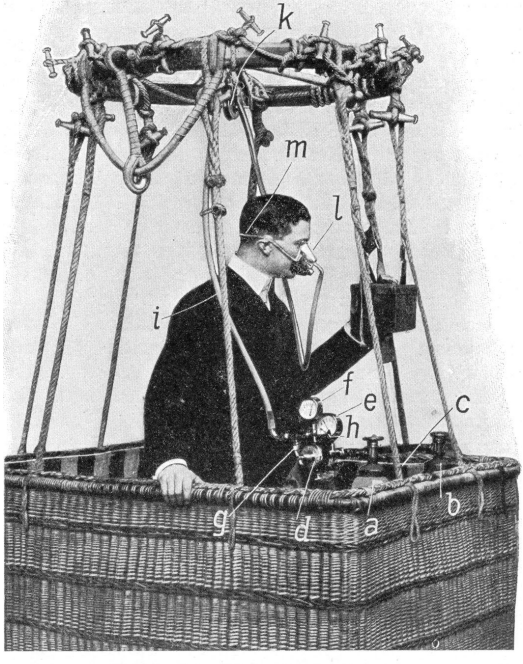
This advance into the stratosphere heralded a new chapter in altitude physiology: stratosphere ascents. The results were especially valuable for the development of aviation and space medicine. As early as 1905, aviation physiologists Nathan Zuntz (Berlin) and his colleague Hermann von Schrötter (Vienna) not only suggested the use of face-fitting breathing masks (Fig. 4) to reach greater heights, but also the employment of a hermetically sealed cabin.[12,13] The Swiss physicist Auguste Piccard (1884–1962) successfully applied this principle in cooperation with Paul Kipfer when they reached a height of 48 132 feet (15 781 m) at an ascent from Augsburg on May 27, 1931 (employing liquid and pressurized oxygen, as well as carbonic acid absorption). In 1933, Russian aeronauts reached a height of about 58 000 feet (19 000 m) in a sealed cabin. The Explorer II



Sauerſtoffausrüſtung für Hochfahrten.
a Sauerſtoffflaſche, b Reſerve-Sauerſtoffflaſche, c Verbindungsrohr, d Reduzier-Ventil, e Inhaltsmeſſer, f Durchlaßanzeiger, g Regulierſchraube, h Abſtellſchraube, i Schlauch, k Schlauchführung, l Maske, m Maskenhalter (Spirale).

Figure 4. Aeronaut with respirator in 1908. In: Flemming, 1909.

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ascended up to over 67 000 feet (22 000 m) in the 1930's in the USA.[7,8] US aviation physician David G. Simons set another milestone in 1957, when he reached a height of about 94 500 feet (31 000 m) as part of the US Man-High-II program in preparation for space travel.[7,11,14]

Technical progress demanded, as demonstrated in the example of the stratosphere ascent, a solution of the medical problems it created. Physiological research at high mountain camps and expeditions provided the necessary preparatory work for aviation medicine (Kronecker, Zuntz, Loewy, Barcroft, Schneider, Haldane, Douglas, Grollmann, Hartmann and others). Berlin physiologist Nathan Zuntz (1847–1920) had been occupied for years with altitude physiological questions in his "pneumatic cabinet," a therapeutically used altitude chamber in a Berlin hospital. His laboratory supported work was complemented by high mountain expeditions as well as practical flight experience. In 1910 he undertook an expedition to Tenerife together with Durig, von Schrötter, Barcroft (Cambridge) and Douglas (Oxford).[15] Zuntz´ fundamental treatise "*Zur Physiologie und Hygiene der Luftfahrt*" (About Aviation Physiology and Hygiene) was published in 1912. In the same year von Schrötter published his treatise "*Hygiene in Aeronautik und Aviatik*" (Hygiene in Aeronautics and Aviation). With their treatises both of them created an awareness of aviation medical tasks.[1,12,13,16]

Scientific and technical advances have always been put to use by the military. For example, the foundation in 1881 of the "German Association for the Promotion of Airship Travel" (Deutscher Verein zur Förderung der Luftschiffahrt) — the first of its kind worldwide — was followed by the opening of the first Prussian airship battalion in 1884. Of special medical interest is the account by medical officer Dr. Flemming, who reported on several sudden deaths caused by arsenic oxygen (composed of sulphuric acid and iron swarfs) in personnel working in the balloon shed or operating the hydrogen generators in the open: (12:173): "In many cases the nausea and the headache were slight so that some of the critically poisoned remained on duty for several hours before reporting sick. Only later did they experience a slight difficulty in breathing, they felt dizzy and

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noticed a tingling feeling in the skin or the sensation that their extremities had gone to sleep. Under the moderate appearance of fever the body became sensitive to pressure and soon followed a nearly unappeasable vomiting of a yellow-green-black substance which only stopped with the increase of exhaustion shortly before death." Nathan Zuntz dedicated an entire treatise to the influence of balloon gases on the state of health of the aeronaut, paying special attention to carbon monoxide poisoning. For the resuscitation of the poisoned persons, Zuntz propagated the methods of artificial respiration after Hall and Silvester, if necessary with the aid of inhalation masks and the use of oxygen (Fig. 5).[13]

The development of aircraft "heavier than air" is inseparably connected with the name of the German engineer and air pioneer Otto Lilienthal (1848–1896).[c] His extensive experimental foundations

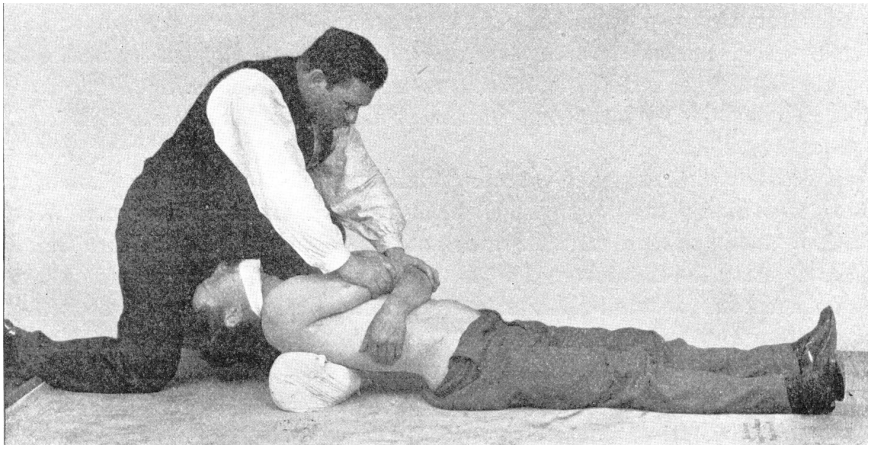

Figure 5. Pulmonary resuscitation after the method of Silvester (picture shows expiration). In: Zuntz, 1912.

[c] To mention all those who have been concerned with the development of aviation would go far beyond the scope of this chapter. Albrecht Ludwig Berblinger (1770–1829) could be mentioned as a representative. Known as the "Tailor of Ulm," he planned to cross the Danube River with a flight apparatus, designed by the Vienna watchmaker Jacob Degen; however, because of an unexpected fast descent into the water, he demonstrated little more than the limits of the technological capabilities of his time.

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were followed by the first glider flights in Drewitz in 1891. In 1896 Lilienthal became the victim of a flight accident in one of his own self-built glider-aircraft. He paved the way for the first motorized flight by the American brothers Wilbur and Orville Wright in December 1903. By the means of serial production of their aircraft, they made aviation available for a greater circle of people. Worldwide, the military also became more and more interested in aviation development: war catalysed the development, which furthered the work in aviation medicine. The employment of aircraft at high altitudes, like zeppelins and Gotha-bombers at the beginning of World War I, exposed the crews to hypoxia, hypothermia and fatigue, and demanded efforts from the medical-psychological, the technical and the military tactical side to protect the aviators. Besides altitude physiological questions, to which it became more and more urgent to find answers with the increasing altitude of the aircraft, also the acceleration and sensory physiology became important fields of aeromedical research. Other areas of increasing importance were the assessment of fitness of the aviators, the practical applications of aviation hygiene and occupational health and, last but not least, how best to use the knowledge gained from aviation accidents.[11]

During the record ascent of G. Linnekogel on December 27th, 1913 a continuous-flow regulator was used. During exhalation the incoming oxygen was collected into a breathing bag and could therefore be fed in higher concentration during the inhalation phase. The required additional breathing volume, however, was taken from the ambient air,

Table 1. Evolution of Flight Altitudes of Airplanes

Year	Country	Name of Pilot	Altitude in meters	Use of Oxygen
1909	France	Latham	410	no
1910	USA	Drexel	2.050	no
1911	France	Garros	3.910	no
1913	Germany	Linnekogel	6.120	yes
1920	Germany	Schroeder	10.000	yes
1929	Germany	von Neuenhofen	12.700	yes
1938	Italy	Pezzi	17.000	yes (pressure)

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which was the major disadvantage of this method. The continuous-flow procedure has an altitude limit, but is still used for emergency oxygen supply in commercial aeroplanes in case of rapid decompression. In Germany, demand regulators came into use in the mid 1930's, allowing greater heights to be reached. At lower altitudes, the outside air could be mixed with oxygen, resulting in better economy with the oxygen supplies carried along. Higher up, pure oxygen was supplied but only during the inhalation phase. This way, the oxygen requirements were reduced, while the aeronaut was supplied with oxygen according to his needs at various altitudes. With the use of a demand regulator, W. von Neuenhofen reached a height of 12 739 m (41 795 ft) on May 26th, 1929 in a Junkers W 34. For ascents above this limit, either pressure devices with close-fitting breathing masks or pressurized cabins and pressure suits are necessary. Later on portable breathing devices were built, which operated on demand or with continuous flow; they were employed for high altitude gliders and parachute jumpers.[11,17]

With the growth of aviation at the beginning of the 20th century, the rapid increase of aviation accidents was unavoidable. In Germany alone, 42 fatal accidents occurred between 1908 and 1912. Every 13th aeronaut in France died within a period of six months in 1911. The frequency of accidents was mainly attributed to the insufficient medical selection and care of the pilots. However, opinions varied[18]: "One of our most successful pilots expressed the opinion that 80% of all accidents happened because of mechanical failures. Another blamed solely the panic of the pilots (!) for all of the accidents. A third aeronaut perceived the danger to be gliding and demanded the descent to be as vertical as possible. A fourth person blamed the innate clumsiness of the pilots for a third of all accidents. The majority confessed that the feeling of loneliness described by me attacked them as often as a suddenly appearing somnolence." This example demonstrates how differently the importance of the "human factor" has been judged in connection with the occurrence of aviation accidents. Technical improvements and minimum requirements for the medical fitness of the pilots should counteract this development. Ernst Koschel from the Medical Committee of the Scientific Society for Aviation Technology (Medizinischer Ausschuss der Wissens-chaftlichen Gesellschaft für Flugtechnik (WGF)) presented

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extensive guidelines for pilot selection in Germany on June 5, 1913, whose introduction into practical aviation, however, was prevented by the war. On the other hand, the military requirements for pilots were raised during the course of the war[19–21]:

> "The enemy's planes were equipped with guns so quickly that our pilots, unable to do the same, could no longer defend themselves. The enemy's defensive weapons were improved, their number of pilots grew more and more, just like the number of tasks for our observers. First he had to operate the heavy aerial camera in the growing headwind, to suffer more and more from the cold in the faster aeroplanes and at increasing altitude, then he had to drop the heavy air-raid bombs with his bare hands, and then he had to operate the machine gun, turn the heavy rotating assembly, remove jams in strong headwind and install the new drum, and finally he had to operate the RT device. During all this he had the responsibility for navigation and the success of the mission."

This rapidly advancing technological development with more and more strenuous demands on the aviation personnel had a negative influence on the accident rate. The high number of pilots who were lost during the first years of the war was considered a consequence of insufficient selection. Losses due to technical failure or enemy action played a relatively subordinate role. When the number of pilots who became unfit for flying because of medical conditions grew more and more, strict examination guidelines were developed for the German air force troops in October 1915; it contained the following demands (26:12)[d]:

1. Heart, kidneys and lungs absolutely healthy.
2. Eyes and ears fine. Pilot students who constantly wear glasses will not be taken on any more; those already taken on will remain.

[d] In the USA, the U.S. War Department released as early as in 1912 guidelines for the selection of pilots candidates. Beside vision and hearing, the cardiovascular and breathing systems were examined.[1]

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Apart from this: at least 5/7 of normal eyesight; when on the right only 1/2 eyesight, then on the left 1/1, or reverse. With glasses in all cases full eyesight and only corrected with regular glasses.
3. Tight, elastic muscular system.
4. Healthy nervous system, no persons who have suffered a nervous breakdown or brain symptoms; no alcoholics and syphilists.
5. In general not under 19 and not over 35 years of age. However, decisive are firstly flexibility and moral qualities.

In 1916, the Chief of the German Army Field Flight Corps (Chef des Feldflugwesens) created a department of aviation medicine, of which he put Koschel in charge, and introduced a multistaged medical examination of the applicants before the training began. By means of a thorough examination of the sense organs, the central nervous system, and the respiratory and circulation systems by a body of medical specialists as well as employing aviation psychological principles, he planned not only to assess the fitness to fly, but also to lower the number of pilots dismissed during training, which lay at about a third of all trainees.[11,21] A parallel development could be observed in other aviation nations. In 1916, a Special Royal Flying Corps Medical Board was founded, which mainly dealt with the medical requirements for pilots. The focus of the examination was on the assessment of the cardiovascular capacity and the capacity to endure at altitude with the "rebreather-bag." In addition, examination of the eyes, the sense of balance and the respiratory tract were included.

The following year, an Air Board Research Committee (Medical) was established to coordinate aviation medical work and research.[22,23] In France, the main focus of the psychophysical test was on the excitability of the test subjects, while in Italy it was on their time of reaction.[9,22] In the USA, the Medical Research Board of the US Air Force was established in 1917 in Hazelhurst Field, Mineola, Long Island (New York). It was among other things entrusted with the compilation of suitability guidelines, besides with the following[24]:

— Research of all those factors which influence the capacity of the pilot

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— Examination of the psychophysical capacity of pilots at altitude
— Oxygen supply for the pilots at altitude
— Creation of a database concerning all questions in connection with the bodily fitness of pilots

The research laboratory with training facilities for flight surgeons (Medical Research Laboratory and School for Flight Surgeons of the Air Service, Signal Corps of US Army (ASMRL)), which was founded in Hazelhurst, New York in 1918, was already equipped with an altitude chamber. From this facility sprang the School of Aviation Medicine (SAM) in 1922. The school was moved to Brooks Field near San Antonio, Texas four years later. Looking back on a long tradition as the most renowned facility in this field worldwide, it is now known as the USAF School of Aerospace Medicine. From the beginning this school trained the new generation of flight surgeons, and it was here aviation personnel and pilot candidates were assessed and attended to by aeromedical specialists. The aim was that the flight surgeon should practice his profession directly within the environment of the aviators and that he also should possess flying experience himself. The first flight surgeon graduated from this institution in May 1918. The following were conveyed during a training period of four months (Ref. 24)[e]:

— The organization and administration of the Medical Department as related to the special requirements of the Air Corps
— The principles and technique of physical examination of candidates for flying, training, and testing of fliers, including the use of special equipment required in conducting such examinations
— The application of tests for physical efficiency
— The physical care of fliers

[e] In continuation of this course, a connection to the training institution was maintained for two years in the form of a correspondence course, followed by a six week period of practical training at the SAM. Apart from this basic course, further education was offered at the school. In the 1950's a three year residency training was founded, which is a specialist physician training program.

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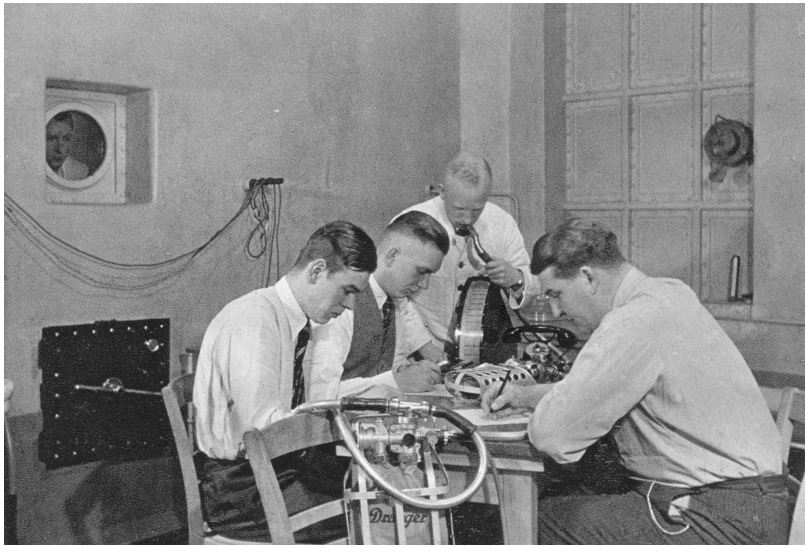

Figure 6. Examination of performance of airmen at high altitudes at the Institute for Medical Research in the Field of Aviation in Hamburg-Eppendorf. In: Harsch, 2003.

— Medical specialties as related to aviation, including neuropsychiatry, physiology, ophthalmology, otology, psychology and cardiology.

The civilian side as well was occupied more and more with selection criteria for pilots. The flight surgeon Louis Hopewell Bauer (1888–1964), the first head of the School of Aviation Medicine, released the first civil medical selection criteria in the USA in December 1926; these are, in their fundamentals, still valid. In 1929, the Aeromedical Association was founded in the USA; it is today the most renowned aviation medical society worldwide. Bauer was elected its first president.[17,19,25]

Practical aspects of aviation medicine were also being pursued in Europe. In 1928, at the Würzburg university, the physiologist Hubertus Strughold (1898–1986) held the first aviation medical lecture, which was complemented by experimental flights with interested students. At this university, Heinz von Diringshofen (1900–1967) started his application orientated acceleration physiological experiments.

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Inspired by the transatlantic flight by Charles Lindbergh in 1927, Ludolph Brauer[26] (1865–1951) founded an institute for medical research in the field of aviation (Institut für medizinische Forschung auf dem Gebiet der Luftfahrt) in Hamburg. Here both aviation medical research and the processing of application related questions of altitude physiology were conducted. Students were trained in aviation medicine, pilots and pilot candidates were examined for their fitness to fly, and "physiological training" was offered for aviators and extreme-mountaineers.[26]

In 1928 the Berlin flight physician Ernst Gillert executed a simulated ascent in the altitude-chamber of DVL in Berlin-Adlershof, up to a height of 14 300 m (46 915 ft), in which he fainted[27] (Fig. 7). The need for a pressurized cabin — as that first installed in the Junkers Ju 49 in 1929 — or a pressure-suit was realized for flights within the stratosphere. Nonetheless, the first operational jet and rocket-plane, the Messerschmitt Me-262 "Schwalbe" and the Me 163 "Komet" were not equipped with a pressurized cabin; furthermore, operational pressure suits were not available for their pilots. However, hypoxia-symptoms were not reported, as the time of ascent, at altitude and descent at critical altitudes were shorter than the "Zeitreserve" (time reserve, i.e., time of useful consciousness — TUC).[11] While the development of protective suits, in spite of the promising work of Klanke and Tietze, did not produce operational usable pressure suits, the US pilot Wiley Post (1898–1935) did achieve a breakthrough of pressurized suits when using the first functional one in 1934. Among his other achievements are several aviation records in the 1930's and, moreover, this monocular aviation pioneer is known as the discoverer of the jetstream.[11,28]

Due to the increasing altitudes reached by modern aircraft, altitude physiology remained the focal point of aviation medicine up to the 1940's. Of special interest in this connection was the effect of acclimatisation and whether the airman was 'altitude proof.' Altitude physiologist Hans Hartmann was in charge of an expedition into the Himalayas in 1931, where significant observations were made. In altitude physiological research facilities, like the Mosso-Institute, situated at a height of 3000 m on the Monte Rosa, and at the facility on

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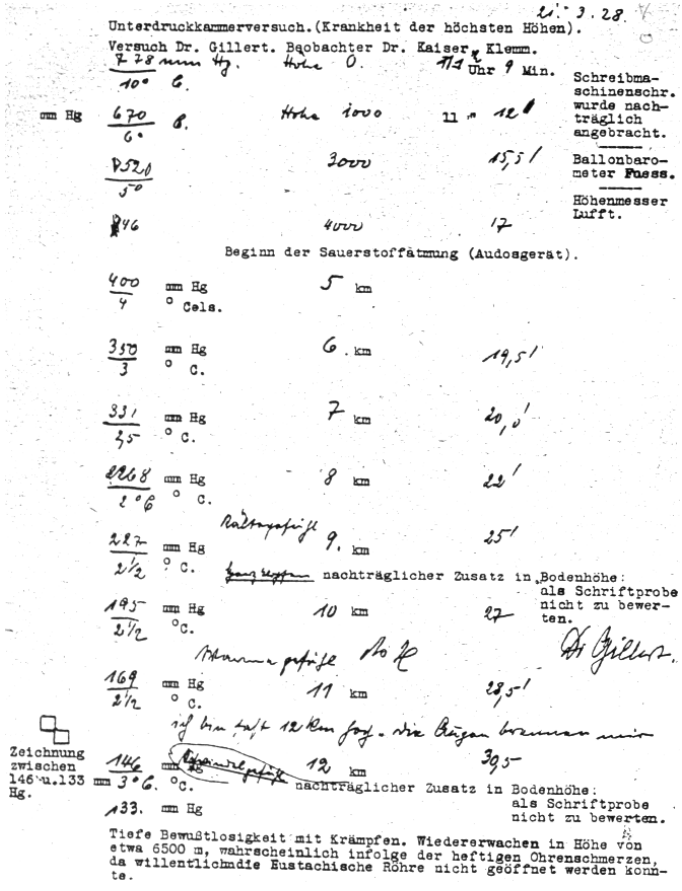

Figure 7. Self-experiment by Dr. E. Gillert in the DVL-altitude chamber up to 14 300 m in 1928. In: Harsch, 2002.

the Jungfraujoch, at a height of 3400 m, lengthy studies were conducted, which methodically were not possible in this form in an altitude chamber. In England, for example, J. Barcroft conducted altitude physiological studies on the effect of hypoxia and acclimatisation during high-mountain expeditions to Mt. Everest and into the Andes. Furthermore, in training examinations on the German side near the front in the 1940's, transportable examination devices for altitude effects after Bruno Müller (1912–1997) were put to use. A mixture of

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oxygen and nitrogen was employed, which, with an oxygen concentration of 7%, simulated a height of 7500 m (24 600 ft) through a technically simple and safe procedure. The aim was primarily to acquaint the test subjects with the subjective warning signals of hypoxia in order to prevent aviation accidents — this is also today an important part of the physiological training worldwide. Furthermore, the time reserves (TUC) were determined for the assessment of the altitude threshold; this was mainly done by use of the writing test after Lottig[29] (Fig. 8).

In civilian as in military aviation, and here especially in amateur flying, the role of altitude physiology was becoming more and more

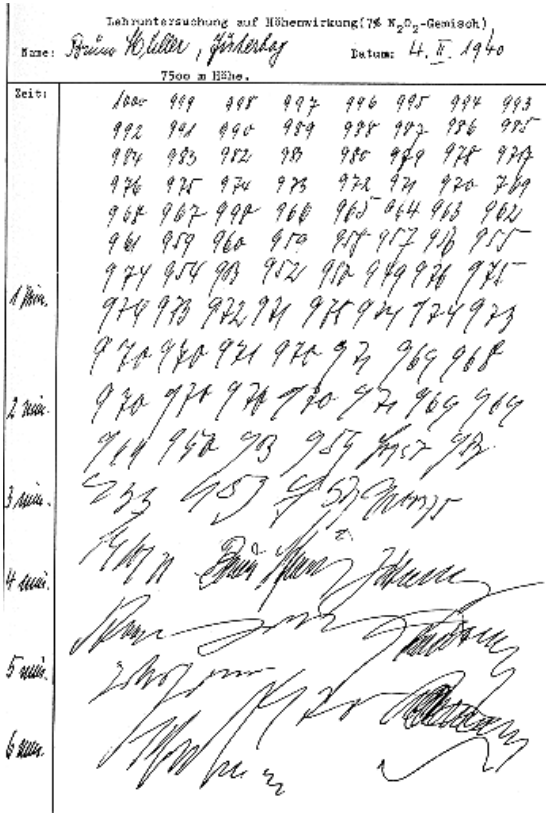

Figure 8. Altitude writing test after Lottig. In: Müller, 1967.

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important. The first glide without loss of height succeeded in the landscape of the Rhön in 1916. It was also here the first gliding competition took place in 1920. With the Olympic motto "citius, altius, fortius" (faster, higher, stronger), more and more records were established, which took the glider pilots to their psycho-physical limits: in 1940 the stratosphere was reached for the first time with a "Kranich" soaring plane (11 400 m ~ 37 400 ft). The admission of gliding into the Olympic Games in Helsinki was planned for the same year, however the war prevented this from happening. Since then, with ultra-light flying, hang gliding, paragliding and parachute jumps, many people have found new, although sometimes also dangerous, kinds of sport activities in the third dimension.[11,30]

Beside altitude physiology, acceleration research was another topic of major interest. In the early 1930's, the effects of prolonged in-flight acceleration were first studied by the flight surgeon Heinz von Diringshofen. He suggested selecting small, but strong flight students with a high G-tolerance (due to a resistant circulatory system) for high-performance aircraft. In addition, body positioning as a means of improving tolerance to G-stress was recognized, and the supine positioning at a 45° angle was suggested.

To obtain more standardized conditions than are possible in flight, examinations were supplemented with a centrifuge (16 ft., 45 G max., first 4 G within 40 s), which was located in Berlin. At the time, a larger 66 ft. centrifuge could not be installed due to air-raids. The physiologist Otto F. Ranke was one of the first to use X-rays to demonstrate the decreased filling of the heart of test-animals exposed to high G_z-forces. These results were cross-checked on voluntary subjects in flight. The medical officer cadet L. Buehrlen exposed himself to 17 G_x over two minutes on the centrifuge and found the supine and prone position effective to sustain high G_z-forces in flight.

In dive-bombers such as the Junkers Ju 87 "Stuka," pilots used to crouch forward and contract their muscles through the pullouts. In addition, these widely accepted manoeuvres were accompanied by increasing the intrathoracic pressure by grunting an e-sound (M-1 manoeuvre) (Fig. 9). Only one aircraft loss due to G-LOC was reported in Germany during WWII. Most likely, no attempts were

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Figure 9. Flight surgeon (and test-pilot, front) and volunteer (back) preparing for aero-medical high-G flight at GAF Testflight-Center in Jüterbog (south of Berlin) in the 1940s. In: Müller, 1967.

made to develop and introduce anti-G suits in Germany because the use of such suits seemed to cause more trouble than it was worth.[11,29,31,32] Since then the use of anti-G suits has gained general acceptance and has made the use of high-performance aircraft more tolerable for pilots. New developments are being made within the field of liquid-filled anti-G suits (e.g. "Libelle"/"Dragon Fly"), as was originally proposed by Otto Gauer in the 1930's.

Beside prolonged acceleration, as described above, the effects of short-term acceleration, caused by vibrations or on impact, ejections etc., were also of physiological and patho-physiological interest. The American officer A. Berry succeeded as early as in 1912 with the first parachute jump from a biplane. However, the parachute was first employed as a life-saving device by the Germans at the end of World War I; one of the rescued was flying ace Ernst Udet who jumped from

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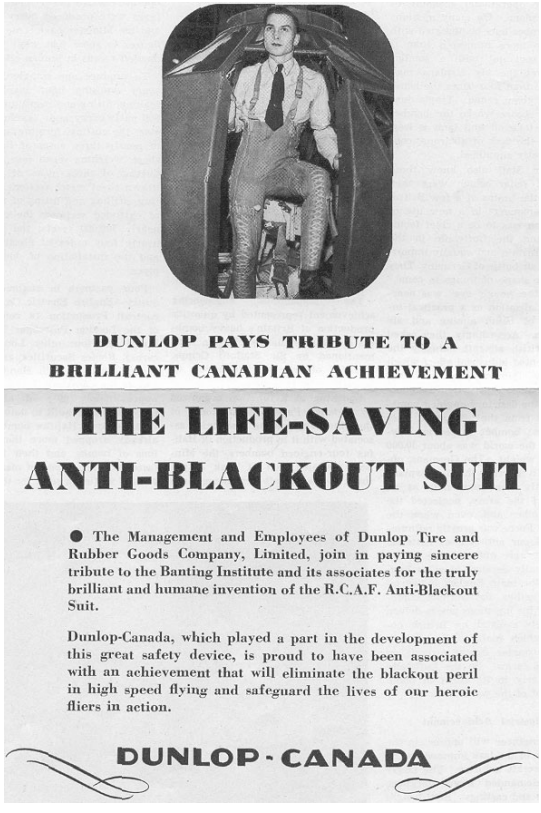

Figure 10. Canadian anti-G suit. In: Canadian Aviation, Mai 1945.

his Fokker D VII on June 29, 1918 and survived with a sprained ankle.[16] With the increasing flying altitudes in World War II, the issue of rescue possibilities from life-threatening heights was evaluated. After parachuting, the development of catapult and ejection seats was taken up. The first ejection seat ever was installed in the Junkers Ju 88 in 1938. The number of accidents increased in which the pilot managed to disembark the plane only to receive fatal injuries afterwards by being struck by the plane's tail. In 1940, the company Heinkel developed catapult seats, of which more than a thousand were built before the end of the war, saving the lives of many pilots. The acceleration sustained was a controllable element, parachute

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Figure 11. Strategic aeromedical evacuation during WWII: Patients are deployed from Focke-Wulf FW 200 "Condor". Picture Archive of Dr. Harsch.

deployment at great heights and thermal factors on the other hand demanded a technical solution.[11,31,34] Modern ejection-seats have to function under extreme conditions (under "zero-zero" conditions and during high speed and high G). After the Columbia tragedy in 2003, a retrofit of the remaining shuttle fleet for the rescue from high altitudes with ejection seats, as had been the case during the flight test phase, is being discussed again.[f]

Next to the development of aviation medicine, ambulance service by air (AirMedEvac) gained practical relevance: by 1943 more than one million patients had been transported by air on the German side of the front. On the opposing side, especially the Americans reported similar numbers and experiences.[11,35]

Also in other countries, WWII catalyzed further development of special fields within aviation medicine. In England, for example,

[f] In the 1950's, Captain Kittinger managed a successful free-fall jump from over 31 000 m, before he opened the stabilizing chute at about 27 000 m and approached the earth with extremely high speed.[7]

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the Physiological Laboratory of the Royal Air Force was founded in Farnborough. In this institute, as in others before, altitude, acceleration and physiology were the main targets for investigation. During the course of the war, the number of staff grew, and the institute also dealt with questions of pilot selection, noise, survival, the influence of heat and cold, decompression sickness, physiological training of the pilots, the development of aircrew equipment, and operational medical support. A part of the experiments were performed through experimental flights by the scientists themselves.[22] In the USA, the Aeromedical Laboratory in Wright Field, Ohio, was the leading force of the development in the field of applied aviation medicine, headed by Harry G. Armstrong. Additionally, the AAF School of Aviation Medicine in Randolph Field, Texas, and the Navy's School of Aviation Medicine in Pensacola, Florida were active in this field. Numerous development projects were carried out as well in the civilian section, especially in the Mayo Clinic in Rochester, Minnesota.

After WW II, the advanced state of aviation medicine was continued at the AAF Aeromedical Center in Heidelberg where the physiologist Otto Gauer and the astrophysicist Heinz Haber reported further development in the field of extraterrestrial physiology. In 1948, a meeting of specialists focussing on the visionary topic "*Aeromedical Problems of Space Travel*" took place in San Antonio, Texas. Aviation physiologist Hubertus Strughold was made first director of the department for space travel medicine at the USAF SAM and was joined by German colleagues K. Büttner, K. Haber and H. Haber in the following year. The biomedical preparatory work for the American manned space programme was initiated under their decisive participation.[11,32,35–37] In 1951 H. Oberth's student Wernher von Braun stated (5:A63): "I believe that the time has arrived for medical investigation of the problems of manned rocket flight, for it will not be the engineering problems but rather the limits of the human frame that will make the final decision as to whether manned space flight will eventually become a reality." We need to remember that the aviation preparatory work contributed decisively to the rapid success of manned space travel.

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Charles Lindbergh's flight of 1927 had heralded another new chapter in the history of aviation, namely that of mass air traffic. Strughold stated at the annual scientific conference of the Aeromedical Association in New York City 1937[11]: "The airplane is changing the world. The distance between countries is shrinking. (…) We all can fervently hope that this is leading to a better understanding among the nations." In the following year the four-engine powered Focke-Wulf Fw 200 "Condor" of German Lufthansa flew from Berlin to New York non-stop and back again the following day and paved the way for the upcoming postwar trans-oceanic air travel.

Today the advancing globalization of medicine is a challenge as well as an opportunity. Aviation medicine has evolved from the stage of high-performance physiology and is now a multidisciplinary science concerned with the well-being of humans under aerospace conditions. While Strughold, at the Olympics of 1936, still defined aviation medicine as 'the sports medicine most connected with technique,' nowadays a broader definition of the interdisciplinary field of aviation medicine is preferable: one which subsumes aviation and space medicine, work and travel medicine, as well as further border sciences into one. Its aim is to protect man in his unity of mind, body and soul in the four dimensions of aerospace and, furthermore, gaining knowledge for the earth-bound technical fields of medicine and the biosciences. In essence, aviation medicine is an applied science with the aim of protecting the most vulnerable link in the man-machine complex, the human being. This encompasses the assessment of the fitness to fly for aviators and passengers, even for space travel, as well as assessment of injured and sick persons for air transport. The aerospace physician follows, in this context, the traditional bioethical rules.

The manifold employment possibilities of telemedicine were catalyzed and brought to functioning maturity through the demands of space travel medicine. However, globalization was not solely achieved through the progress in information technology but also through the substantial contribution of mass air traffic. Connected with this, travel medical aspects have gained more and more importance,

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as highlighted during the outbreak of infectious diseases of international public health concern such as SARS. A further focal point of practical aviation medicine remains in the training of pilots and pilot candidates in the field of human performance limitations (HPL), which as the factors most frequently causing aviation accidents still require intensive attention, always with our common goal in sight: "*Keep 'm flying!*"

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