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REVIEW PAPER

Helicopter emergency medical service: motivation for focused research

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Abstract Since the early helicopter developments, there has been tremendous progress in performance, handling qualities, comfort and efficiency. This is why helicopters have conquered their niche in the aircraft market despite their very limited capabilities in terms of maximum speed and range or fuel efficiency, especially when compared with modern fixed wing aircraft. However, some features make helicopters very useful for many missions, which to date cannot be performed by any other contemporary series production aircraft. These features include their capability to hover, to climb or sink either vertically or almost vertically, to fly slowly in any horizontal direction (even backwards) and still maintain good handling qualities. When compared to other aircraft which are able to hover (e.g. tiltrotors or fixed wing vertical take-off and landing aircraft), they even show in that flight regime superior flight performances. These features allow helicopters to fly "nap of the earth" at low altitudes within an obstacle backdrop and land almost anywhere, even in confined areas (provided any obstacles do not present a threat level which is too high). These capabilities make helicopters prone not only to simply rescue people in distress (e.g. from mountains or ships in emergency situations), but also to provide full emergency medical service. This service is called helicopter emergency medical service (HEMS). No other aircraft is more suitable for such a service than helicopters. This is why many nations have established professional HEMS systems in their countries; ranging from young systems such as that adopted in Japan to the oldest one, located in Germany. This paper aims to first give an overview on some historical aspects on the development of HEMS. Secondly, it outlines HEMS Systems established in various nations like Germany, Switzerland, Japan, and the United States of America. Next the paper gives a short survey on statistical data on rescue helicopters and to some extent on noise aspects of helicopters in general. The latter topic will be discussed briefly, since noise problems are linked to all helicopters not just to rescue helicopters. Following this, some sobering facts on HEMS will be reviewed, more precisely the high number of accidents. Finally, the paper concludes with some remarks and gives a brief outlook on a research concept dubbed the "Rescue Helicopter 2030" which has been started recently at the Deutsches Zentrum für Luft- und Raumfahrt (DLR, German Aerospace Center).

Keywords Helicopter emergency medical service (HEMS) · Air rescue · Rescue helicopter · Helicopter safety

Abbreviations

ABC	Advancing blade concept
ACN	Automatic crash notification
ACT/FHS	Active control technology/flying helicopter simulator
ADAC	Allgemeiner Deutscher Automobilclub (General German Automobile Association)
AE, AME	Aeromedical evacuation
AH	Ambulance helicopter
AHS	American Helicopter Society
AMPA	Air Medical Physician Handbook
ANWB	Algemene Nederlandse Wielrijders Bond (Dutch Automobile Association)
BMI	Bundesinnenministerium (German Federal Department of the Interior)

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BVI	Blade vortex interaction
CARESOM	Coordinated Accident Rescue Endeavor—State of Mississippi
CFIT	Controlled flight into terrain
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
DRF	Deutsche Rettungsflugwacht (German Aviation Rescue Guard)
EDH	Emergency doctor helicopter
EHEST	European Helicopter Safety Team
EPN	Effective perceived noise level
ERATO	Etude d'un Rotor Aéroacoustique Technologiquement Optimisé
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FW	Fixed wing aircraft
GPS	Global Positioning System
HCM	HEMS crew member
HELLAS	Helicopter laser radar
HEM-Net	Emergency Medical Network of Helicopters and Hospitals (Japan)
HEMS	Helicopter emergency medical service
HICAMS	Helicopter Intensive Care Medical Services
HOGE	Hover (altitude) out of ground effect
HTAWS	Helicopter Terrain Awareness and Warning System
ICAO	International Civil Aviation Organization
CAEP	Committee on Aviation Environmental Protection
IFR	Instrument flight rules
IHST	International Helicopter Safety Team
ISA	International Standard Atmosphere
ISS	Injury Severity Score
ITH	Intensive care transport helicopter
JUH	Johanniter-Unfall-Hilfe e.V. (Johanniter-Accident-Care)
MAC	Moscow Aviation Center
MAST	Military Assistance to safety and traffic
MEDEVAC	Medical evacuation
MTOW	Maximum take-off weight
NOTAR	No tail rotor
NTSB	National Transportation Safety Board
NVG	Night vision goggle
ÖAMTC	Österreichischer Automobil-, Motorrad- und Touring Club (Austrian Automobile, Motorcycle and Touring Association)
REGA	Rettungsflugwacht Garde Aérienne (Air Rescue Guard)
RTH	Rescue transport helicopter
RW	Rotary wing aircraft
SAR	Search and rescue
SEL	Sound exposure level
SRFW	Schweizerische Rettungsflugwacht (Swiss Air Rescue Guard)
TCAS	Traffic Alert and Collision Avoidance System
TCS	Touring Club Switzerland
USA	United States of America (short US)
USAF	US Air Force
VFR	Visual flight rules
VTOL	Vertical take-off and landing
WAH	Wide area helicopter
WW	World War
ZSH	Zivilschutz-Hubschrauber (Civil Protection Helicopter)

List of symbols

DL	Disc loading
H	Impact factor for price estimation in Eqs. (1) and (2)
m_e	Empty weight
m_f	Fuel weight
m_{TOW}	Take-off weight
$m_{UL,\ ff}$	Useful load mass at full fuel
N_{BL}	Blades per rotor
l_{FW}	Fuselage width
l_{FL}	Fuselage length
R	Rotor radius
$P_{total,Engine(s)}$	Total engine/engines rated power in shp
S	Rotor disc area
V_{cab}	Cabin volume
$V_{Cruise,\ econ}$	Economic cruising speed
μ	Advance ratio $\mu = V/(R\Omega)$
Ω	Rotor rotational frequency

1 Introduction

Since the early developments of rotary wing aircraft in the late nineteenth century, the first flight in 1907, and a period of maturation during 1920–1945, helicopters have made tremendous progress in performance, handling qualities, comfort, reliability, and efficiency. Some additional features make helicopters especially useful for many missions, which to date cannot be performed by any other contemporary series production aircraft. These include their capabilities to hover, to climb or sink vertically or almost vertically, to fly slowly in any horizontal direction (even backwards), and still maintain good handling qualities and maneuvrability. When compared to other aircraft which are able to hover (e.g. tiltrotors or fixed wing VTOL aircraft), helicopters show superior flight performance, whilst also displaying good handling qualities in the hover and low-speed flight regime without increasing the technical complexity of the aircraft too much. This is why helicopters have conquered their niche in the aircraft market despite their very limited capabilities in terms of maximum speed and range or fuel efficiency. This is especially true when compared to modern fixed wing aircraft. These advantageous, but also their relatively small outer dimensions (i.e. their footprint), allow helicopters to fly "nap of the earth" at low altitudes within an obstacle backdrop and land almost everywhere even in confined areas, provided the obstacles do not present a threat level which is too high. In summary, these capabilities make helicopters suitable not only to simply rescue people in distress (e.g. from mountains or ships in emergency situations), but to provide full emergency medical service. This service is called helicopter emergency medical service (HEMS). So far, no other aircraft is more suitable for such a service than helicopters. Igor Sikorsky has culminated that capability when saying in 1947: "If you are in trouble anywhere in the world, an airplane can fly over and drop flowers, but a helicopter can land and save your life." [1]. A definition of an HEMS flight is given in EU CR No. 965/2012 [2]:

"A flight by a helicopter operating under a HEMS approval, the purpose of which is to facilitate emergency medical assistance, where immediate and rapid transportation is essential, by carrying:

(i) medical personnel; or
(ii) medical supplies (equipment,
(iii) blood, organs, drugs); or
(iv) ill or injured persons and other persons directly involved."

Three different HEMS missions can be distinguished that address the aspects of the above given list: the primary rescue mission is provided by a rescue transport helicopter (RTH) and intends to transport an emergency doctor and a paramedic from the HEMS basis to the operating site. After life saving treatments the patient is being taken from the operating site to a hospital or trauma center.[1] To provide medical treatment at the operating site as well as during the transportation phase, the helicopters are fitted with extensive medical equipment like:

- electrocardiogram/defibrillator,
- respirator, clinical oxygen device,
- suction pump,
- blood pressure measuring equipment,
- monitoring equipment,
- chest tube/tube thoracostomy set,
- immobilization material (e.g. cervical spine, extremities), and
- antidote.

The minimum medical equipment list for EMS helicopters is defined in Europe in DIN EN 13718-2. Other EMS missions aim to transport intensive care emergency patients in urgent cases during their stay at a hospital from that hospital to another one, which can provide much better treatment. This mission is called secondary rescue mission, but sometimes also Helicopter Intensive Care Medical Services (HICAMS) and the helicopter intensive care transport helicopter (ITH). ITHs are specifically tailored to the requirements of transfer flights such that an already started clinical intensive care therapy does not need to be suspended during the flight. This applies, for example, to the possibility to continue with complex artificial respiration patterns. Finally, EMS helicopters are also used in some cases to transport banked blood, transplant organs, etc. These three missions are subsumed simply as HEMS in this paper.

In-between many countries have established professional HEMS systems as part of their health care system ranging from young systems such as that in Japan to the oldest one, located in Germany. However, the various systems differ in many aspects, including crew composition, organization of HEMS bases or reimbursement of the HEMS operators, and the helicopter models utilized for missions. In addition, some HEMS operators are for-profit organizations, while others are for non-profit ones. These are sometimes operated in the same market. Often, the helicopter airborne medical aid complements ground-based ones.

Despite these aspects, the benefits of HEMS to the society are well accepted. One example is the treatment of stroke patients. The time from suffering a stroke to first medical treatment by an emergency doctor is one key aspect to convalescence. In contrast to the cost, if the patient later suffers from permanent disability, the costs of the HEMS mission are small, not to mention the personal fate of the patient. To provide rapid medical aid, the HEMS bases are located in many cases, such, that an EMS helicopter can reach its destination within 15–20 min. For short distances, other rotary wing aircraft than helicopters are of no benefit. This might change in the future, if speed and range requirements become driving factors even for HEMS missions. Such need could be driven by the desire to cover remotely located, but sparsely populated areas, which are not covered by rapid air medical provision so far or from offshore EMS applications. Higher speed and range than those of helicopters are being offered by tiltrotors, such as the V22, which has been introduced to the military rotorcraft market. AgustaWestland is currently

[1] A trauma center is a hospital equipped and staffed to provide comprehensive emergency medical services to patients suffering from traumatic injuries. Trauma centers are classified as Level I, II, III or IV, Level I being the highest.

working on a smaller civil variant, the AW609. They indeed have caused a desire for higher speeds, even for rotorcraft, since Sikorsky has revived its XH-59A Advancing Blade Concept (ABC) studied in the 1970s [3], [4] with the X2 [5, 6] and the S-97 Raider[2] [7–9]. For the same reason, Airbus Helicopters is investigating the compound helicopter with its X^3 [7]. With their advantages in terms of speed and range compared to helicopters, and since the HEMS market is one of the large civil rotorcraft applications, such aircraft may be also introduced for dedicated missions to the HEMS market.

The origins of HEMS go back to 1944, when first evacuation flights of wounded soldiers were undertaken. After almost 70 years of serving ill, injured or wounded patients by helicopter, it is worthwhile to summarize the achievements of modern HEMS. Therefore, this paper aims to firstly give an overview on some historical aspects on the development of HEMS. Secondly, it outlines HEMS systems established in various nations like Germany, Switzerland, Japan, and the United States of America (USA), and emphasizes special features of the various systems, some of which have already been mentioned above. Next, the paper gives a short survey on statistical data on rescue helicopters and, to some extent, on noise aspects of helicopters. The latter point will be discussed briefly, since noise problems are linked to all helicopters and not just to rescue helicopters. Following this, some sobering facts on HEMS will be reviewed, more precisely the high number of accidents. Finally, the paper concludes with some remarks and gives a brief outlook on a research concept dubbed the "Rescue Helicopter 2030" which has been started recently at the Deutsches Zentrum für Luft- und Raumfahrt (DLR, English: German Aerospace Center). This research concept is strongly motivated by the insight presented in this paper.

2 Historic background

The established HEMS systems in the various countries were motivated by different factors. Some reasons to build up such efficient rescue systems are given by large catastrophes, others are more of evolutionary considerations. This chapter intends to give a brief overview on the historic background on the usage of helicopters for aeromedical transportation or HEMS. HEMS is specifically provided by helicopters. A more general denomination is aeromedical evacuation (short AE or AME) or medical evacuation (MEDEVAC). An overview on the development of MEDEVAC in general is given in [10].

[2] The S-97 Raider focusses on military customers and civil variants are not foreseen so far.

The development of a military aeromedical transport system was the first significant advancement in pre-hospital care. The usage of aircraft to rescue or transport ill persons or casualties was, for a long time, believed to date back to the year 1870. In that year, a hot air balloon was allegedly used to transport mail and other freight out of the encased Paris during the Franco-Prussian war, but not patients [10–13].

The first evidence of the usage of an aircraft for AE goes back to the First World War (WWI). In 1915, the French evacuated a wounded soldier from Serbia by aircraft [12]. The French then adapted military planes for use as air ambulances. Modified Dorand II aircraft were used at Flanders in 1918 in what was the first AE of casualties in airplanes specifically equipped for transporting patients [14]. However, no medical attendance was on board these aircraft. It was after the war in 1920, when DE HAVILLAND DH-4A aircraft were modified such that it could carry two litters and a medical attendant [12]. Later, the Cox-Klemin aircraft became the first aircraft built specifically as an air ambulance aircraft [14]. Between WWI and the Second World War (WWII), British and French forces used aircraft in their colonies for transporting casualties resulting from these conflicts [13].

The first developments of AE were motivated by military needs. However, after WWI, aircraft were also used in supporting civil health care. In 1928 sufficient funds were raised in Australia and the flying doctor scheme was established [12, 13].

Long distance, high altitude AE was pioneered by the German Luftwaffe during the Spanish civil war (1936–1938). The Germans used unpressurized trimotor Junkers JU 52 aircraft in missions lasting up to 10 h and which were flown at altitudes of 18,000 ft [12, 13, 15]. By the time of the WWII, the organized air transportation of wounded patients had been established in the armed forces. The US-Army Air Corps, for example, had evacuated 1.25 million patients by aircraft by 1945 [15].

It was also during WWII when the first helicopter deployments of casualties were conducted first. The development of rotary wing aircraft was of significant relevance, because of their ability to land in confined areas [13] as mentioned above. This means that helicopters can land much closer to the casualties or wounded than fixed winged aircraft (FW) can do.

In April 1944,[3] the first military combat rescue was conducted by the US armed forces in Burma. This was following the crash of an L-1 airplane behind Japanese lines, with three wounded British soldiers and the US pilot

[3] The exact date is not quite clear. In most sources April 26–27, 1944 is being mentioned. Some sources mention the 23rd of April, others simply refer to April.

on board. The copilot's seat of a Sikorsky YR-4B helicopter was removed and a stretcher and extra fuel in canisters was taken on board. Lt. Harmon, see Fig. 1, of the US Air Forces (USAF) flew the aircraft from his commando base in India to the operation base covering a distance of 500 miles and stopping for fuel every 100 miles. He then flew to the crash site and evacuated one person at a time due to the limited payload capability of the helicopter. High altitude, humidity, and tropical temperatures reduced the helicopter's performance. Although the soldiers were evacuated over a distance of just 10 miles, the engine overheated after the second trip and the mission was continued the following day [16–18]. This mission is believed to be the first air rescue mission conducted to transport a trauma patient by helicopter [13].

More information on further missions performed with YR-4 helicopters in Burma can be found in [13] and [20].

In Germany, helicopters were investigated also in April 1944 to perform sea rescue missions. An Fl282 helicopter was used for training such missions. The rescue scenario was such that the pilot to be rescued was evacuated from his rubber raft as an external load [21] (see Fig. 2).

Similar rescue maneuvers were foreseen for the much larger Fa223 "Drache" (engl. Dragon) helicopter. However, the rescue itself would have been much more comfortable with the Fa223. The aircraft is shown in Fig. 3 (top) transporting a radial engine of a crashed aircraft as external load. The small inserted picture shows a rescue bucket which was used to rescue pilots from their awkward situation. The rescue system was comparable to a kind of simple elevator. The pilot who was supposed to swim in the ocean or to float in a raft had to climb into the bucket which then was lifted towards the aircraft. A bay was foreseen in the fuselage which was large enough to get the bucket into the aircraft. Of course this maneuver would have required that the crashed pilot was still able to get into the bucket by his own effort [22]. Rescue buckets or baskets are still in use today, see [23], and may have been inspired by the bucket shown in Fig. 3.

The Fa223 was used in Europe to perform the first rescue mission during WWII on March 6, 1945 roughly 1 year later than the mentioned rescue mission with the YR-4B in Burma. During this mission, lieutenant Gerstenhauer[4] rescued a Me109 pilot after forced landing [24], near Gischkau, Danzig. He could land beside the wreck with the help of his crew chief, the two men extricated the injured pilot, who was trapped in the cockpit, and flew him to a nearby airbase for emergency treatment. Gerstenhauer's flight logbook with the entry of the flight is shown in Fig. 3 (bottom, see last line) saying: "Search for forced

Fig. 1 USAF Second Lieutenant Carter Harman (*left side* standing) and his YR-4B in Burma. Source: [19]

down Me109 (pilot recovery). First helicopter emergency relief deployment." Covered distance and duration of the flight were, however, just 10 km and 8 min.

A brief comparison of some technical and performance data are given in Table 1 for the three aircraft (YR-4B, Fl282 and Fa223D). The data show that YR-4B and Fl282 are almost comparable with respect to the flight performances, while the installed power to weight ratio of the twin-rotor Fl282 is much better than for the single-main rotor YR-4B. This can be attributed to the larger rotor disc area for the Flettner helicopter. The empty to take-off weight ratio is also slightly better for the Fl282. However, this is paid for with a missing large cargo compartment. More statistics of multi-purpose helicopters which also serve as EMS helicopters will be given in Sect. 4. The achieved flight performances, payload capability, but also installed power give evidence to the enormous improvement that helicopters have undergone during the decades since.

Shortly after the end of WWII, a more powerful R-5 helicopter than the YR-4B performed the first civil helicopter hoist rescue mission. This mission is another early milestone on the road towards an effective civil based helicopter emergency rescue system. On November 29, 1945, a violent storm with wind speeds close to those of a hurricane raged at the US East Coast. The two man crew of an oil barge was stranded near Fairfield, Connecticut on a reef in the Long Island Sound. The two men were in danger of being washed overboard. Since the Sikorsky Aircraft plant was in nearby Bridgeport, it was decided, to contact Sikorsky. Dmitry "Jimmy" Viner, who was a nephew of I. Sikorsky and test pilot at that time at Sikorsky, inspected the barge during a first flight. Since the barge was in danger of breaking, it was decided to return to Sikorsky and use an R-5 for the rescue mission, since one R-5 had been equipped with a hydraulic hoist for experimental purposes. The idea of using a cable to pull people out of danger was a new concept in USA. The hoist was equipped with a simple

[4] Hans-Helmut Gerstenhauer died in October 23, 2014 at the age of 99 years.

Fig. 2 Test pilot Captain Hans Polzin during a sea rescue field trial of an early version of the Fl282. Source: Helicopter Museum Bückeburg, Germany

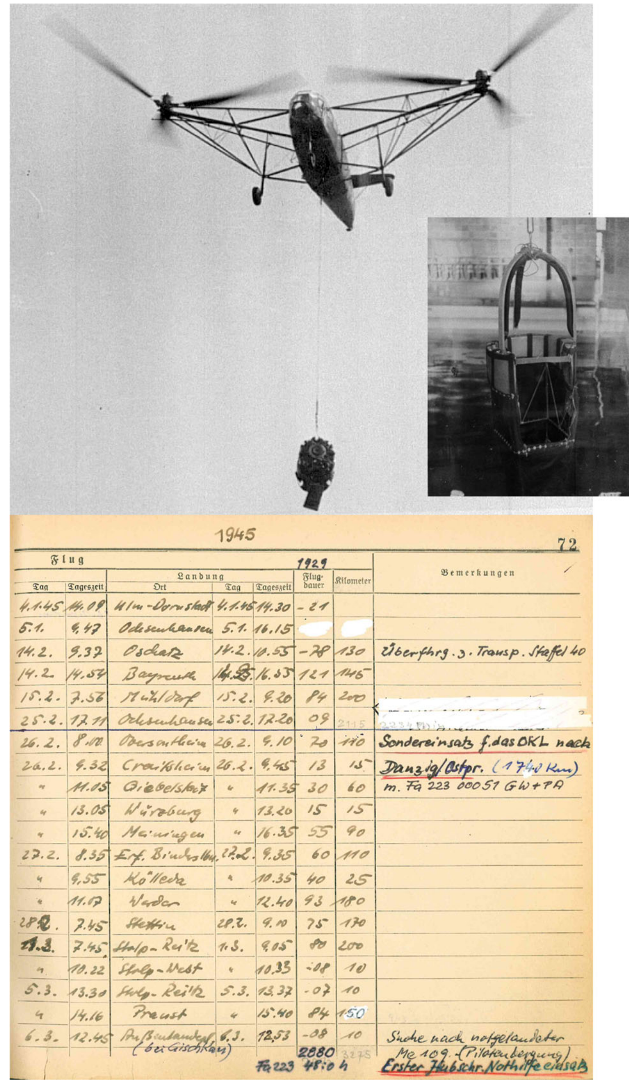


Fig. 3 Fa223 "Drache" during flight with radial engine as external load, top, and flight logbook of test pilot Hans-Hermann Gerstenhauer, *bottom*. Source Helicopter Museum Bückeburg, Germany

rescue harness. Since the cabin of the R-5 was too small both barge crew members were transported one by one to the nearby beach. During the rescue of the second man, the hoist jammed. He was hanging 30 feet (approx. 9 m) below the helicopter and was transported in that position to shore. This scene is shown in Fig. 4.

During WWII it was clearly demonstrated how beneficial helicopters could be for rescue purposes. The fast development of helicopters, especially in USA, finally led to their full establishment as a rapid rescue means. The benefits of helicopters for rescue missions were then widely displayed during the Korean War, when transferring patients directly from the battlefield to medical treatment facilities [12]. In particular, the Bell 47 and the Sikorsky S-51, which was a company funded commercial version of the R-5 helicopter, became famous during the Korean War [13, 25]. However, in most cases, no medical attendant was on board during these evacuation flights. This rescue technique of very rapid evacuation with little or no medical treatment of the patient at the spot of the emergency is called "scoop and run" or "load and go" and contrasts the philosophy that intends to stabilize the patient and prepare him for the transport by an emergency doctor prior to transportation to the hospital. This method is called "stay and treat" or disrespectful "stay and play" [26]. Both doctrines are still utilized today, even in modern civil HEMS scenarios. To perform rescue missions, both aircraft were fitted with external litters mounted to the fuselage. Patients were lashed up and covered with a canopy to prevent injuries from wind or rotor downwash. More than 20,000 wounded soldiers were rescued in this way [13].

The conflict in Vietnam then saw a further development of the approved AE procedure, which had been developed in Korea. Now, the Bell UH-1 Iroquois became renowned for this task. The Vietnam War was, definitively, the final proof for demonstrating the efficiency of helicopter AE. Under the codename "Operation Dustoff" more than

Table 1 Technical data of YR-4B, Fl282, and Fa223D

Value	YR-4B	Fl282	Fa223D
Radius	19 ft	19.7 ft	19.7 ft
	5.8 m	6 m	6 m
Take-off Weight	2540 lbs	2205 lbs	9480 lbs
	1152 kg	1000 kg	4300 kg
Empty Weight	2020 lbs	1676 lbs	7011 lbs
	916 kg	760 kg	3180 kg
max. Speed	82 mph	93 mph	109 mph
	132 km/h	150 km/h	176 km/h
Cruising Speed	65 mph	71 mph	83 mph
	105 km/h	115 km/h	134 km/h
Range	153 miles	186 miles	296 miles[a]
	246 km	300 km	477 km
Engine	200 hp	150 hp	1000 hp
	149 kW	110 kW	746 kW
	1 × Warner R-550	1 × Bramo Sh14A	1 × Bramo 323

Source: [19, 22]

[a] With ferry tanks 435 miles/700 km

Fig. 4 The captain of a stranded barge is lowered to the beach from a Sikorsky R-5 helicopter. Source [19]

400,000 patients were transported by helicopters [13]. Since the cabin of these AE helicopters was spacious these helicopters were manned by paramedics. Operation Dustoff was so successful that most casualties could be moved from the battlefield to a field hospital within 20 min of wounding [12].

When reviewing military MEDEVAC statistics, the data clearly show a consistent trend: the faster the patient is evacuated from the trauma scene to a hospital, or at least a base hospital, the lower the mortality rate [11]. While the mortality rate of wounded soldiers was about 18 % in WWI [11], this decreased to about 4 % in WWII and further to only 1 % during the Vietnam War [15].

The benefit of helicopters to rescue people in distress and for military AE has been outlined. This success of the military helicopter utilization for casualty evacuation during the Korean and Vietnam Wars was brought to the public through television news programs and it was quickly realized that helicopters could also have an important impact on civilian emergency health care [13]. First trials to use helicopters for civil AE were undertaken in many countries like USA, Switzerland, Germany, and others in the 1950s and 1960s. However, the first initiation of a nationwide professional HEMS system goes back to 1970 in Germany [13].

The German rescue idea is based on the principle to bring the emergency doctor to the patient and to provide live saving measures before he then is being ferried to a hospital. As mentioned above, this principle is called "stay and treat" and dates back to the surgeon Kirschner. Kirschner postulated in 1938 that the emergency doctor had to come to the patient and not vice versa [26–28]. Kirschner laid knowingly, or unknowingly, the fundaments of a preclinical emergency treatment. The background of his argument was the fact that, at those times, 90 % of the casualties died at the emergency scene, on the way to the hospital, and within the first 24 h [26]. Today, it is accepted that the earlier the therapy is provided after the trauma, the higher the success rate for healing when compared to the case where no lifesaving treatments were undertaken at the emergency scene [26]. In the following decades, a road-based emergency rescue system was built up which aimed to bring an emergency doctor and a paramedic to the emergency scene. In a first attempt a modified bus, which had been converted into a mobile surgery room, was used. But since this solution was much too sluggish and a fully equipped surgery room was not mandatory for maintaining vital functions of the patient, this first model was replaced by smaller cars later on. First field tests with such vehicles were conducted in Cologne and based on the success of these emergency transportation vehicles also in other large cities [28]. Helicopters were considered for EMS at the end of the 1950s and beginning of the 1960s. The first planned mission of EMS helicopter was during Pentecost 1960. Caused by the increasing traffic during these public holidays higher fatality rates were expected. The German Army positioned four rescue helicopters along the highway between Hamburg and Hanover. Six hospitals were provided with provisional landing spots [28, 29]. Later, the idea of a private organized nationwide helicopter rescue system in West Germany with 90 stations was raised. In 1964 the idea of such a rescue system was discussed with the social ministry in Lower-Saxony [28]. In 1967, the Allgemeine Deutsche Automobil Club (ADAC, engl. General German Automobile Association) participated during first field tests using a Brantley B-2 as emergency doctor helicopter. In the following 3 weeks, this helicopter was utilized in 52 cases. In another case, a Vertol H-21 helicopter of the German Army was used, which was fully equipped like any other rescue vehicle of that time, but also featured mechanical tools for rescue purposes. An emergency doctor, two paramedics and a fire men were part of the crew. Especially this helicopter raised concerns among some doctors due to its high vibration level [30]. Another accusation was the cabin interior noise level [28].

Since this helicopter was much too large, the ADAC started another field study utilizing a Bell 206 Jet Ranger in co-operation with the German Red Cross and the Federal Ministry of Transportation. The crew consisted of the pilot and a physician. A paramedic was not on board due to space constraints. The operating radius was set to 100 km (62 miles). An important result of this campaign was that the operating radius chosen was too large, and that a radius of 70 km (44 miles) would be sufficient. In addition, it was learned that the helicopter could complement ground-based rescue traffic, but not replace it. This helicopter operated already under the name "Christoph[5] München" [28]. Requirements for a future HEMS system, which based on this pilot test, were defined like the need for a coordinating control center, a paramedic as supplement to the doctor, and 50 km (31 miles) normal operating radius, in maximum 70 km.

Since the traffic fatalities peaked in 1970 (see Fig. 5), the ADAC finally started an open-ended operation of an EMS helicopter as "Christoph 1" on November 1, 1970. The helicopter, a twin-engine Bo105, was stationed at the city hospital Munich-Harlachingen. The ADAC negotiated with the public health insurances an operation fee of DM600 (€307) per mission [29].

The Bo105 was well suited for that purpose and during its development, special requirements for HEMS were considered. The crew consisted of a pilot, emergency doctor and a paramedic. It could transport a lying patient and the required medical equipment [28, 29].

Soon after, and since the results of Christoph 1 were impressive, the federal government decided to establish a nationwide HEMS system and participated within this effort. Search and Rescue (SAR) helicopters of the German Army and helicopters of the Bundesinnenministerium (BMI, engl. Federal Department of the Interior) were placed at the disposal of such a HEMS system. On March 19, 1973, the Deutsche Rettungsflugwacht (DRF, engl. German Aviation Rescue Guard), the predecessor of today's DRF Luftrettung, stationed an SA 316 Alouette III helicopter in Stuttgart. In the following decades, the German Army withdrew from the HEMS care and the respective stations were handed over to ADAC Luftrettung and DRF Luftrettung (the German word Luftrettung stands for air rescue, as both companies are now called). After the starting signal in 1970, the next HEMS stations were very quickly put into operation. An overview on the HEMS stations and its initiating date with the status of 2008 is given in [31] and indicates the rapid growth. The rapid growth itself proves that a nationwide HEMS system was intended almost right from the beginning in 1970. Today, the HEMS map of Germany encompasses 76 stations (RTH and ITH only). More information is given in Sect. 3.

Mountainous countries represent a demanding topology for helicopters. High altitudes require sufficient power reserves to transport a given payload. Not very many helicopters are suited for this. Slopy mountainsides make landing in many cases impossible and hence, other rescue maneuvers have to be invented for picking up injured people, etc. Switzerland is such a mountainous country, but still has established one of the leading HEMS systems. In Switzerland the foundation of a civil air rescue system began soon after WWII. In November 1946 a DC-3 Dakota stranded on the Gauli Glacier. On November 24 two military pilots rescued the passengers using two Fieseler Storch aircraft. The pilots managed to land their aircraft directly on the glacier [31]. This rescue mission might be viewed as the initiation of the Swiss air rescue [32]. On

[5] Saint Christopher was a Christian martyr (third century) and is patron of travelers. The name means carrier of Christ.

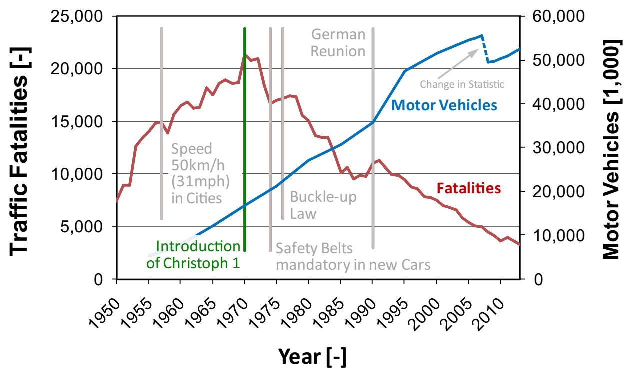


Fig. 5 Traffic fatality rate and registered motor vehicles in Germany. Data: Federal Offices for Statistics and Motor Transportation, Germany

April 27, 1952, the Schweizerische Rettungsflugwacht (SRFW, engl. Swiss Air Rescue Guard), a predecessor of the Rettungsflugwacht Garde Aérienne (REGA, engl. Air Rescue Guard) was founded. SRFW was probably the world's first civilian helicopter air ambulance [13]. At the time of foundation, rescue parachutists were used first to tackle the problem of sloppy and high mountainsides, since the available helicopters had insufficient performance [33]. Since this method presented considerable risks to the rescuer himself, helicopters were consequently tested for rescue purposes. In December 1952, a first helicopter rescue mission was undertaken with a Hiller UH-12A, however, details of this mission are unknown. Since the UH-12A could be operated up to altitudes of 1600–2000 m (5249–6562 ft) with only half total fuel capacity [31], it is more than likely, that this mission was more of a purely rescue than of EMS nature. Further helicopter rescue missions were then accomplished outside Switzerland during the flood catastrophe occurring in Holland, in February 1953. The following years saw a slight increase in the number of rescue helicopters, but it was not until 1957 that medical attendants were on board an aircraft when a Bell 47J was donated to SRFW [32, 33]. In the 1960s, SRFW experienced a financial crisis. To solve that problem, SRFW introduced a patron ship as it still exists today. For a donation of CHF20, helicopter rescue free of charge was offered [32]. Two further milestones were the purchase of the first turbine helicopter, a Bell 206 A Jet Ranger, in 1968 which could transport two casualties and a medical attendant [31, 32]. Finally, the first twin engine Bo105C helicopter was brought in operation in 1973 [32]. Slowly, but surely, REGA, as the company now is being called, could increase its number of HEMS bases throughout Switzerland with the exception of the canton Valais and two further stations in the canton Bern. Here two other operators are active: Air Glaciers and Air Zermatt. Both companies were founded in 1965 in Sion and 1968 in Zermatt, respectively [31, 34, 35]. Both companies quickly introduced SA 316 Alouette III and later even more powerful SA 315B Lama helicopters which are still well suited for high mountain rescue missions. Since 1973, Air Zermatt employs its own emergency doctors and nurse anesthetists [34].

Finally, after long negations, the government in Zurich agreed in 1975 to a test phase for using EMS helicopters in context with traffic accidents [32].

Today, REGA operates 17 EMS helicopters, at 13 bases of which the one in Geneva is run by a partner with its own helicopter. REGA intends to reach every casualty within 15 min through Switzerland with the above-mentioned exception. In Valais, Air Zermatt operates two bases with 9 helicopters. For Air Glaciers the number of stations and helicopters is not quite clear, but from [35] about 16 helicopters have been estimated at 9 stations. While Air Zermatt and Air Glaciers fly a majority of one engine helicopters, REGA operates twin-engine ones only. As REGA, Air Zermatt and Air Glaciers finance their services partly by patron ships.

All three companies are rather innovative. Air Zermatt, for example, introduced sensors for localizing ferromagnetic parts like cars below avalanche snow and REGA as the first civil organization equipped all bases with night vision goggles (NVG) [34, 32].

In Austria the foundation of an air rescue system goes back to severe avalanche catastrophes and the flooding over wide areas in 1953 and 1954. The need for rapid air rescue motivated the foundation of a police squadron. At that time flying was allowed to the Allies only, but in 1955 they agreed that flying for rescue purposes would not be objected further on. The agreement was granted for five helicopters and five fixed wing aircraft. Three policemen were trained in Switzerland. On March 14, 1956 the first rescue mission of an injured skier was, however, performed with a Piper aircraft [31, 36].

The following years saw an increasing number of rescue missions. Till end of the 1950s first rescue missions were flown by the Austrian Army and till mid of the 1960s, the police squadron increased its helicopter number to 8 [31]. In 1978 more than 1000 people were rescued. In parallel to fixed wing aircraft, first helicopters were purchased that were specifically dedicated for the rescue of people. Based on the gathered experiences medical needs motivated the same recue doctrine as in Germany: the doctor has to come to the patient. With respect to the legislation system, an administrative problem needed to be solved as well, since the competence for public order and safety lies at the federal government, the one for emergency services at the individual states. This issue was sorted out by an individual treaty [36].

After the National Assembly agreed upon the review of an air rescue service, a first field trial of a helicopter-based rescue service was initiated in Salzburg. The funding of the trial was taken over by the Allgemeinen Unfallversicherungsanstalt (engl. General Accident Insurance Institution). On July 1, 1983 the Österreichischer Automobil-, Motorrad- und Touring Club (ÖAMTC, i.e. Austrian Automobile, Motorcycle and Touring Association) brought its first EMS helicopter as Christophorus 1 in service. This date might be viewed as the birth of the Austrian HEMS system. Since then, the rescue service was quickly enlarged and from 1983 till 1987 a nationwide rescue service has been established. The federal government again negotiated a treaty for regulating the HEMS system with the federal states; however, Niederöstereich (engl. Lower Austria) and Burgenland did not sign this treaty and provided own solutions. From January 1, 2001, the department of the interior pulled out of the rescue system. The ÖAMTC took over the respective stations step by step and operates presently 17 stations (one in cooperation with ADAC Luftrettung, see below) with 18 helicopters in operation. In 2013, the ÖAMTC flew 16,043 missions [37]. The ÖAMTC can reach every destination in Austria within 15 min (likewise as the German system) [38]. The average costs per rescue mission are €3500 [37]. The EMS helicopters of the ÖAMTC are named Christopherous, similar to the ones in Germany. The purchase costs of an EC135 are given by the ÖAMTC presently with €4.3 million including medical equipment [37].

In-between, other private operators also offer their services for helicopter EMS [36]. The ÖAMTC cooperates with some of those private companies like the German ADAC Luftrettung. Both companies operate Christophorus Europa 3 in Suben, next to the Bavarian border [37, 39]. DRF Luftrettung holds two stations in Austria [40]. An overview on operators and stations is given in [31] and [41]. Based on the information given, 8 operators are active in Austria, 24 stations which are in operation all the year round are complemented by 13 seasonal stations (e.g. during the winter skiing time) and it can be estimated that approximately 43 rescue helicopters (all with two engines) are in operation.

After WWII the utilization of helicopters to rescue people was demonstrated in USA also for civil purposes [13]. However, these missions were more on an occasional basis and were far from something featuring medical aid. Nevertheless, it took till 1965 when efforts merged into a first air rescue program called Helicopter Emergency Lifesaving Patrol. This patrol was set up in Philadelphia and air medical service was provided to the Delaware Valley. Medical personnel came from a local hospital. The program was in so far unique, since the commercial helicopter was also used for air traffic reporting [11, 13].

In 1966, a report of the National Academy of Science outlined the impact of death and disability caused by trauma, particularly due to car crashes. It also noted that a coordinated response to trauma is missing and pinpointed that helicopter ambulances were not adapted to civilian needs in peacetime [42]. In 1969, it was concluded on the bases of medical AE helicopters in Vietnam that wounded soldiers had better chances to survive than motorists injured in a traffic accident [25, 43]. Several programs were later established to evaluate helicopters for civilian EMS. The first project, called Coordinated Accident Rescue Endeavor—State of Mississippi (CARESOM) was funded by a federal grant and three helicopters were stationed throughout Mississippi. When the CARESOM grant expired a year later, two out of the three helicopters were terminated although CARESOM was viewed a success and just the one located in Hattiesburg was taken over by the community [25, 43]. In the same year, the state of Maryland received a grant to purchase Bell Jet Ranger helicopters. The Maryland State police and the University of Maryland started a joint police/HEMS service covering the whole state. The four helicopters were manned by paramedics. When not in use for HEMS, the helicopters were used for law enforcement and traffic control [42]. Another program was launched a year later on July 15, 1970 in Fort Sam Houston in San Antonio, Texas, and was called Military Assistance to Safety and Traffic (MAST) [44]. Further MAST units were established later that year in Colorado Springs (Colorado), Seattle (Washington), Phoenix (Arizona), and Mountain Home (Idaho). The project was an experiment by the Departments of Defense, Transportation, as well as Health, Education, and Welfare [44]. It intended to analyze whether military helicopters could be used to supplement existing civilian emergency medical services, in particular to respond to highway accidents. As in Germany, USA suffered from a very high number of more than 55,000 of traffic fatalities at that time. As of May 8, 1972 a total number of 1049 missions were flown [44]. It might be interesting to note that among the helicopter models used within the MAST program the Kaman HH-43 Huskie was utilized, too. The Huskie differs from the helicopters mentioned so far, since it features two Flettner intermeshing rotors that eliminate the need for torque compensation. The pilot controls the helicopter not by blade root control, but by servo flaps at the trailing edge of the blades, see Fig. 6. It also features clam-shell doors at the rear and a rather low disc loading, $DL = m_{TOW,max}/S$, of 12.87 kg/m^2 (2.64 lb/ft^2) which gave this aircraft excellent lifting and high altitude capabilities.

According to [42], retired military medical helicopter pilots who were hired by law enforcement and other public safety flying units might also have had an influence on the way towards the establishment of HEMS programs.

Fig. 6 Kaman HH-43 Huskie, Source: Olympic Flight Museum, WA

So far, the programs were more on a preliminary study bases like CARESOM, used military helicopters like MAST or featured dual-purpose helicopters like the Philadelphia and Maryland programs. In 1972, however, the first civilian hospital-based medical helicopter service was established, when Flight for Live Colorado stationed an Alouette III helicopter, based at St. Anthony Central Hospital in Denver, Colorado [42, 43, 45]. This was basically the same model that was established for Christoph 1 at the hospital of Harlaching, Munich, Germany. Flight for Live now operates five bases and has chosen Airbus Helicopters AS 350 B3 helicopters for its high altitude capability. All helicopters are leased from Air Methods Corporation in Englewood, Colorado. Pilots and mechanics are employees of Air Methods Corporation. The helicopters are used in two roles, primary and secondary rescue [45]. Later on, many hospitals throughout USA also developed these services in conjunction with the implementation of organized trauma systems [42]. Therefore, this date in 1972 can be viewed as the launch of a nationwide HEMS system in USA. The system that individual hospitals establish their own air medical services might be an explanation for the high number of small HEMS providers in USA. However, the model of Flight For Live Colorado reduced the impulse for state and local governments, and the military, to further develop civil HEMS programs. Today, governmental and public HEMS programs are limited to a few states and a few municipalities within USA [42].

By 1980, about 32 helicopter EMS programs with 39 helicopters were established and the number of treated patients grew to 17,000 per year. Ten years later, the numbers were 174 services with 231 helicopters flying almost 160,000 patients. In 2010, 309 services, operating 900 helicopters and 311 airplanes, were reported [42].

Figure 7 shows this fast development since 1980 for both, HEMS providers and EMS helicopters. Please note

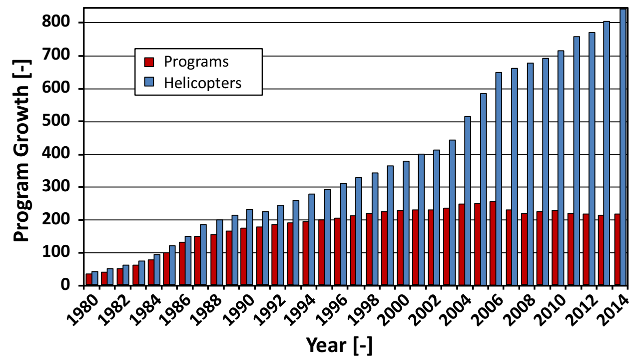


Fig. 7 Development of HEMS programs and dedicated EMS helicopters in USA since 1981, Source: I. Blumen

that the numbers shown there differ from the ones mentioned above. This is also highlighted in [46]. The correct counting of HEMS helicopters is mentioned to be difficult in USA. One explanation might be the large number of service providers and helicopters as well as the definition when a helicopter is being counted as an EMS helicopter. The numbers shown in Fig. 7 include “dedicated” EMS helicopters only. It does not include, spare, military or dual-purpose helicopters. Dual-purpose helicopters in USA are not dedicated specifically to HEMS, but are used for other purposes, too. The number of MEDEVAC capable aircraft in USA is given in [46] to 960. This might also include aircraft that are not configured to MEDEVAC, but might be converted in one, and aircraft that are parked.

Nevertheless, Fig. 7 gives a good overview on the phenomenal growth of HEMS in USA. The numbers of helicopters has increased by almost 150 % since 1998 (343 helicopters) to about 843 helicopters. From 1985 till 2005, the number of helicopters has doubled approximately every 10 years. In contrast, the increase in programs has slowed since 1989, with little improvements before 2007. Since then, the trend has reversed and the number of HEMS programs has decreased from about 250 programs in 2006 to 215 programs in 2014 due to mergers and closures. This might be attributed to the economic aspects. More information on providers and utilized helicopter models is given in Sect. 3.

Japan just has recently introduced a HEMS system. Japan, as an island, is situated in a tectonic active region. It is more often haunted by earthquakes and tsunamis than many other countries, the latest one in March 2011. These natural disasters often destroy infrastructure and make land-based rescue of injured people difficult, sometimes impossible. Japan is an insular state and comprises four main islands and 6848 smaller ones. Approximately 425 of these islands are inhabited. A mountain chain runs across the country, covering more than two-thirds of the landscape. Agriculture, industry and settlements cover only

20 % of the country. This all would have motivated an early introduction of an HEMS system and since the country is one of the very high industrialized ones and since income of the population is higher than for comparable countries, costs should not have been an argument. However, this was not the case.

The way to establish a Japanese HEMS system is documented in [47, 48], and it is worthwhile to include Japan also in the historic retrospective view. The Japanese HEMS system, called Doctor-Helicopter or short Doctor-Heli, was strongly influenced by the German system. Especially Gerhard Kugler[6] functioned as a counselor for the Japanese initiators [47, 49]. In fact, it is similar to the "Munich model", although financing of both systems differ. A Doctor-Heli stands ready at a hospital with medical equipment. The crew comprises an emergency doctor, a nurse and in addition to Germany a mechanic. At the scene, the patient is first being stabilized before he then is transported to the most suitable hospital [47]. The mechanic sits on the co-pilot seat and assists the pilot during flight. On the scene, he co-operates with the doctor and the nurse in providing medical care [50]. More information on the mechanic will be given in Sect. 3. A major step forward in motivating a Japanese HEMS was as in Germany the high number of traffic fatalities. While in Germany, the mortality after traffic accidents was reduced from 21,332 in 1970 to 10,070 in 1985, the Japanese number stagnated at a very high level (16,756 in 1979), without any sign to decrease. In 1989, a TV documentary showed the benefit of HEMS operations in Germany, especially regarding their benefits in reduce traffic fatalities. The documentary included an interview of G. Kugler by Y. Yamano, one of the directors of the later founded Emergency Medical Network of Helicopters and Hospitals (HEM-Net) [51]. The documentary won the Prime Minister's Prize for quality and constructive content and raised a discussion as to why the Japanese government does not care more about the traffic fatalities. In the following years, however, no attempt was undertaken, to establish a first HEMS base. It took until 1994 till the Japanese Aeromedical Society was founded. In 1995, when the Hanshi-Awaji earthquake killed 6000 people in Japan [48], the non-existing HEMS became sadly obvious. The infrastructure was heavily destroyed and transportation capabilities as well as emergency care were completely insufficient for the high number of casualties. Just 17 casualties were evacuated and transported by helicopter within the first 72 h [48]. Some years later, in 1999, HEM-Net was established. HEM-Net

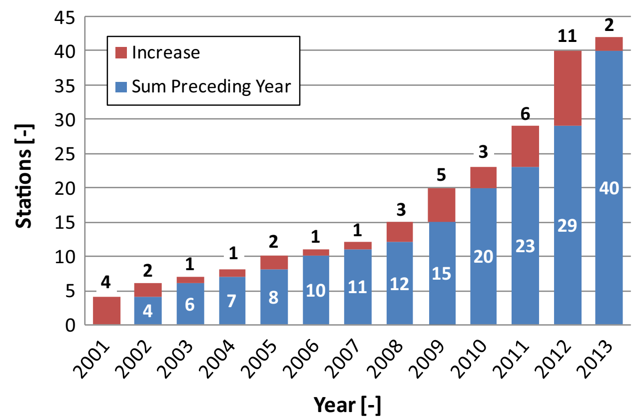


Fig. 8 Increase of HEMS Stations in Japan. Year resembles date when stations entered service, data taken from [51]

is a non-profit organization that promotes nationwide emergency medical services by helicopters. Finally in 2001, the first five stations were established. The costs were financed equally between the responsible local governments and the central Ministry of Health, Labor and Welfare. The fund totaled ¥170 million (about €1.14 million or $1.41 million[7]) per HEMS basis for the period 2001–2007. In 2008 this amount was increase to ¥210 million (about €1.41 million or $1.74 million) for one HEMS station and the share between the stake holders was finally changed in 2009 to 90 % for the central and 10 % for the local government [47]. Finally, the introduction of Doctor-Heli contributed to the reduction of traffic fatalities [48].

The numbers of HEMS stations and their annual increase is shown in Fig. 8 for the period from 2001 till 2013. The speed with which the stations increased since 2011 is much faster when compared to other countries. This might be attributed to the governmental financing of the system. The objective was to establish at least one HEMS base in each of the 47 Japanese prefectures. In [47] it is expected that 50 bases will be established by 2020, with the number of bases eventually totaling 70, as in Germany (note: Germany now has 76 HEMS bases for RTHs and ITHs), since both countries have almost similar surface areas. However, since Japan is covered to a large extent by mountains, 100 bases will be probably necessary, to reach equal survival chances between both countries [47].

The diversity of EMS helicopter manufacturers is higher than in other countries (e.g. Germany). In Japan AW109, Bell 429, BK117/EC145, EC135, and MD 900 helicopters are being utilized [48], although Airbus Helicopters is still

[6] G. Kugler (1935–2009) was one of the pioneers of the German HEMS system. In 1971, he took over the position of the head of the young air rescue department at ADAC. From 1990 till his retirement in 2000 he was CEO of the ADAC Luftrettung GmbH and author of [30].

[7] The exchange rate was taken on Dec. 7, 2014.

the dominant provider [49]. All helicopters are powered by two engines and have FAA CAT-A approval [52].

Finally, before selected HEMS systems in various countries shall be outlined in more detail, the benefit of HEMS shall be outlined once more. A 17-month study was conducted in Denmark, where till 2010 the usage of helicopters was not considered. In this study a 5-month period without HEMS was compared to a 12 months lasting phase with one EMS helicopter stationed in eastern Denmark, which operated outside a 30 min radius from the Trauma Center in Copenhagen. Especially the so-called 30-day mortality rate showed an impressive reduction from 29 % without HEMS to 14 % with HEMS. There were 6.7 "unexpected" survivors per 100 treated patients [53]. In Germany, a study has been conducted between 2007 and 2009 to analyze the mortality rate of casualties transported by EMS helicopters versus those transported by ground-based rescue transport vehicles (RTV) [54]. Traumatized patients with a so-called Injury Severity Score (ISS) larger nine were analyzed, only. A total number of 13,220 patients were included in the study. Although the HEMS transported patients had a higher ISS (ISS 26.0 versus 23.7), the authors resume: "In conclusion, the present study demonstrates that HEMS rescue has its merit on traumatized patients. Despite an increased injury severity and a higher incidence of clinical complications, HEMS has a beneficial impact on survival." A more recently conducted study covering even 52,281 patients in the period, from 2002 to 2012 confirms these findings [55]. A study on the benefit of HEMS has been also conducted on a European level although some countries did not participate in this study [56]. A questionnaire was submitted to 143 European HEMS bases and 73 reported on base characteristics and medical sample data. Cardiac etiology (36 %) and trauma (36 %) prevailed, mostly of life-threatening severity (43 %). Onboard physicians rated that they had contributed to a major decrease of death risk in 47 % of missions, possible decrease in 22 %, and minor benefit in 17 %, although the patient would have been treated by other medical personnel, if the EMS helicopter would not have been dispatched. Earlier treatment and faster transport to hospital were the main reasons for benefit. In Japan, a similar study to [55] was conducted, including 24,293 patients who were injured in the period from 2004 to 2011 [57]. All patients were older than 15 years and showed an ISS larger 15. The helicopter transported patients showed a higher ISS than the ones transport by RTV. Here, too, the patients transported by helicopter showed an improved chance of discharge from hospital than those transported by RTV. The great earthquake in the north-east of Japan on March 11, 2014, with a magnitude of 9.0, again caused fatal infrastructure damages. This time, 18 out of 26 Doctor-Helicopters that were available back then were deployed into the disaster area and rescued 149 patients within the first 4 days [48].

3 Examples of HEMS systems

This chapter aims to give an overview on various HEMS programs inside and outside of the European Union.

3.1 Europe

In Europe, the organization of a HEMS program is within the responsibility of the national states. No general pan-European organization exists. However, some states have agreed to operate single HEMS stations on a joint basis or at least have agreed to a cross boarder operation of an EMS helicopter. Examples are the helicopters Christoph Europe 1 in Aachen-Würselen, Christoph Europe 2 in Rheine, both in Germany and operated by ADAC Luftrettung, and Christoph(orus) Europe 3 in Suben, Austria, operated by ADAC Luftrettung and ÖAMTC, Lifeliner Europa 4 in Groningen, The Netherlands, operated by ADAC Luftrettung and ANWB (Algemene Nederlandse Wielrijders Bond, i.e. the Dutch Automobile Association) and Christoph Europa" in Niebüll, Germany, operated by DRF Luftrettung [31].

Christoph(orus) Europe 3, see Fig. 9 for its location, is a true cross national EMS helicopter.

Christoph Europa 3 became operational July 23, 2002. As usual in Germany and Austria, it has an operational range set to 50 km (31 miles). Each destination within this range can be reached within 15 min. Before this base was built on Austrian side, "white spots" on the HEMS map on German as well as on Austrian side were visible. Patients in that area often had to wait for medical aid from the air for 25 min. The base is shared between ADAC Luftrettung and ÖAMTC. During the winter months, ADAC Luftrettung provides the pilots and ÖAMTC during the summer season. The medical crew is being also built up from both nations and is dispatched throughout the year and does not change like the pilots from one season to another. The great success of this concept is displayed by the number of missions: in 2013 Christoph(orus) Europe 3 conducted 1731 missions [58].

In Europe, the European HEMS and Air Ambulace Committee (EHAC) is an association that represents European organizations which are providing emergency medical services with both, helicopters and ambulance airplanes. EHAC maintains a network between members and experts, from both authorities (e.g. EASA) and industry [59]. A HEMS base map has been published by EHAC in [60]. This map is shown in Fig. 10 as far as the operators have reported their bases to EHAC.

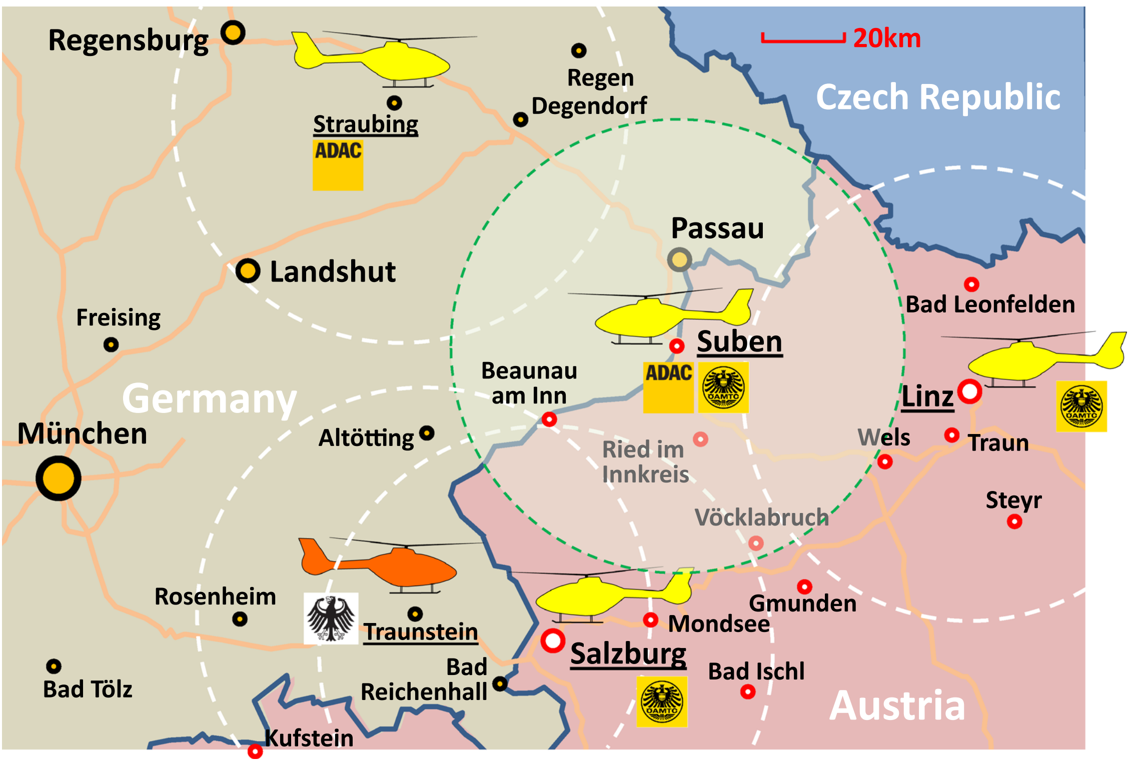


Fig. 9 Location of Christoph Europe 3

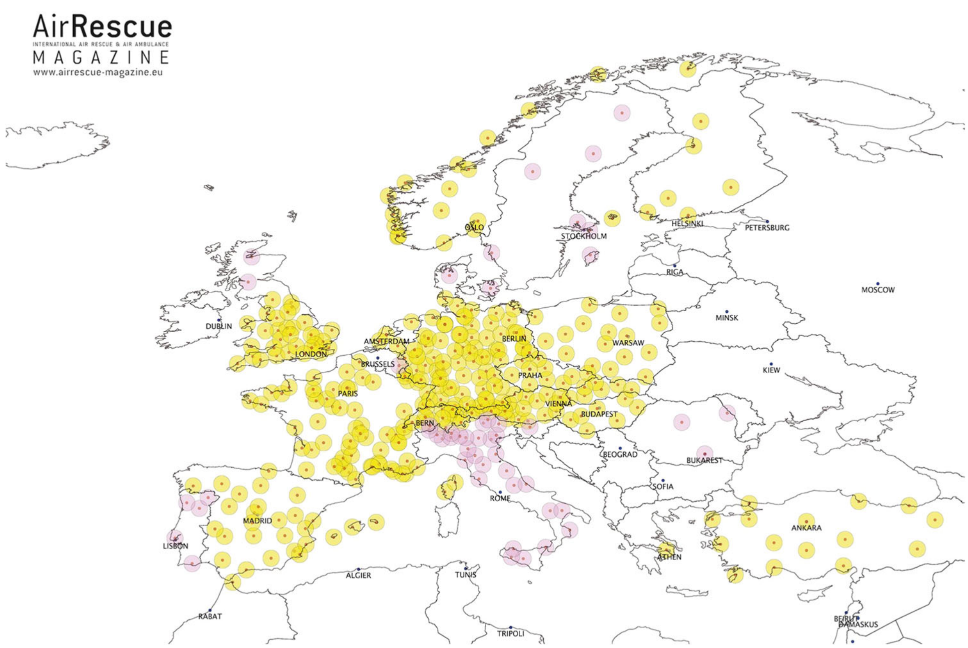


Fig. 10 European HEMS bases. *Yellow circles* denote EHAC member HEMS stations, *red ones* other HEMS stations. Source: [60]

In Europe, requirements for the operation of any civil helicopter for the purpose of commercial air transportation were prescribed by JAR-OPS Part 3. JAR-OPS Part 3 has recently been replaced by EU CR No. 965/2012 [2]. This regulation lays down detailed rules for commercial air transport operations with airplanes and helicopters and became effective not later than October 28, 2014. Subpart J of annex V defines HEMS operations. Besides minimum requirements for the operation like cloud ceilings and visibility requirements as well as crew requirements, it defines performance requirements. These requirements define under which performance class the operator may conduct which flights. One performance requirement for example is given in section SPA.HEMS.125 b (1) and specifies that EMS helicopters "conducting operations to/from a final approach and take-off area at a hospital that is located in a congested hostile environment and that is used as HEMS operating base shall be operated in accordance with performance class 1." Article 2 (4) defines operation under performance class 1 as "an operation that, in the event of failure of the critical engine, the helicopter is able to land within the rejected take-off distance available or safely continue the flight to an appropriate landing area, depending on when the failure occurs." This can be reached only by EMS helicopters with at least two engines with sufficient one engine inoperative performance. SPA.HEMS.130 specifies, for example, a minimum number of flight hours experience for the pilots or the crew composition for day and night flights.

In the following paragraphs, some European HEMS programs shall be outlined in more detail.

3.2 Germany

Germany has established the oldest nationwide and probably one of the most efficient HEMS systems. Therefore, the situation in Germany shall be outlined first.

Germany has about 80.8 million citizens (status 2013) and a surface of 357,340 km^2 (137,970 $mile^2$) which results in a population density of about 226.1 citizens/km^2 (585.6 citizens/$mile^2$). Not counting Russia, Germany is the fourth largest country in Europe. Its geography is characterized by three large parts, the north Germany low land, the Central German uplands and the Alps in the south with the forelands. The first is encompassed by the Baltic and North Sea and comprises of a couple of islands in both seas. The elevation does not exceed 200 m (656 ft). The center of Germany is shaped by several mountains, with elevations of 500–1000 m (1640–3281 ft). Exceptions are some summits that reach heights of up to 1493 m (4898 ft). The Alps foreland reaches elevations ranging from 300 to 800 m (984 to 2625 ft). Germany owns just a small fraction of the Alps with the Zugspitze being the highest summit 2963 m (9721 ft). Hence, the altitude requirements for helicopters are less demanding than in other countries (e.g. Switzerland).

Rescue service is a public duty of existence welfare. Germany, as a federal republic, consists of 16 federal states that are responsible for the rescue services [28, 31]. Three factors are listed in [30], which have supported the setup of a German HEMS system:

(i) the contractual agreement on the reimbursement of the mission costs with the health insurance companies,
(ii) the acceptance of own large financials shares by the operators, and
(iii) the implementation of rescue service laws since 1974.

The federal states have established individual rescue service laws. In general they define a so-called "Hilfsfrist" (rescue time limit). This rescue time limit is the leading value for the infrastructure of the rescue service in Germany and resembles a compromise between emergency medical requirements and economic feasibility. It defines the time from receiving the emergency call at the emergency operations center (in Germany they can be reached nationwide at the emergency call number 112) till the first rescue device reaches the emergency scene. A good example can be found in [61]. Here, it is stated that the rescue time limit shall be not more than 10 min, in maximum 15 min from an emergency medical point of view. This plan value is defined for rescue scenes at streets and roads. It is being considered as fulfilled, if 95 % of all rescue missions in the preceding year have been within that limit for the whole rescue service domain. It also prescribes, that the required qualifications have to be setup that an emergency doctor can reach the emergency scene in the given rescue time limit. A brief overview on the existing requirements in different states is given in [62].

The federal states are also responsible for the air rescue service. They decide about the location of an EMS helicopter station and operators can apply during an open tender [28].

In Germany, four principal HEMS providers are active: ADAC Luftrettung, DRF Luftrettung, BMI, and Johanniter-Unfall-Hilfe e.V. (JUH, engl. Johanniter-Accident-Care). The Helicopters of JUH are operated by Heli-Flight. Number of stations and helicopters are listed in Table 2. In total, 76 stations and about 120 EMS helicopters are in operation. In 2015, the ADAC Luftrettung will open its 35th station [39]. Heli-Flight operates a third helicopter, a R44, which is being used as a so-called emergency doctor helicopter. Its purpose is to bring an emergency doctor to the rescue scene. Its advantages are its small exterior dimensions which make this aircraft suitable to land in smaller confined places than other aircraft and its low operating costs. Its disadvantage is that the patient always has to be transported with another vehicle.

Usually, the crew of an EMS helicopter comprises pilot, emergency doctor and a paramedic. The paramedic holds a qualification as HEMS Crew Member (HCM) now according to EU CR No. 965/2012. The paramedic supports the pilot during the flight. If the helicopter is

Table 2 HEMS providers, stations and helicopters in Germany

Quantity		Operator	Status 9/2014
Stations	Helicopter		
34 (+2)	51	ADAC Luftrettung (+1 station in the Netherlands and 1 in Austria)	
28 (+2)	About 50	DRF Luftrettung (+2 stations in Austria)	
12	16	Federal Ministry of the Interior	
2 + 1	3 + 1	Heli-Flight on behalf of JUH + 1 emergency helicopter in Rostock	

equipped with a rescue hoist or winch, a fourth crew member, the flight attendant, operates the winch. During night flights, usually two pilots are on board the aircraft [28], see also below. Usually, the pilots are hired by the rescue organization. To become pilot at the ADAC Luftrettung, for example, one has to prove 1500 flight hours and 500 h as (co-)pilot of an EMS helicopter [39]. At ADAC Luftrettung flight attendants are also employed by the ADAC Luftrettung while paramedics are usually employed by the local rescue organization, fire department or hospital with which the HEMS operator co-operates. The physicians are mostly anesthetists from a local hospital [31, 39].

The HEMS stations in Germany are shown in Fig. 11.

On the first inspection, the map seems to be overloaded and many circles cover the same area. There are just small “white spots” remaining, which are not covered yet. Some cities seem to have more than one rescue helicopter station like Hamburg in the north of Germany. However, a closer look shows, that in most of such cases the one helicopter is a RTH, while the other is an ITH. In Germany, these functions seem to be more separated from each other than in other nations. However, this does not mean, that an ITH does not fly primary rescue missions and vice versa. However, RTHs are usually less suited for secondary missions, than ITHs for primary missions. This is a direct consequence of the aircraft types. RTHs are in most cases smaller aircraft (e.g. EC135) while ITHs are often larger (BK117 or EC145) and can transport more medical equipment, which is specially needed for intensive care patients [63]. The designations RTH and ITH hence refer to the primary purpose of the aircraft. Some aircraft are dedicated dual-use aircraft for primary and secondary rescue. From the 76 stations in Germany 53 are RTH stations, 14 ITH stations, and 10 offer dual-use service[8] [63].

The majority of these stations are in operation during daylight hours. For ADAC and DRF Luftrettung as well as BMI, the aircraft are usually in service from 7 a.m. (or sunrise whatever is later) till sunset, for JUH from 30 min before sunrise to 30 min after sunset, if the station is not in operation for 24 h/day. This is the case for 13 of the 76 stations listed. Of these 13 stations and corresponding helicopters, nine helicopters are ITHs, three dual-use RTH/ITH and one is an RTH. The latter one serves the East Frisian Islands in the North Sea and is very important for primary rescue at these islands. This explains its operating hours throughout the whole day. Since EMS helicopters operate in unprepared areas to conduct primary rescue, night flights without ground-based infrastructure is difficult, but is occasionally conducted. Currently, NVGs are also introduced to support night flights. More information on EMS night flights will be given below in context with the flight statistics of the HEMS operators.

The four operators in Fig. 11 can be distinguished from their color, see legend. The circles depict operation radii from 50 to 70 km (31 to 44 miles). The latter is the maximum radius, the first the most efficient radius [31]. This is based on the flight duration for the given distances. After the helicopter crew has been alarmed, the helicopter is ready for take-off within 2 min during daylight working hours [39, 40, 64, 65]. A modern rescue helicopter with a cruising speed of about 240 km/h (124 mph or 130 kts) then needs about 9 min for 30 km (19 miles), for 50 km about 15 min and for 70 km about 21 min in total to reach its destination [31]. For secondary missions, the dispatch of the ITH takes longer. Prior to take-off for a secondary flight, there will by a physician-to-physician talk which aims to hand over all relevant medical information from the doctor of the source hospital to the emergency doctor of the ITH. Depending on the circumstances of the mission, the ITH usually takes off within 30 min [63].

The mission radii in Fig. 11 are no firm boundaries. They shall guarantee an efficient dispatch of the rescue helicopters. Usually, the helicopter with the shortest distance to the emergency scene is being ordered by the emergency operation center to perform the mission, if an emergency scene can be reached by more than one EMS helicopter.

The above-mentioned emergency operations centers decide upon the dispatch of the EMS helicopters. In general, a dispatcher decides, whether an ambulance car with no emergency doctor on board is sufficient, or if a physician needs to be dispatched. This can be done either by

[8] The numbers sum up to 77 instead of 76, since DRF Luftrettungs counts its station in Halle only once, although two helicopters with different call signs are operated at this station. Usually, this is counted as a separate station, but the figures of the operator were used in Table 2.

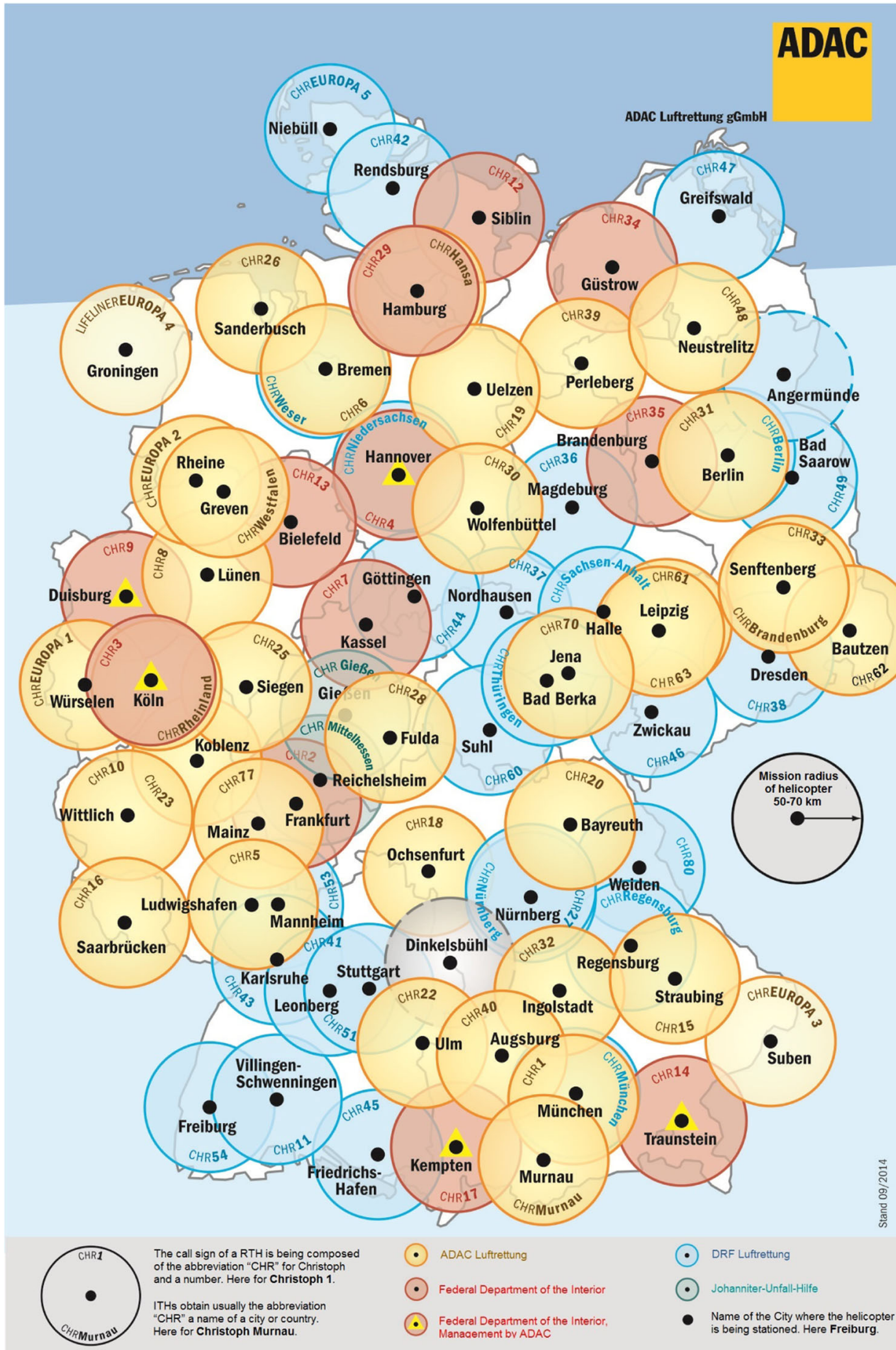


Fig. 11 HEMS bases in Germany. Source: [39]

ground-based emergency rescue vehicle or by EMS helicopter. In this case, the helicopter is mostly the fastest transport means [31, 40]. The decision of which transport means is being sent depends on a criteria catalogue (e.g. available rescue means, information reported during the emergency message, emergency location, weather, etc.) [39]. If a helicopter is being dispatched, usually a ground-based ambulance is also being sent in parallel to the scene. Firstly, this allows a better treatment of the patient in a small treatment room and, secondly, the EMS helicopter is faster ready for further missions, if it should become apparent that the emergency is not severe [28]. To ease the decision for the dispatcher, which EMS helicopter shall be sent to the emergency scene, a system has been installed in Germany called "RescueTrack". It was introduced first by DRF Luftrettung [67], but in-between ADAC Luftrettung

[63], and the ZSH [70] also use this technique. On board the helicopter, a satellite-based telephone is being connected with a Global Positioning System (GPS). The helicopter then sends mission status and position to a central protected server. These data are then made accessible for the emergency operating centers. The dispatcher gets every second minute an update of the position of the EMS helicopter, its status and destination, and when the destination will be reached [67]. RescueTrack is also available for ground-based ambulance vehicles.

The 28 stations of DRF Luftrettung are equipped just with Airbus Helicopters machines, with the exception of two Bell 412 which are utilized as ITHs. They are the largest EMS helicopters in Germany, offer a specious cabin and a maximum take-off weight (MTOW) of 5398 kg (11,900 lbs). EC135 helicopters represent the majority of the fleet (mostly used as RTHs), followed by BK117 (both purposes RTH and ITH) and finally by EC145 (mostly used as ITHs) [40]. Eight stations are operated 24 h/day, however, just three of them use NVGs (introduced since end of 2008). DRF Luftrettung has recently received the first EC145 T2 model. In total, DRF Luftrettung will receive 20 of these machines till 2022. It features a 4-achis auto pilot, satellite-based navigation, NVG-compatible cockpit layout, certification for instrument flight rule (IFR), weather radar, and collision warning equipment. The autopilot allows automatic instrument approaches till hover. For the medical equipment of the EC145 T2, DRF Luftrettung has teamed with ADAC Luftrettung, ADAC Luftrettung recently has received its first EC145 T2, too, and has ordered 14 of these aircraft. They will be delivered till 2018 and will replace 17 older BK117. ADAC Luftrettung invests €130 million in its fleet modernization [39]. ADAC Luftrettung operates exclusively Airbus Helicopters aircraft. The fleet comprises EC135, EC145 and BK117. Four stations of ADAC Luftrettung are in operation 24 h/day. One station uses NVGs since May 2012.

The aircraft operated for JUH are ITHs. Out of its two stations, one is 24 h/day in operation. During night time, this ITH is ready for take-off within 15 min. JUH operates three SA365 (N and N2, respectively). A fourth helicopter, an older SA365C3 version, is used as backup, but is rarely used. The rather large aircraft offers a spacious cabin such that medical specialist can be on the flight, too [64]. These aircraft are among the largest ones in Germany for HEMS. The N-model has an MTOW of 4000 kg (8818 lbs), the N2-model even 4250 kg (9369 lbs) [66].

Pursuant to [63], some helicopters of ADAC and DRF Luftrettung as well as JUH are equipped with weather radar. These aircraft are mostly ITHs.

To operate its 12 stations, the BMI utilizes 16 EC135 T2 helicopters which have been introduced from 2007 to 2008. All of them are RTHs. They are also known as "Zivilschutz-Hubschrauber" (ZSH, engl. Civil Protection Helicopter). The helicopters are not directly operated by the BMI, but by the Federal Agency for Civil Protection and Disaster Relief [65]. The ZSHs are part of the equipment provided by the federal government to the federal stats for civil protection. While the helicopters are flown by pilots from the federal police, physicians are staffed by the station hospital, and paramedics by rescue organizations or fire departments.

Fig. 12 ZSH with HELLAS. Source: German Federal Police Air Support Group

All 16 ZSH are equipped with an active, laser-based obstacle warning system, called HELLAS (HELicopter LASer Radar), see Fig. 12.

This system is capable in detecting obstacles, which are hard to see with unaided eyes like wires, trees, and poles in about 1000 m (0.62 miles) in front of the helicopter and informs the pilot acoustically and optically about detected obstacles. The probability of detecting a 10 mm (0.39 in.) thick wire in 600 m (0.37 miles) is at least 99 %/s [67], [68]. The installation on all ZSHs was probably motivated by a severe accident of Christoph 17 on February 10, 1995. During a mission in the south of Germany in the Allgau Alps the helicopter, a Bo105, collided with a non-marked cable of a material cable car during its approach to the emergency scene and fell to the ground. The pilot was killed, the other crew members seriously injured. In the context of the flight test program of HELLAS, this accident was re-staged [28, 74]. In addition, they feature a traffic alert and collision avoidance system which informs the pilot of approaching aircraft, IFR flight certification, EuroNav IV navigation, equipment for measuring radiation from the air, for some regions detecting spilled avalanche casualties, and an external double hook for longline (see below at chapter "Switzerland") operations [65]. The medical equipment can be removed to use the helicopter—if required—for further missions.

In Germany, Airbus Helicopters is almost the sole provider for EMS helicopters and all RTHs and ITHs are twin engine helicopters.

The numbers of missions flown in 2013 for stations of the three large operators are shown in Fig. 13. The enormous number of missions becomes evident. Few stations flew less than 1000 missions in 2013. For both, ADAC and DRF Luftrettung, a further increase in missions for the first 6 months in 2014 are reported [39, 40]. No reason has been given for the very high number of the ADAC stations in Berlin. At the two stations of JUH about 1232 missions were flown in total in 2013.[9]

Three of ADAC's helicopters are equipped with a rescue hoist (Christoph 1 in Munich, Christoph Murnau in Upper Bavaria, and Christoph 26 in Sanderbusch). At DRF Luftrettung, just one helicopter out of the stations shown in Fig. 11 utilizes a rescue hoist (Christoph 27 in Nuernberg). In 2013, three ADAC helicopters flew 275 missions with hoist operation [39]. Compared to the total missions flown by the ADAC Luftrettung in 2013, this numbers is negligible for the statistics. However, often hoists or longlines are the only means for rescuing people out of inaccessible terrain, ships or from offshore wind turbines which are currently installed by many countries.

As mentioned above, so far just eight stations out of the 28 stations of DRF Luftrettung, four out of the 34 stations of ADAC Luftrettung and one out of JUH's two stations are in operation 24 h/day. Since especially primary rescue missions afford landing in unprepared areas, primary mission night flights are still an exception and limited to very urgent emergencies. However, motivation is high to increase night flights in general. Especially in rural areas, hospitals are being thinned out. Many hospitals are not capable any more to treat complex injuries especially during night. In addition, in some areas, there is a lack of physicians [28, 75]. This development causes a demand for increasing night flights for primary and secondary rescue. For primary rescue, the demand rises, since many life-threatening accidents or cardiovascular attacks happen during night. Almost each second heart attack or apoplectic stroke happens at night [28]. Although not a major driver, traffic accidents at night time are severe. 35 % of all fatalities and 28 % of all severe injuries are noted during twilight and night time [69]. Traffic during night, however, is just about 25 % of the traffic during the whole day.

Primary rescue missions, if conducted at all, are mostly rendezvous maneuvers of an ambulance car which transports the patient to a distinct landing spot. This spot has to be explored prior to landing of the EMS helicopter by the local fire department and needs to be well illuminated to allow a safe landing to the helicopter [28, 75].

For secondary rescue missions, the ITHs of ADAC Luftrettung usually fly just between defined helipads which need to be certified for night flights [39]. The equipment of some helicopters comprises also the technical provisions to conduct IFR compatible flights. During night flights, this IFR capability is used for example at DRF Luftrettung. The IFR equipment is supplemented at DRF Luftrettung by a satellite navigation system with digital map. In addition, special flight profiles are adhered to [76]. Since most HEMS flights are being conducted according to visual flight rules (VFR), IFR equipment is in general advantageous if the meteorological situation deteriorates. IFR-equipped helicopters may continue while others have to suspend the flight [2].

In 2013 the eight 24 h stations of DRF Luftrettung flew in total 9495 missions. Of these missions, 7538 (79.4 %) were flown during daylight, 1957 (20.6 %) at night of which 7.4 % were primary and 13.2 % were secondary rescues. Out of the 7.4 % primary rescue missions, almost 2/3 was conducted by stations that use NVGs. In relation to the missions of all DRF Luftrettung stations in 2013 (34,832), the 20.6 % reduce to 5.6 %. Unfortunately, no information on ADAC Luftrettung or JUH night flights are available. Compared to other nations, the utilization of NVGs is less prevalent than in Switzerland or USA for example, although NVGs could significantly increase the safety during night flights [75]. This can be explained by the high administrative hurdles against civil utilization of NVGs in Germany. Until recently, the certification of NVGs for civil helicopters was missing and the German Army and police were the sole users of NVGs [75]. The first NVG is in use in Germany since end of 2008. The advantages of NVG lie at hand. Since the residual light at night is being intensified, they ease the detection of obstacles in the dark, allows detection of changing weather conditions, assessment of terrain, and orientation for navigation. In this context, NVGs definitively enhance flight safety for night VFR flights. From a technical point of view, the utilization of NVGs to conduct night flights under VFR requires an NVG-compatible cockpit which avoids glare of the highly sensitive NVGs. A radar altimeter with terrain proximity warning and a second power supply for the NVG are also required [2]. So far, all EMS helicopters in Germany that use NVGs are EC145 [63, 75]. Pilots also need to be trained in using NVGs [2], since NVGs also imply a couple of disadvantages which need to be considered [77, 78]. The field of view extents usually up to 90° in the periphery, but is being reduced down to 45° with NVGs [77]. To compensate this, the pilot has to move his whole head, since the pilot cannot direct his sight by simple eye movement. [75]. This might result in difficulties to

[9] The mission number of JUH can be found at the web site given for Ref. [29].

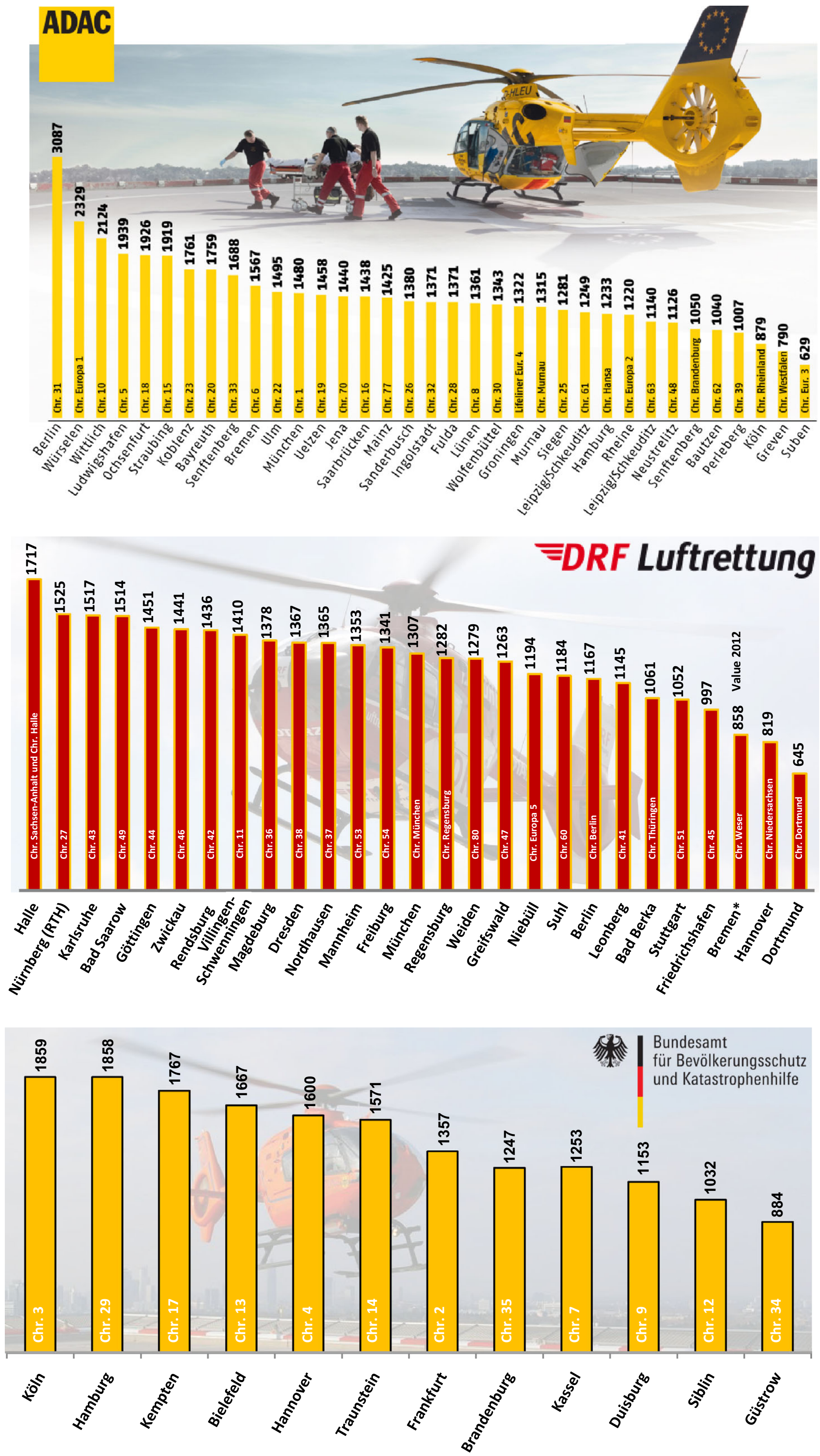


Fig. 13 Missions per station in 2013 of ADAC Luftrettung, DRF Luftrettung, and BMI. Source/data source: [39, 40, 65]

correctly estimate flying altitude, speed and position [77]. The quality of the vision depends very much on weather conditions. Below 3 km (1.86 miles) visibility they lose their clarity and video noise is being produced [78]. Please note, the minimum visibility according to [2] is 2.5 km (1.55 miles) for VFR night flights with two pilots. Looking at non-compatible light sources with NVGs causes halos which might irritate the pilot. Since the stereographic view and hence the depth perception is reduced compared to the natural sight, this can cause difficulties during landing when this information gets important [77]. In addition to the weight of the system which is mounted in front of the helmet a counterweight is needed. This increases stress on neck muscles and leads to a fast fatigue of the eyes. Finally, the instruments cannot be read through the NVGs. The pilot has to look below the NVGs on the dashboard [75].

As mentioned above, SPA.HEMS.130 of [2] specifies crew composition during day and normal night flights. During day a pilot and a HEMS technical crew member are in principle required. During night two pilots are the first choice, but the second pilot might be replaced by a HEMS technical crew member under specific constraints. Crew composition for NVG flights is laid down in SPA.NVIS.130 and shall be greater than stated in the helicopter flight manual, the operating approval for the NVG operation or specified for the underlying activity. Usually, two pilots are deployed by the operators during any night flight.

The growth in missions flown for ADAC Luftrettung since 1970 is shown in Fig. 14. The figure has been enhanced by the numbers for DRF Luftrettung since 2004. The steady increase might also be typical for the other operators. Almost 51,000 missions were flown by the ADAC Luftrettung helicopters in 2013, for DRF Luftrettung about 38,180. For all operators this sums up to more than 100,000 missions. In 2010 a dip is visible, which is more severe for DRF than for ADAC Luftrettung. In total, about 1.8 million missions were flown for all operators since 1971 [70]. This proves to be a very great success of the German HEMS system.

One explanation for the steady increase is seen by DRF Luftrettung by the structural changes in the German health system. As mentioned in context with the NVGs, ground-based emergency doctors and qualified hospitals become increasingly rare. In addition, hospitals specialize on certain disease patterns which require transportation of emergency and intensive care patients over longer distances. Therefore, the air rescue system becomes more and more important [40, 76].

In 2002, a first analysis of the HEMS situation in Germany was undertaken. Since 2005 an annual questionnaire is being sent to all HEMS stations in Germany. This also includes stations in neighboring countries provided they fly HEMS missions in Germany. The aim of this monitoring is to provide a data base for political decisions and to identify trends [71]. An analysis for 2013 can be found in [72]. For primary rescue missions using RTHs or ITHs, a majority of 35 % of all missions covered flight distances to the emergency scene below 15 km (9.3 miles). The average flown distance to the scene was about 25 km (15.5 miles). For secondary rescue missions, a majority of 40 % of all missions covered inter-facility transport distances between 31 and 60 km (19–37 miles). On average, RTHs generally covered shorter distances than ITHs [72].

Figure 15 shows the number of missions flown in Germany for primary and secondary missions as well as total number of missions. Not shown are dispatches following

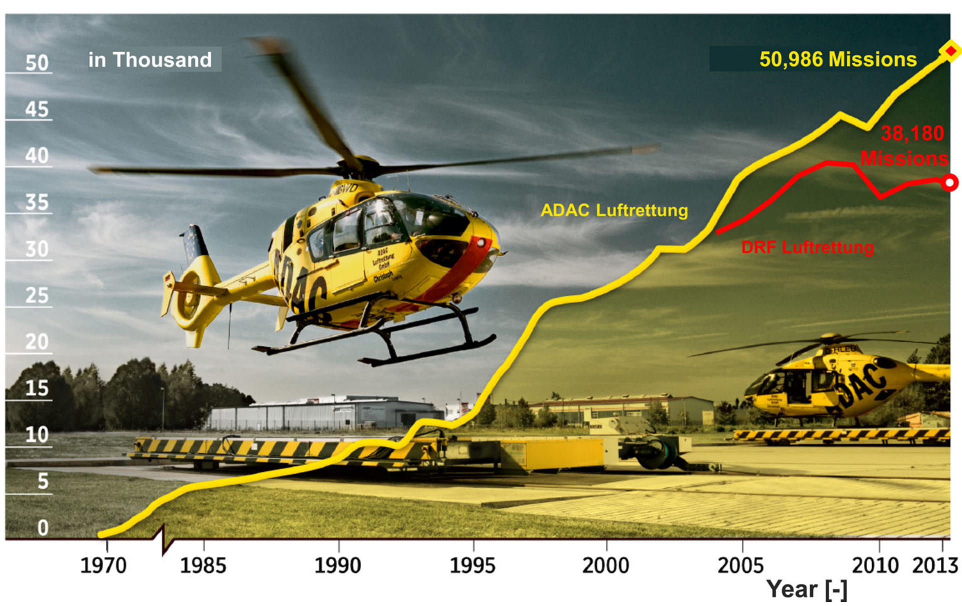


Fig. 14 Missions since 1970 for ADAC Luftrettung. Source: [39, 76]

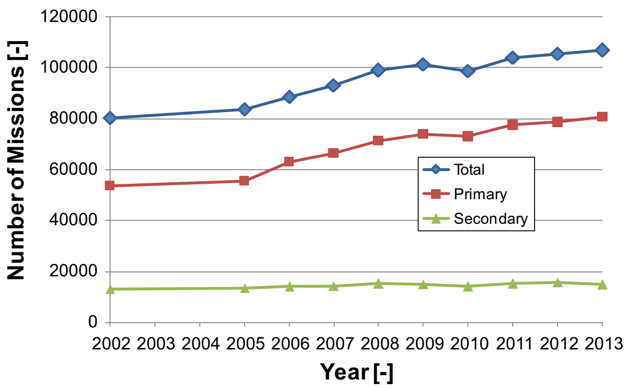


Fig. 15 Total, primary and secondary missions in Germany since 2012. Source: [72]

nuisance alarms and other missions like organ transports, etc. While the number of secondary missions is almost constant throughout the covered time frame at roughly 1500 missions/year, the number of primary missions is steadily increasing on average. The small dip in the curves in 2010 is also visible in Fig. 14.

The main motivation to introduce a nationwide HEMS system in Germany was the high accident rate in the 1960s. Since then, this rate has decreased significantly. In 2013, 2,414,011 accidents were counted in Germany. They resulted in 377,481 injured or dead persons, including 310,085 slightly, 64,057 heavily injured casualties, and 3339 fatalities [69]. In contrast to that, cardiovascular diseases in general account for the highest fatality rate in many countries, in Germany with 354,493 deceased persons in 2013 (i.e. 40 % fatality rate), too [73]. About 270,000 people per year suffer from stroke. It is the highest cause for disability in higher ages and the third highest cause of death. Accidents in households and other accidents account for 8675 and 9037 fatalities, respectively [73]. Therefore, traffic accidents do not represent the largest cause for EMS helicopter dispatch anymore. The causes to dispatch EMS helicopters follow the trend pinpointed above. Out of the 49,243 missions of ADAC Luftrettung in 2012, about 49 % were related to internistic emergencies like cardiovascular diseases. Second highest cause was accidents at work, school, household or leisure time (15.2 %), followed by neurological emergencies (12.5 %), and finally traffic accidents with 10.1 % [39]. With respect to age, two groups of patients dominate: between 70 and 90 years, and between 45 and 70 years. Women were less often transported than men [72].

Costs are often quoted against HEMS. In Germany the sickness costs totaled €254.3 billion in 2008. The highest cause was related to cardiovascular diseases with €37 billion [73]. The total health care costs were even €300.4 billion in 2012 (€264.8 billion in 2008), whereas €80.5 billion fell on medical goods (medication, aids and appliances, dentures, etc.), €15.2 billion on administration, and just €5.5 billion on transportation (ground and air rescue). This relativizes the costs for rescue services. The air rescue costs in Germany are given in [79] to be just 0.04 % of the total health care costs and are negligible against the other costs.

In general, the costs for air rescue are covered in Germany by the reimbursement of health insurance companies to a large extent. However, according to [76], the costs of DRF Luftrettung to maintain its HEMS bases are just covered by 80 % through the health insurances. In addition, increasing costs for kerosene and maintenance are included just partly in the reimbursement. Therefore, DRF Luftrettung and ADAC Luftrettung try to recruit for patrons and fund donations [39, 40]. DRF Luftrettung is supported for this by about 500,000 patrons. Thanks to this, DRF Luftrettung can invest in pilot, physician and paramedic training, medical equipment and in the modernization of the aircraft fleet. On average, about €500,000 each year is being invested at DRF Luftrettung to purchase or maintain medical equipment [76]. For ADAC Luftrettung the situation is different, since it is a 100 % daughter of the ADAC. According to a press release in Mai 4, 2000, €230 million have been invested by the ADAC in its air rescue system since it was started with it in 1970.

Regarding the cost per flight minute they are negotiated individually between the operator of an HEMS station and the responsible health insurance companies. For each of the 16 federal states an individual agreement on tariffs is being contracted. Pursuant to [80], these costs per flight minute vary from €35 to €53 per flight minute.

Two challenges or new fields of operation emerge in Germany for the future. As shown in Fig. 11, there are less white spots left in Germany, which are not covered by the "rescue circles". However, as mentioned above, there is a trend of closing hospitals or at least some hospitals are no longer capable of treating complex injuries, provide surgeries or medical treatments for certain illnesses during night. Moreover, medical offices and the number of emergency doctors decrease in some areas, too. This is especially problematic in rural areas, where the density of qualified hospitals for complex treatments or medical offices, etc., is anyhow lower than in cities. The area-wide provision of rescue service to the population in these regions requires a large number of ground-based ambulance stations. But due to the low population density and the further decreasing population these ambulance stations will have low mission frequency which in turn causes higher costs per mission. One consequence will be the closure of ambulance stations, if they cannot be operated cost efficient any more. As a consequence the medical care for the people living there will deteriorate further. On the

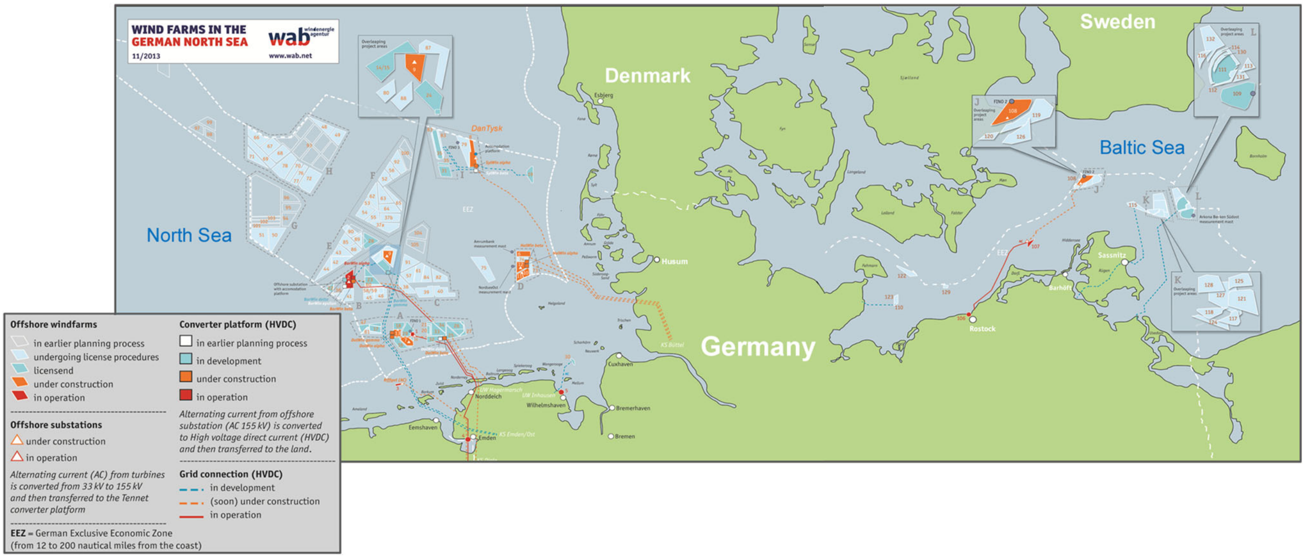


Fig. 16 Offshore wind energy parks. Source: wab Windenergie Argentur, http://www.wab.net

other hand, the residents in Germany are becoming older, which will increase the number of primary rescue. In addition, the specialization of hospitals on certain disease patterns will require increasing numbers of transportations of emergency and intensive care patients over longer distances.

Therefore, the Federal Department of Education and Research has started a project on primary air rescue in less populated areas called PrimAir [81]. The project aims to develop an innovative model for the overall rescue service in low structured and less populated large area regions. An airborne rescue system builds the backbone for these considerations. Today, rescue helicopters are utilized complementary to the ground bases rescue vehicles. The new approach in PrimAir is to study, whether a primary airborne helicopter rescue can be implemented as an alternative to the ground-based rescue service. First results and discussions can be found in [81]. In general, this concept could be also suitable for other countries with less populated large area regions (e.g. USA, Canada, Russia, Scandinavia, etc.). Such an idea requires capabilities of helicopters which they do not have today and would go beyond the utilization of NVGs to rescue patients at night. It would require a true 24 h/day capability independent of weather conditions. This includes also icing conditions. Icing is for light helicopters still a problem today due to costs and weight constraints. The equipment necessary for such a capability will be expensive. This needs to be considered for the reimbursement of the operators.

A second new field of operation might result from the increasing offshore activities of the energy suppliers, e.g. in Europe. Many countries have decided to increasingly establish offshore wind energy parks along their cost lines. Germany is one of them. The target in Germany is to install 6.5 GW power offshore till 2020 and 15 GW till 2030, either in the North or Baltic Sea. The operational wind parks or the ones under construction provide already half of this power target for 2020. An overview of the planned and established wind parks is shown in Fig. 16.

This energy target requires a high number of technicians on sea to build up these wind parks and later on to maintain the turbines. This will result in work accidents and likely other emergencies that require rescue service. However, the provision of medical services in wind farms is not a question of public existence welfare, but according to the German Occupational Safety and Health Act it is the obligation of the employer (e.g. the wind park operator) [82]. Hence, the operator of the wind park negotiates rescue service with an EMS provider. For offshore EMS, high speed of the rescue transportation means is a must. Undoubtedly, EMS helicopters reach higher cruising speeds than vessels and hence are already in use for EMS and a couple of HEMS programs have been established along the north German coast line. For offshore HEMS, one more comparison might illustrate the benefit of helicopters when compared to vessels. According to [83] ships can be used in average at 70 days a year to transport technicians for installation or maintenance purposes to the respective site while helicopters can do so at more than 200 days per year. The same should hold for rescue crews. Two years ago, 2–4 HEMS deployments were counted for two operational wind parks and three construction sites. Based on these numbers, up to 20 deployments per week were estimated in [84]. Surely, during the construction phase of the wind farms the number of rescue missions will be higher than in the later operating phase. Nevertheless, in this phase, too, maintenance activities and assembly or disassembly of segments will result in a constant state of change, which will result in a high rate of rescue operations [84].

DRF Luftrettung has started its HEMS effort for offshore wind farms beginning of 2013 [63]. ADAC Luftrettung has teamed with Wiking Helikopter Service, an experienced offshore helicopter service operator [82]. The helicopter is being provided by Wiking Helicopters exclusively for the HEMS purpose including two pilots and a hoist operator, the medical equipment, emergency doctor and physician by ADAC Luftrettung. The helicopter is in operation 24 h/day and is ready for take-off during daylight within 15 min, during night in 45 min. A new offshore HEMS provider is Northern Helicopter which has stationed an EMS offshore helicopter on the island Helgoland to provide rescue services for a wind park cluster north of Helgoland. While an onshore EMS helicopter would need 30–35 min to reach that cluster, it can be reached within 9 min from Helgoland [85]. The speed advantage over rescue vessels is demonstrated by the EMS helicopter Air Ambulance 02 of DRF Luftrettung, which crashed very sadly during a night winch training mission in February 2014. Its purpose was to provide HEMS to the offshore wind energy parks Baltic 1 and 2 in the Baltic Sea. The helicopter was stationed in Gütin on the island Rügen and could reach the wind park Baltic 1 within 15 min and Baltic 2, which is approx. 70 km far away from Rügen, within 20 min [63]. The helicopter was in service 24 h/day. The next SAR patrol boat is stationed in Sassnitz on the island Rügen, too, and needs for almost the same distance 2–2.5 h.

If true 24 h/day operation shall be provided independent of weather, similar requirements hold as stated above in context with PrimAir. In addition, it has to be considered, that offshore flights are very challenging. This is being complemented by very complex rescue procedures which afford excellent coordination of helicopter and "ground" crew in some cases [86].

3.3 The Netherlands

In relation to its population (16.8 million citizens, status 2013), the Netherlands is a relatively small country (41.548 km^2, 16,042 miles^2). This results in a rather high population density of about 404.4 citizens/km^2 (1047.3 citizens/miles^2). About 17 % of its surface falls on rivers, lakes, tidal flats, and canals. Most of the country (40 %) lies below sea level. Nevertheless, the Netherlands have established a HEMS system with four helicopters, called Lifeliner. They are stationed in Amsterdam, the oldest base which was founded in 1995, Rotterdam, Volkel and Groningen. Two further helicopters are used as reserve. All six aircraft are EC135. Since the Lifeliners often operate in dirty and sandy spots inlet barrier filters were installed on the aircraft, to prevent the engines from early wear [87]. In 2011, night flights were approved using NVGs, but the Dutch government still prohibits landing at night in built-up areas. The helicopters are very often used, just to transport the emergency doctor to the scene. The transport of the patient is done in most cases by road ambulances. In just 10 % of the cases, the patient is flown to the hospital. The reason for this is seen in the possibility of the nurse to assist the doctor during the transport in the road ambulance, while it assists the pilot during flight. The number of deployments is steadily increasing. The number rose from 4935 in 2012 by 16 % to 5570 in 2013 [87].

3.4 Hungary

In Hungary a government-owned HEMS provider called Hungarian Air Ambulance Nonprofit Ltd. is the nationwide sole operator offering emergency medical services for 10 million people. The HEMS history started from 1980 onwards using Polish fabricated Mi-2 helicopters. Today, the Hungarian Air Ambulance operates five EC135 and two AS350 on seven bases. As in other countries, the duty crew comprises pilot, doctor, and paramedic. The average number of missions is about 2500 per year, including primary and secondary missions. The average duration per mission has stabilized between 35 and 38 min. For the future, the purchase of a spare helicopter and the slight increase of number of bases is favorable, the latter to increase the coverage of the country [88].

3.5 Finland

In contrast to other countries and established HEMS systems, Finland differs in very many ways. Compared to Germany with a population of 80.8 million citizens and an area of 357,340 km^2 (137,970 mile^2), Finland has 5.4 million citizens, but a size of 338.424 km^2 (130,666 miles^2) which is just about the one of Germany. The country is very sparsely populated, but still has established an efficient HEMS system, see Fig. 17. Finland often has challenging geographical conditions like lakes (Finland is often called "Land of 1000 Lakes"), rivers, long coastline, large forests, etc. Further challenges derive from its location between the 60th and 70th latitude. Finland belongs to the most northern countries, about one-third lies above the Arctic Circle. This implies less sunlight and severe arctic conditions during the winter months. The Finish HEMS system was launched in 1992 with the first base, but later on was restructured. In 2011 all six bases were consigned to the responsibility of FinnHEMS, a government funded non-profit organization [89]. Currently,

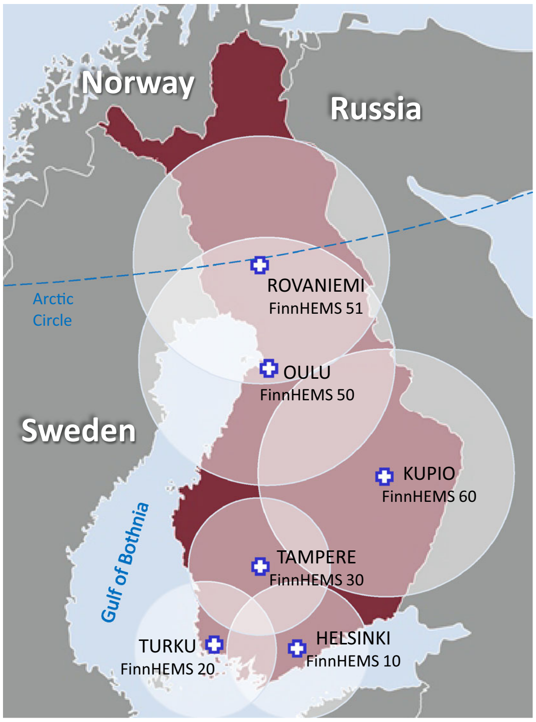


Fig. 17 HEMS stations in Finland. Based on data in [89]

the government funding is under re-evaluation, but this model will continue till 2017 [90].

The average time to the patient is 17–36 min. At present, 70 % of the population can be reached by one of the six EMS helicopters within 30 min [89, 90]. Compared to the population and the size of the country, this can be viewed as a very good result. Five out of the six helicopters are EC135. The crew of these helicopters comprises one pilot, an EMS doctor, and a HEMS crew member. The latter has an additional qualification to support the pilot in the cockpit and the doctor at the emergency site, see [89]. Due to the long travel distances and the harsh climatic conditions, a SA365 Dauphine was favored for the station in Rovaniemi, the capital of the province Lapland. For this aircraft, two pilots and two paramedics form the crew. As in Germany and other countries, the HEMS philosophy follows the principle to provide pre-hospital care and to stabilize the patient before he is being transferred to the hospital. Inter-hospital missions are not provided by FinnHEMS. Currently, the Crews are being alerted by 10 dispatch centers, but the number will be reduced to six in the future [89].

From a technical point of view especially the all-weather capabilities of helicopters are highly desirable [90]. This would also include the capability to fly in known icing conditions. Till now, this is an unsolved problem for helicopters of the light-twin class. FinnHEMS also has introduced NVGs to extent the helicopter operation over the daytime hours, especially in winter [89].

3.6 Ireland

Many countries have established effective HEMS systems. So far, most of those nations have a very high standard for medical services or an excellent health system like Germany, Switzerland, Austria, Japan, and USA when compared to other countries. But even in Europe, not every country was running an air ambulance service. According to [91], Ireland was the only country without an air ambulance at all. In March 2011, however, the first ambulance jet was brought in operation by, AeroMedevac Ireland [92]. The aircraft shall be used for emergency medical evacuation and repatriation of patients to and from Ireland. This might be the signal to also establish a national HEMS system. A feasibility study [93] has been conducted and according to it, up to 4 bases would be sufficient to cover Ireland and to reach 100 % of its population within 30 min. According to [94], four S-92 SAR aircraft of the Irish Coast Guard are now being also utilized for HEMS within the Irish island. The aircraft are stationed along the coastline while a fifth aircraft, an AW139 of the Irish Air Corps is stationed in the center of the country.

3.7 Switzerland

Switzerland is shaped by its mountainous surface. Roughly one half of the country has an elevation above 1000 m (3281 ft). The Alps in the south cover 60 % of the country, the uplands Jura cover 10 % (highest mountain: Monte Tendre with 1679 m or 5509 ft north west of Lousanne) in the north west and the surface in-between is 30 %. The Alps reach their highest elevation in the canton Valais in the south west of Switzerland: Dufourspitze 4637 m (15,213 ft) and Matterhorn 4478 m (14,692 ft) for example. Especially the high mountain regions require special methods for HEMS operations as well as helicopters capable of operating in high altitudes with a given payload even at high temperatures, e.g., during summer time, known as “hot and high” conditions.

Switzerland has about 8.14 million (Status 2013) citizens which is about 1/10 of the population in Germany and a surface of 41,285 km^2 (15,940 mile^2) which equals nearly that one of The Netherlands. This leads to a population density of about 197.2 citizens/km^2 (510.7 citizens/mile^2).

According to [95], rescue service, including air rescue, lies in the responsibility of the individual cantons. The EMS helicopter operations are provided by REGA, Air Zermatt, and Air Glaciers, as pointed out above. Recently, a fourth provider, the Touring Club Switzerland, (TCS) [96], has been established. REGA is the dominating HEMS provider in Switzerland with the two exceptions of the canton Valais and two further stations in Lauterbrunnen and Gstaad/Saanen in the canton Bern. In Valais, Air

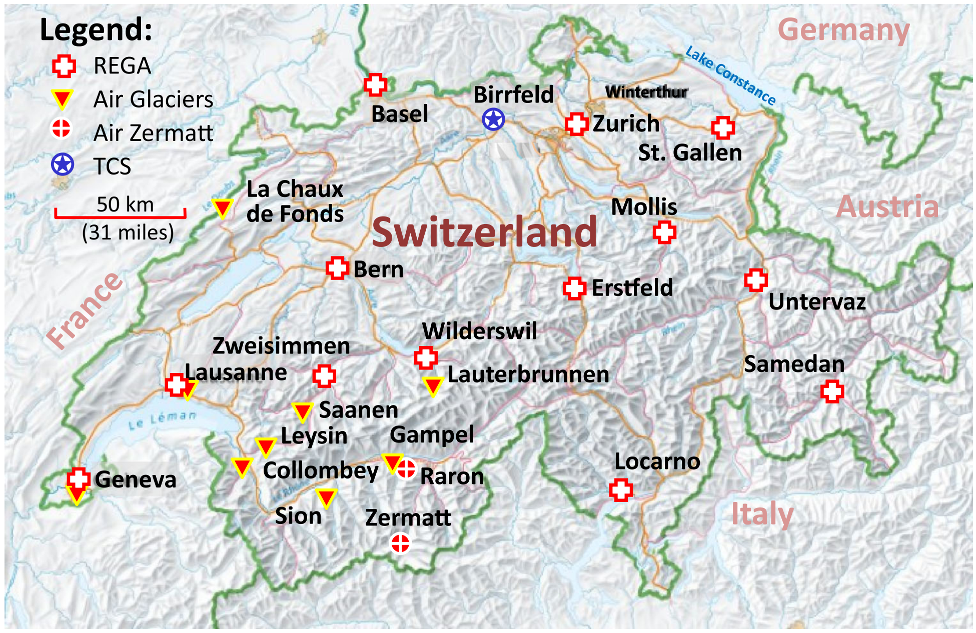


Fig. 18 Map of Switzerland with the HEMS stations. Source map: Federal Office of Topography, stations: [32–35, 96]

Zermatt and Air Glaciers care for the HEMS operations. Air Zermatt covers Upper Valais and Air Glaciers Lower Valais. This situation is shown in Fig. 18.

A physician and a paramedic together with the pilot usually form the crew at REGA. For special rescue missions, e.g. from steep cliffs, a rescue specialist of the Swiss Alpine Club is being called in. At its 12 own bases, REGA operates 17 dual-use EMS helicopters, 11 are AW109 DaVinci and 6 EC145. The 17 aircraft include five reserve machines which are either in maintenance or are used for training. This fleet is rather modern which already underlines REGA's innovative orientation. The DaVinci helicopters were introduced since 2009 on REGA's mountain bases. According to REGA [32], this step was necessary due to an almost duplication of the flight hours within the last 20 years before 2009. The 11 DaVinci helicopters replaced 15 older AW109K2 models. These latter helicopters were introduced to REGA from 1991 to 1995, replacing 12 older SA 319B Alouette III and three MBB Bo105 CBS. The EC145 models were introduced by REGA to its midlands bases in Lausanne, Bern, Basel and Zurich in 2003. REGA's partner in Geneva, the University Hospital, is operating an EC135 T2.

The new DaVincis were developed by AgustaWestland in compliance to REGA's requirements. Requirements were a larger cabin than the predecessor, flight altitudes at gross weight of 4500 m (14,764 ft) above sea level at ISA + 20 °C (ISA = International Standard Atmosphere) which resembles a hot and high condition mentioned above, and a permissible altitude of 6000 m (19,685 ft) [32]. The MTOW of the DaVinci is 3175 kg (7000 lbs) and empty weight 2100 kg (4630 lbs) including equipment.

The corresponding performances of the EC145 are somewhat lower: the hover ceiling out of ground effect at 3300 kg (7275 lbs) is 3445 m (11,302 ft) and the maximum operating altitude 5485 m (17,995 ft) pressure altitude. However, its MTOW is 3585 kg (7904 lbs) at an empty weight of 2200 kg (4850 lbs) including equipment. This gives a payload advantage for the EC145.

The DaVincis feature a 4-axes digital flight control system, Euronav V digital map, IFR, an enhanced vision infrared camera, an obstacle and traffic warning system FLOICE, a derivate of FLARM, and a traffic alert and collision avoidance system (TCAS). FLOICE intends not only to caution the pilot against other traffic equipped with FLOICE/FLARM, but also against registered obstacles such as power lines or towers. The first caution makes sense, since the coverage of gliders with FLARM is quite high in Switzerland and more and more general aviation aircraft are also equipped with such devices [32]. The latter caution still leaves some uncertainties to the pilot, since it is not an active device such as HELLAS. Nevertheless, REGA provides in its area of responsibility HEMS operations 24 h/day by using NVGs.

Table 3 gives an overview on some remarks on the REGA bases. Compared to the missions flown by ADAC Luftrettung and DRF Luftrettung in Germany, the numbers of REGA are much lower.

The number of missions (total and per mission type) is shown for the period 2000–2013 in Fig. 19. The numbers of all REGA stations sum up to somewhat between 10,000 and 11,000 missions per year for the last years, of which roughly 1900–2000 are flown at night. Primary missions (about 58 %) are dominant, followed by secondary

Table 3 Information on REGA bases

Base	Helicopter	Elevation of base	Remarks
Zurich	EC145	408 m 1339 ft	Approx. 900 missions/year, majority of flights are secondary rescue. Primary rescue dominated by traffic accidents followed by work accidents
Basel		260 m 853 ft	Approx. 1000 missions/year of which more than 50 % are flown in Germany and 10 % in Elsass, France
Bern		542 m 1778 ft	Approx. 800 missions/year, 50 %/50 % primary/secondary rescue. High number of traffic casualties
Lausanne		495 m 1624 ft	Approx. 800 missions/year, high number of traffic and sports accidents
Untervaz	AW 109 DaVinci	564 m 1850 ft	Approx. 600 missions/year, high number of winter sports accidents
Locarno		200 m 656 ft	Approx. 500 missions/year, mostly winter sports accidents flies missions also in Italy
St. Gallen		675 m 2215 ft	Approx. 600 missions/year, flies also in Liechtenstein and Germany
Erstfeld		460 m 1509 ft	Mountain and winter sports accidents
Samedan		1700 m 5577 ft	Approx. 500 missions/year, 90 % primary rescue
Wilderswil		586 m 1923 ft	
Mollis		433 m 1421 ft	Operates from December till Eastern, during summer time at weak ends
Zwei-simmen		947 m 3106 ft	Similar to Mollis

Source: [32]

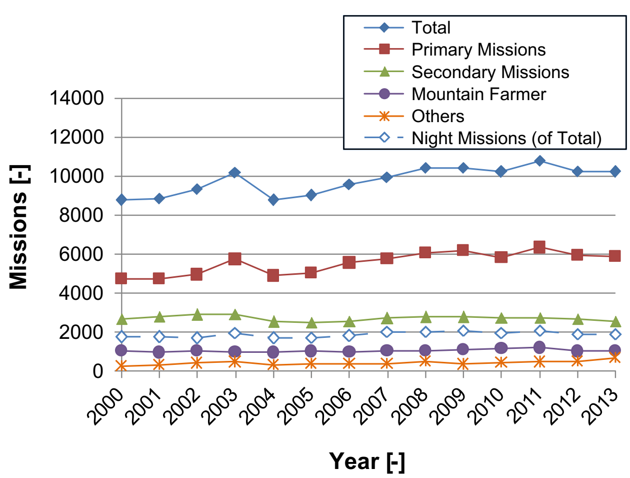


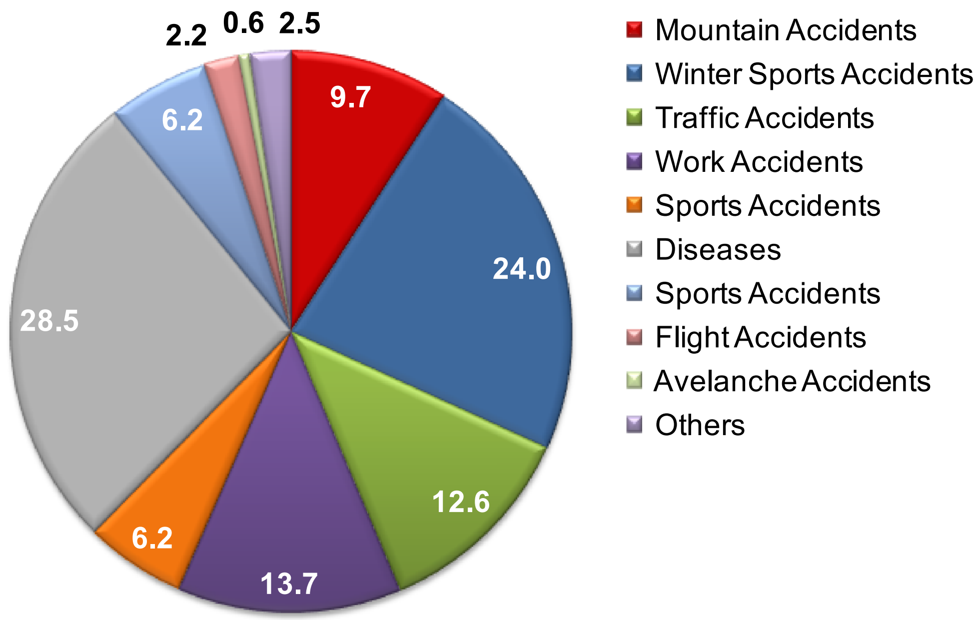
Fig. 19 Total missions and missions per type for REGA since 2000. Data source: [32]

missions (about 25 %). REGA flies also rescue missions for cattle of mountain farmers. This will be briefly mentioned in context with the patron ships of the Swiss HEMS operators below.

The relative indication for primary missions in 2013 is shown in Fig. 20. Transport of ill patients is the largest cause for EMS helicopter dispatch followed by winter sports and work accidents. Since its foundation till November 16, 2006, REGA has performed about 250,000 missions [31]. Pursuant to information of REGA, about 600 patients each year cannot be supplied with medical aid due to weather restraints [32].

In Upper Valais Air Zermatt operates two HEMS bases with 9 helicopters (two SA 315B Lama, five AS350B3, one EC135T2, and one Bell 429). The twin engine Bell 429 is fitted with rescue hoist, infrared camera, high-performance search lights, IFR equipment, and NVG-compatible cockpit. Both twin engine helicopters are dedicated exclusively for HEMS and are ready to operate 24 h/day from the bases in Zermatt and Raron [95, 98]. The other helicopters perform also missions like transport flights for construction work, heli-skiing, tourist flights, etc. [34]. The advantage of this mix in operation spectrum is that pilots are kept flying in a very demanding environment. Transport flights add up to 50 % of all flights at Air Zermatt, HEMS missions to 30, and 10 % are tourist flights [97]. In addition to both EMS

Fig. 20 Percentage of primary missions of REGA in 2013. Data source: [32]



helicopters, especially the Lama still plays an important role for high mountain rescue. In the future, the Bell 429 ($m_{TOW,\ max}$ = 3175 kg or 7000 lbs, empty weight in standard configuration: 2035 kg or 4487 lbs) can replace the Lama for this mission. The important measure for high mountain rescue hoist or long rope operations (see below) is the altitude to hover out of ground effect (HOGE). For the Bell 429, these values are [99]:

(a) ISA: 4843 m (15,888 ft) at 2722 kg (6000 lbs); 3438 m (11,282 ft) at 3175 kg (7000 lbs)
(b) ISA + 20 °C: 2744 m (13,884 ft) at 2722 kg (6000 lbs); 2427 m (7963 ft) at 3175 kg (7000 lbs).

Depending on air temperature and mission weight, the Bell 429 can perform missions also at the high mountain summits. The Matterhorn for example has an elevation of 4478 m (14,690 ft). However, the Bell 429 is a rather expensive helicopter. The purchase costs in EMS configuration were about $7 million [98]. Besides the good HOGE performances for the Bell 429, the purchase became necessary, since for HEMS flights during night twin engine helicopters are mandatory in Switzerland [98]. In 2006 1376 HEMS missions were flown [31], in 2010, 2011, 2012, and 2013, 1502, 1580, 1625, and 1673 missions, respectively. On November 15, 2007 Air Zermatt reached its 30,000th HEMS missions since its foundation in 1968 [34].

Unfortunately, less information is available for Air Glaciers, which serves Lower Valais. From [35] 16 helicopters have been estimated (SA 315B Lama, Alouette III, AS350B3 and B2, EC120, EC130, EC135) at 9 stations. Some of the stations are mentioned to be seasonal stations like the one in Gstaad/Saanen, which is opened during the winter season. At least two EC135 have been identified which are utilized in EMS configuration. One is stationed in Sion, the other in Lauterbrunnen. The AS350, Alouette III, and Lamas are used for various missions and are not solely dedicated to HEMS, but are listed also for rescue missions. They can be equipped with external stretchers for transporting casualties. The EC120 and 130 are not used for rescue missions. Air Glaciers performed in 2006 1852 [31] and in 2014 1951 EMS missions (1849 primary and 102 secondary missions). The busiest station was Sion with 1377 missions, Lauterbrunnen performed 288 missions [35]. Since its foundation in 1965 till 2005, Air Glaciers has allocated 40,000 missions in context with mountain and avalanche accidents, winters sports and traffic rescue missions, as well as evacuation and further medical emergency cases [35]. As Air Zermatt, Air Glaciers also offers further services as air taxi, heli-skiing, material transport, aerial work, and others.

For both operators, Air Zermatt and Air Glaciers, the majority of the helicopters are one engine helicopters. In contrasts to that, REGA operates twin engine helicopters, only.

Figure 21 gives an overview on the situation in the canton Valais. The map shows the helicopters bases in the canton and the bases in the south of the canton Bern. It also gives an overview on some of the summits in Valais. The well-known ones are also given with its names. This shall provide an idea on the demanding environment in which Air Zermatt and Air Glaciers operate. High mountain helicopter flights are still a challenge today, especially under hot and high conditions.

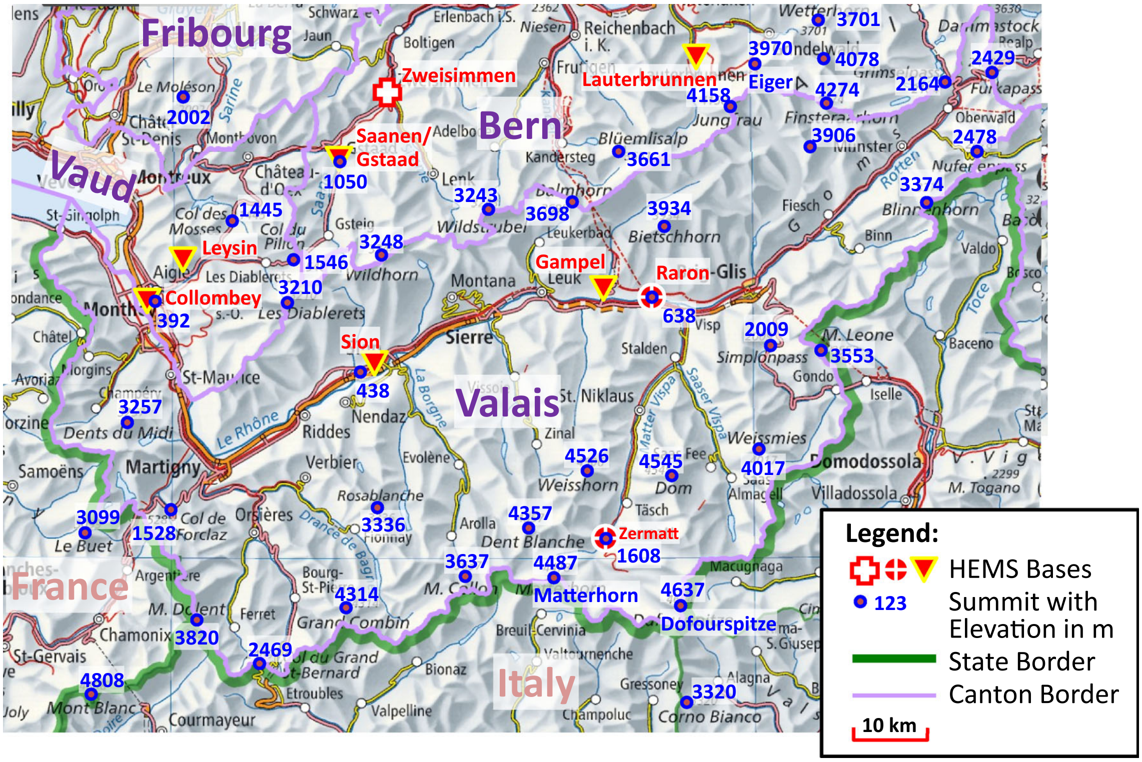


Fig. 21 Map of Valais, neighboring cantons, summits and HEMS stations. Source map: Federal Office of Topography, source of stations: [32–35]

Since the SA315B Lama was especially designed for high mountain operations, this explains, why this aircraft is still in operation for both companies, although its first flight dates back to March 19, 1969. It can lift a slung load of 1000 kg (2205 lbs) towards an altitude of 2500 m (8202 ft) [34]. Like the Lama, the AS350 is well suited for high mountain missions. The altitude world record was achieved with an AS350B3 when 12954 m (42,500 ft) was reached. The old record of 12.442 m (40,820 ft) was held by a Lama helicopter for about 30 years. An AS350B3 has recently demonstrated its high mountain rescue capabilities. In April 29, 2010 three mountaineers were evacuated from an elevation of about 6950 m (22,802 ft) below the Annapurna summit in the Himalaya Mountains in Nepal using a so-called longline technique, see below. Pilot and mountain rescuer, were from Zermatt and were honored with the US Heroism Award in 2011 [34]. For the AS350B3, the empty weight in standard configuration is 1241 kg (2736 lbs) and MTOW of 2250 kg (4960 lbs). The HOGE altitudes are [100]:

(a) ISA: 5425 m (17,800 ft) at 1800 kg (3968 lbs); 3383 m (11,100 ft) at 2250 kg (4960 lbs)
(b) ISA + 20 °C: 4724 m (15,500 ft) at 1800 kg (3968 lbs); 2606 m (8550 ft) at 2250 kg (4960 lbs).

Another difference between the three large HEMS providers in Switzerland (besides their area of operation and utilized helicopter models) is their form of organization. While REGA is a non-profit foundation, Air Zermatt and Air Glaciers are incorporated companies [32, 34, 35].

Regarding the organization of the emergency medical service there seems to be a separation of the canton Valais from the rest of the country. In 1997 the canton founded its own rescue organization which is responsible for the canton's rescue services. The operations center is located in Sierre (between Sion and Gampel) [31]. This center can be reached under the Swiss general emergency call number 144 and is responsible for all emergency missions on ground or in the air. REGA itself can be reached via its own emergency call number 1414. For this, REGA operates its own wireless communication net with 42 stations in the country. REGA's operation center is located at the Airport in Zurich [102]. REGA also uses RescueTrack to monitor helicopter dispatch. If emergency calls from Valais reach REGA, these calls are forwarded by REGA to the emergency operations center in Sierre [32].

Regarding the other bases of Air Glaciers in the canton of Bern, accusation was raised by Air Glaciers in Lauterbrunnen, against REGA. The accusation was that REGA would not always dispatch the closest EMS helicopter to the emergency scene, but preferably its own ones. In the past REGA was responsible for dispatching the Air Glaciers EMS helicopters in the canton Bern. A solution could have been that the Air Glaciers helicopters would have been dispatched by the 144 emergency call center in Bern. In-between, both HEMS operators have agreed upon that the dispatch of all EMS helicopters in the uplands of the canton Bern is still being done by REGA [63].

Recently, another HEMS operator emerged in the canton Aargau. Here, the Touring Club Switzerland (TCS) has partnered with Alpine Air Ambulance of Zurich and has stationed an EC135 EMS helicopter at the airport in Birrfeld, first for secondary rescue missions, only, but since spring 2013 for primary rescue missions, too [96].

In many cases a landing spot in reasonable proximity to the casualty might not be always available, due to steep mountainsides, forests, over waters or since casualties have to be rescued from buildings. In this case, winch or hoist operations may allow to lower a rescue team down and later up again including the patient. Today, modern rescue hoists show a cable length of 90 m (295 ft) and depending on the class of the helicopter 270 kg (595 lbs) load capacity. Therefore, rescue hoists are often standard for rescue helicopters in demanding environments like mountains or over sea. REGA for example, utilizes rescue hoists for both helicopter types (EC145 and AW109 DaVinci). At many other operators a fourth crew member, the hoist operator, is on board the aircraft, if hoist operations become necessary. At REGA, the hoist operation is being done by the paramedic, while the emergency doctor is being lowered down, cares for the patient and prepares him for the hoist operation. For difficult missions like cliff rescue missions, an alpine rescue specialist is on board, too, [32]. Older helicopter models, however, used hoists with shorter cable length and lower load capacity. Therefore, an alternative rescue method was demonstrated by Air Zermatt in 1972 called the "longline" [34]. This method is still in use by all three larger Swiss HEMS providers, if the cable length of the hoist is not long enough or if the person to be rescued cannot be reached by using the hoist [32]. A further advantage is that more than two persons can be transported at the same time. In [101] up to four persons are being mentioned. In this case a rope of fixed length of up to 220 m (722 ft) [32] is being used to transport a rescue specialist to the patient and later on evacuate both again. For longline rescue, the rescue rope is fixed to a double hook bracket underneath the fuselage, see Fig. 22. This method is also being used by other operators outside Switzerland like in Italy, Austria, etc.

The rescue helicopter business in Switzerland is highly deficient and would not be possible without patron ships and further donations. For REGA, for example, the patrons dues (REGA has about 2.5 million patrons) contributed in 2013 to 62 % (CHF85 million) to the whole budget, while "just" 38 % (CHF53 million) were paid by health, accident or travel insurances [102]. In return, the providers care for their patrons in carrying those costs of an EMS mission,

Fig. 22 Longline rescue. Source [32]

which are not paid by the patron's insurances. For mountain farmers this can also include transport of injured or ill cattle, but also a cadaver, if the farmer holds a family patron card. Family cards cost CHF70/year at REGA and CHF80/year at Air Zermatt and Air Glaciers. The three rescue organizations, REGA, Air Glaciers, and Air Zermatt, have negotiated a firm rate per flight minute of CHF87.20 for illness related missions and CHF89.10 for accident-related missions with the insurance companies. For night missions an additional rate of CHF13.65 adds to these fares. The rates have been kept constant since 1996. TCS charges CHF82.00 per minute [103]. Due to its high technical effort (modern fleet, medical equipment, own operation center as well as own wireless network, see [102]) and employed personnel REGA's fixed cost are relatively high. To cover the true costs of an average helicopter EMS flight would require CHF200 per minute. The difference between the actual costs per minute and the mentioned CHF200 are covered by the patron dues [103]. Regarding cost per mission, in average each HEMS dispatch costs at REGA CHF3000 to 3500, [102, 104]. The missions per day in average sum up to about 70 min duration [104]. For the two operators in Valais, the situation is different. They operate many single-engine helicopters which offer cheaper operating costs and some are rather old models helicopters which are probably written off. These lower costs are contrasted on the other side by fewer patrons. Air Zermatt's patrons dues are in total about CHF500,000 per year. Both companies have to cover a underfunding in rescue flights by the yield of other flights (taxi services, material transport, heli-skiing, sight-seeing, etc.) [103].

Costs of EMS helicopters have caused in Switzerland a discussion, although the majority of costs are carried by the patrons. Nevertheless, the pressure of insurance companies has increased, although the Swiss helicopter rescue system is less than 0.1 % of Swiss health cost [104]. Pursuant to [79], helicopter rescue missions cost five to 6 times the value for ground-based rescue, but the relative share of the EMS helicopter costs are just 0.4–0.9 % of the whole healing costs of a poly-trauma patient. Compared to a patient who cannot earn his own living anymore (e.g. after trauma caused by an accident) these costs are low. Such a patient, besides the individual loss of living quality, costs in average CHF1,840,000 in Switzerland. If such a trauma patient gets fit for work again, the costs for the national economy in Switzerland are about CHF210,000 [102].

3.8 Russia

Russia has a long history in rotary wing aircraft. Kamov and Mil are renowned for their co-axial rotor designs or very heavy helicopters, respectively. In the past Russian helicopters were, however, rather large ones. Especially the Mil helicopters were too large for HEMS operation. Even the Ka-32 with an MTOW of about 6900 kg (15,212 lbs) would be oversized for such a mission. This situation may change with the Ka-226 helicopter, see Fig. 23, which is also available now in a HEMS configuration [105] and the light-twin multirole helicopter Ansat.

The Ka-226 has an MTOW of 3600 kg (7937 lbs) with a useful load of 1500 kg (3307 lbs), maximum speed is 250 km/h (155 mph). It features a very compact size, since the tailboom does not extend over the blade tips. This could be a very helpful feature for operating in cities. In addition, no tail rotor, etc., is necessary for torque compensation which is often mentioned to be a threat for persons in the proximity of the helicopter. This makes the helicopter an interesting design for EMS applications and Russian helicopters may become one more provider of EMS helicopters in the future.

Fig. 23 Kamov Ka-226 in HEMS configuration. Source: Russian Helicopters, http://www.russianhelicopters.aero/en

Besides this technical discussion, an HEMS system for a country like Russia with its very large distances and the poor infrastructure for ground transportation would be an important contribution to health care. However, compared to the enormous size of the country and the sparsely populated country side, an area-wide HEMS system would be a tremendous challenge. Unfortunately, there are not very many information available on HEMS in Russia. It is very likely, that HEMS is concentrated to larger cities, especially Moscow. In [106], six EMS helicopters are mentioned for the city of Moscow, but just 10 landing sites, including airports, heliports, and helipads. For the whole country a rough number of a few dozen EMS helicopters is being given. Even the numbers for Moscow are small, compared to other cities of that size [106]. Responsible for the service is the Moscow Aviation Center (MAC) since about 2009. MAC is a government-run organization and operates three EC145 that contribute to save around 600 lives each year. The aircraft have conducted 5480 flights from 2009 to 2012. Two further ones will be delivered in 2015 to the Health Department's Scientific and Practical Centre of Emergency Medicine [107]. In contrast to other HEMS organizations, the aircraft of MAC are flown by two pilots. The medicinal team comprises an emergency doctor and a doctor for reanimation.

3.9 USA

USA comprises 50 federal states, a total population of 318.9 million residents (status 2014), and a surface of 9,826,630 km^2 (3,794,083 $miles^2$). This leads to an average population density of 32.5 citizens/km^2 (84.1 citizens/$mile^2$). This is a rather low value when compared to other countries. However, the population varies significantly among the states. While California, Texas, and Florida have 38.8, 27.0, and 19.9 million citizens, respectively, large states in the west like Utah, Montana or Wyoming are less populated (2.9, 1.0, and 0.6 million citizens). The highest population densities can be found in general at the states along the east coast. USA is the third largest country in the world and its geography is rather versatile. Continental USA can be split roughly into four regions: the eastern coastal region, the high land of the Appalachians which run from Main in the north to Alabama in the south and comprises several mountains with elevations of up to 2040 m (6693 ft), the North American Cordilleras in the west (including the Rocky Mountains in the east with elevations of up to 4396 m or 14,423 ft and the Sierra Nevada at the Pacific Coast with elevations of up to 4421 m or 14,504 ft), and the inner plains comprising the central and Mississippi low-land as well as the Great Plains in-between. The diversity in population, the geography, the often vast distances, but also the climatic conditions ranging from tropical to arid and arctic conditions represent significant challenges to establish a nationwide HEMS system.

Nevertheless, North America is in general the largest helicopter market worldwide. According to a presentation by Airbus Helicopters, the North American civil and parapublic helicopter market above 1.3 to (2866 lbs) is about 25 % of the global market [108]. With respect to the global civil helicopter market, USA accounts for 41 % of it [109], and concerning the HEMS market, the numbers that have been provided already in Sect. 2 for different countries show, how large the US EMS helicopter market is.

As pointed out above, traffic fatalities have been in many cases a strong motivation for utilizing helicopters for EMS. In USA the number of motor vehicle traffic fatalities showed a steep increase since 1963. In 1972 a maximum of around 55,000 fatalities were counted. Since then, the numbers were decreasing with periodic oscillations and remained on an almost constant level since 1995. Between 41,000 and 43,000 fatalities were reported for the following decade [110]. According to [111], motor vehicle crashes were the major cause of trauma in USA. In addition to these fatalities, 3 million people were injured and 2 million of these injuries were disabling. 250,000 injuries were serious and life-threatening. Besides the individual tragedy, this results in a tremendous cost burden, first of all for those who were involved, but economically for the entire country, too. In 2000, the costs of motor vehicle crashes in USA reached $230.6 billion including lifetime costs for fatalities, non-fatal injuries, and damaged vehicles [112]. Medical expenses totaled $32.6 billion. The report further more calculates the lifetime economic costs for each fatality to society to total $977,000. Finally, each critically injured survivor cost in average $1.1 million.

As a consequence of the high number of vehicle crashes, a number of technologies have been developed or are still in development that shall either actively prevent crashes (e.g. Anti-Skidding, Lane Keeping/Lane Departure Warning, Blind Spot Warning or Active Braking Assistance), reduce consequences of crashes (e.g. air bags, safety belts, crash optimized car bodies, active headrests) or shall automatically notify emergency centers in case of a severe crash. These latter systems are being called Automatic Crash Notification (ACN) Systems and aim to sense serious crashes and report their occurrence and location by an automatic cell phone call via a telematics service provider to an emergency center. The benefit of such a system is obvious: information about the crash is made available to EMS dispatchers within minutes of the crash prior to anyone arriving at scene. However, the advantages of such a technology will be fully realized only, if the closest EMS provider to the scene will be immediately notified and deployed [111]. This includes also HEMS providers. To support ACN technology, the Atlas and Database of Air Medical Services (ADAMS) was built up. ADAMS is a geographic information system containing data on aeromedical service providers their communication centers, base helipads, rotor and fixed wing aircraft information as well as receiving hospitals [113]. A comprehensive outline and analysis of the data included in ADAMS can be found in [111, 114] for the status of 2004. ADAMS is an excellent data base for EMS helicopters. Indeed, the 900 helicopters mentioned in [42] and reported in Sect. 2 were based on the data given in [113].

The air medical bases in the US are shown in Fig. 24, for rotary wing (RW) and fixed wing (FW) EMS aircraft. The number of RW air medical bases is given with 846 and FW bases with 188. In total, 300 air medical providers are noted that operated 998 EMS helicopters in 2014. The grey circles resemble 10 min RW fly circles around each base. They represent a nominal 15 min response area (5 min for RW launch plus 10 min flight time).

The map shows a trend that differs from other industrialized countries. The east of the country is very densely covered with HEMS stations, while the middle and the west with the exception of California show by far fewer stations per area. Of course, the Middle West is less populated then the east part of the country. This might explain the less dense HEMS bases in that region. However, this might not explain the oversupply in the east. An explanation for this might be the fact, that HEMS is mentioned to be a $2.5 billion “business” [46].

While many countries as Germany, Switzerland or Austria have established a nationwide HEMS system covering the whole country, stations are located such, that an oversupply is being avoided. Several stations in one region are established only, if population density drives closer positioning of bases and primary rescue helicopters are backed up by secondary rescue helicopters as in the case for Germany. As a consequence of the densely located HEMS bases in the east part and a more sparsely situation in the west and since critical care services and specialists have largely disappeared from rural areas, see [42], 46.7 million people in the US did not have access within 1 h to level I or II trauma centers in 2005, even not through air medical services [115]. Those 46.7 million Americans (i.e. about 15.8 %) lived mostly in rural areas. In [42] a drop in the number of rural community hospitals from over 2500 in 1988 to under 2000 in 2008 is being mentioned. In addition, the number of emergency departments in community hospitals has been reduced from over 5100 to roughly 4600 in approximately the same period. On the other hand, 42.8 million Americans had access to 20 or more level I or II trauma centers within an hour in 2005 [115]. They lived mostly in urban areas. Finally, helicopters provided access to level I or II trauma centers for 27.7 % or 81.4 million US

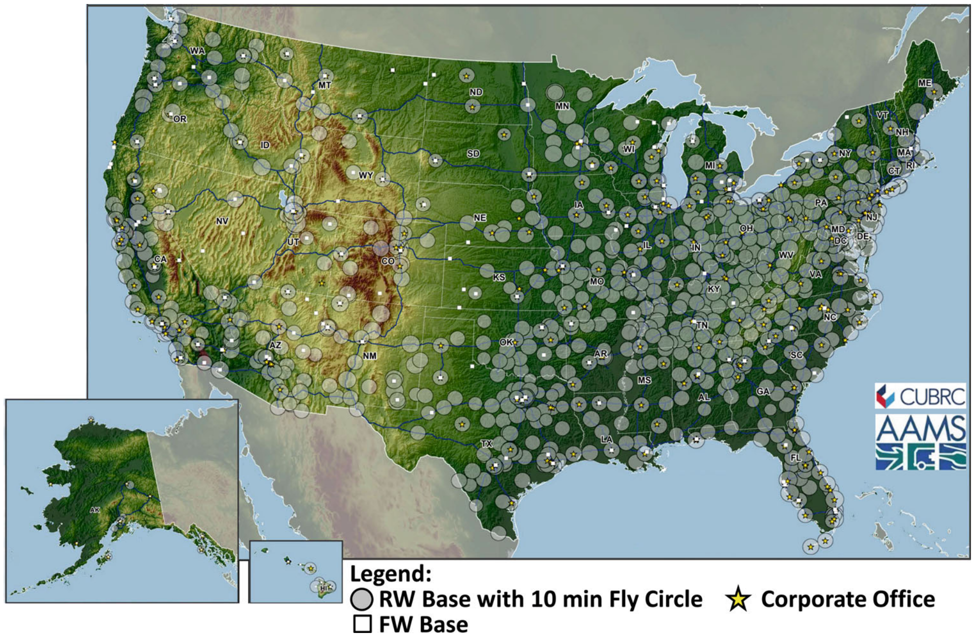


Fig. 24 Air Medical Service bases in USA, Status: September 2014. Source: ADAMS [The Atlas and Database of Air Medical Services (ADAMS) is compiled by CUBRC in alliance with the Association of Air Medical Services (AAMS)] [113]

residents who otherwise would have not been able to reach such a center within 1 h [115].

The consequences of an imbalance in medical care and access to trauma centers for rural versus urban areas were investigated in [116]. The results are disillusioning, since, in general, trauma is the leading cause of death among individuals in the age from 1 to 44 years in USA and causes 47 % of all deaths in this age range. Across all age groups, it is still on number three [117]. Injuries create an annual economic burden of more than $260 billion in USA. This qualifies the costs for the HEMS business of $2.5 billion mentioned above by far. The disparity in access to trauma centers mentioned above results in disproportionately high injury mortality rates for the rural population: fatality rates in rural areas are more than twice as high as in urban areas [116]. It is therefore legitimately being concluded in [115], that more reasonable selected trauma centers based on geographic need and appropriately located medical helicopter bases should be considered to improve access to trauma center care in USA. However, the situation has not changed much since 2005 regarding the imbalance between east and west in USA.

With respect to the initial motivation for HEMS to reduce motor vehicle traffic fatalities, see above, a study has been performed to assess whether fatal crash site density patterns match population density patterns [113]. The study shows that both patterns differ and that there are still rural areas with significant numbers of fatal crashes, but little or no rapid access to air medical services. According to [42] 60 % of the fatal crashes in the US occur in rural areas, a rate nearly twice that of suburban or urban areas.

An example for analyzing the economic operation of a rescue helicopter in a rural area can be found in [118] for the Humboldt County in Nevada, see Fig. 25. The Humboldt County (about 16,100 citizens in 2010) is located at the border to Oregon in the north of Nevada. In that county patients with complex medical cases (e.g. heart attack, stroke or other emergency care needs) had to rely on rapid transfer to larger urban health care centers, usually to Reno 150 miles to the southwest of the Humboldt General Hospital. By ground ambulance, this is a trip of 2 h and 10 min. The alternative would be to wait for helicopter services from Reno or elsewhere, which can take up to 4 h in some cases. The time for inter-hospital transfer could be reduced by 50–60 min, if a helicopter would be directly available in the county itself. Therefore, considerations were started, to establish an EMS helicopter in the county. To run such a helicopter economically the report mentions 360 missions per year. In some limited cases, using a less expensive helicopter, the demand for missions could reduce to 240 trips per year.[10] The report also mentions, that the demographic change (aging of the population) could increase emergency calls of heart attack and stroke patients, but population loss would be estimated by 2026 to be −13 %. Nevertheless, in [119] it is being mentioned on the basis of a study on Kentucky, that the usage of EMS was highest in the population group older than 65 with the

[10] The average number of patients flown in the US from 2002 till 2007 was about 410–460 patients and the average flight hours about 580 h per helicopter. The number of missions has steadily gone down since 1990 from an all-time high of about 690 patients per helicopter [155]. In recent years, these numbers are even lower (about 340 patients and 490 flight hours per helicopter).

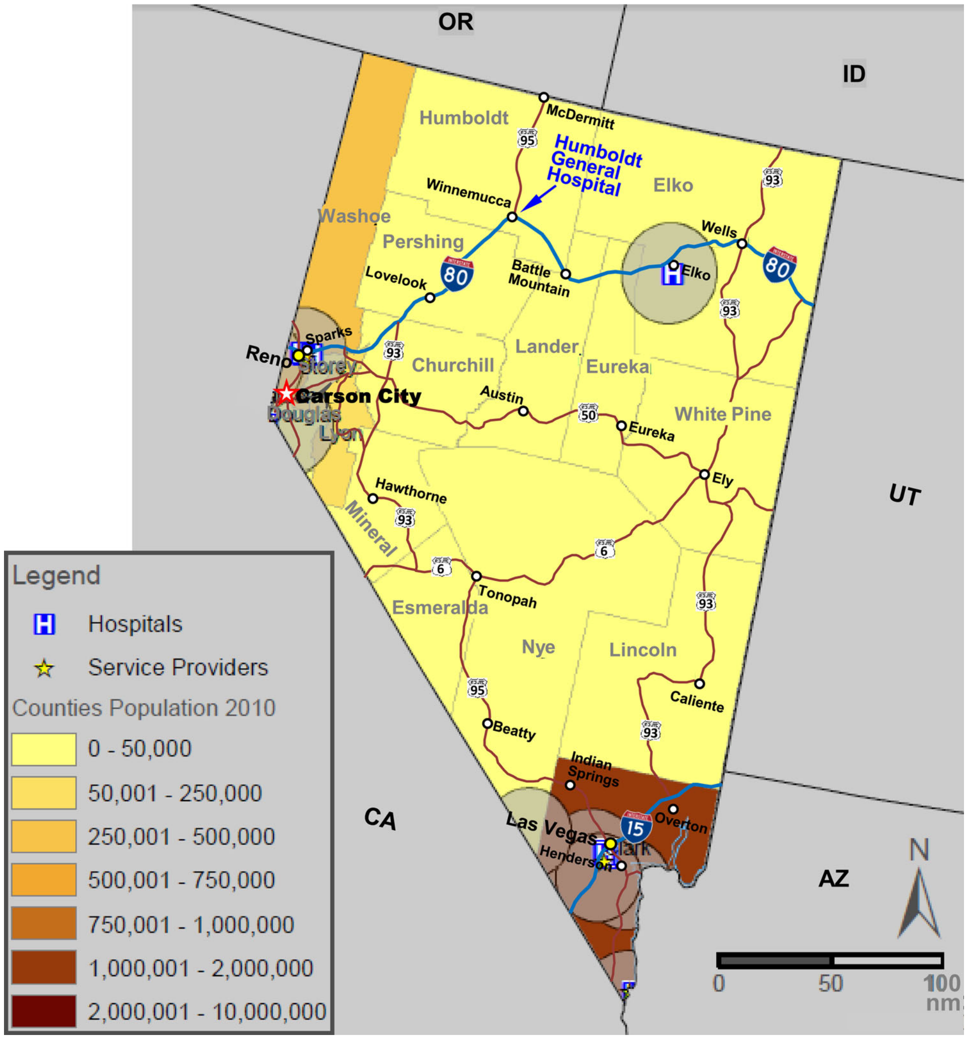


Fig. 25 EMS helicopter bases and population in counties of Nevada, Graphic based on information in the ADAMS database [113], *grey circles* represent 10 min fly radius

rate increasing exponentially with increasing age in this group. This results in a demand for EMS for those older than 65 years which is 4.8 times higher when compared to those under the age of 65 years. This could also be a driver to consider new EMS models in other sparsely populated areas as in some parts of Germany, see project PrimAir above. Based on such assumptions, a total need of about 528 EMS transports/year was estimated for the Humboldt County [118]. If 180 or 280 HEMS deployments (this number does not consider emergency scene flights, i.e. primary rescue, since they were considered to be of minor importance) were assumed out of these 528 EMS transports, the fixed operating costs per trip for a single engine helicopter like the Bell 407 would sum up to $9301 and $6788, respectively. The variable operating costs per flying hour would be $904.

However, so far no EMS helicopter base is integrated in [113] for the Humboldt County, see Fig. 25. The figure shows that the by far largest part of Nevada is not covered by HEMS fly circles. This also affects the interstates as well as highways and country roads. In total, 10 EMS helicopter are stationed on 7 bases of four different providers in Nevada (2.79 million citizens in 2013), five helicopters are stationed in the south in or near Las Vegas (603.488 citizens in 2013), one in Reno, two in Gardnerville (south of Carson City), and two in Elko. The first three locations might be explained by the population in these areas. They follow the larger cities in Nevada. However, Elko (about 20,070 citizens in 2013) has two EMS helicopters.

The second state, which shall be briefly outlined, is Missouri, since an interesting increase of EMS helicopters and bases have been noticed since 1985 as for many other states, see Fig. 26.

In 1985, the HEMS system in Missouri encompassed seven HEMS bases [120], while the ADAMS database [113] now counts 35 RW bases of 11 different operators with 36 EMS helicopters in 2014. Please note the difference in the fly radii of upper (30 and 10 min) and lower graphic (10 min only). While the 30 min fly radii covered almost the largest part of Missouri in 1985, it seems that there is an excess supply for 2014. In the same time, the population grew from 5 million in 1985 to 6.044 million citizens in 2013. Neither the growth in population can explain the increase in HEMS bases, nor can it be motivated by the demand, to cover the whole state at a reduced flay radius of about 15 min (see e.g. Germany). If the latter requirement would have been a driver, 16–20 bases could be sufficient, depending on the base location and whether bases could be shared with the neighboring states. As can be seen from the lower figure, the interstates and major highways are much better covered by HEMS services than for Nevada.

Comparing Nevada and Missouri, Table 4 shows 2.3 times the population per base and about 8 times the area per base for Nevada. However, as pointed out in [118], economic considerations have to be taken into account when considering HEMS bases in rural areas which are loosely populated. Numbers as lifetime economic costs for each fatality, etc., obviously play a less dominant role.

In addition to Fig. 7, Fig. 27 shows the increase in flown patients since 1980. This once more illustrates the rapid increase of the HEMS system in USA. It also proves the enormous success of HEMS in USA, since about 4.3 million patients were flown in total from 1972 till 2007 [121] and about 5.8 million from 1980 till 2013. However, since 2007 the number of annually flown patients is decreasing slightly.

Using the number of EMS helicopters from Fig. 7 and HEMS patients from Fig. 27 results in an approximate average number of 427 flown patients per helicopter in 2007. Other sources mention 400,000 patients flown in 2008 and over 900 EMS helicopters [122]. Taking these numbers, an average of 444 patients per EMS helicopter can be estimated. This number has decreased since 1989/1990, when it reached a maximum at about 690 annually transported patients per helicopter. Again, the difference in various counting methods of US EMS helicopters shall be mentioned. 30 % of all HEMS flights are scene calls (primary missions), and 70 % are inter-facility transports (secondary missions) [122]. For patients who are severely injured and require inter-facility transfer, a four times higher likelihood to die is mentioned in [42] after the HEMS serving that area has been discontinued.

Regarding the operation of the EMS helicopters, there are three different business models [46] for helicopter operation:

1. operator-owned, also known as community based,
2. hospital owned/based, and
3. government-operated or public-use.

According to [122], most of the operators in the US are for-profit. In addition, to the above given list, there evolve hybrids of the first two models. The basic difference between the first two models bases on the control of the service. In the first case, a helicopter/aviation operator provides the aircraft including pilots and mechanics, and hires or contracts paramedics as well as nurses. In this case the operator also cares for billing, the private operator controls the service and his revenues depend to a large extent on the numbers of missions flown. In the second case, a hospital is in control of the EMS service. The hospital provides the medical crew and cares for the billing. The hospital leases the helicopter from an operator and pays a fee for the rental of the helicopter, pilot, and mechanics as well as an hourly fee for the helicopter running time. In this case, the operator receives revenues whether or not he flies [46]. Typical lease agreements run a minimum of 3 to 5 years [118]. This second model was considered in [118] for the Humboldt HEMS study. No matter which model is being chosen, the service is being paid for primarily by the patients and their insurance companies [43].

An analysis of the 10 largest HEMS providers is given in [46]. 10 providers utilizing more than 10 helicopters (see Table 5) were found, five with more than 50. The rest on the civil side are smaller operators. While some providers are 100 % community based, like Air Evac Lifeteam or EagleMed, some are 100 % hospital based like Metro Aviation and EraMed, others run both models like Air Methods and Omniflight or prefer hybrid variants like Med-Trans. STAT MedEvac is mentioned to be the only non-profit HEMS provider. Some companies employ own nurses and paramedics. None of these providers is mentioned to operate with physicians. Besides the medical equipment, some operators are also utilizing Night Vision Goggles (NVG), satellite tracking, Helicopter Terrain Awareness and Warning Systems (HTAWS) or weather information systems like weather radar or XM satellite weather. Air Evac Lifeteam and Omniflight are mention to offer membership programs for \$60 or \$49 per family/household. These programs are similar to the Swiss patron ship programs.

As briefly mentioned above, staffing of the medical crew of US EMS helicopters differs from other HEMS systems in other nations. Most of the US EMS helicopters are staffed with a nurse/paramedic team with additional, specialized critical care certification [42, 123]. Less than 5 % of HEMS programs have a flight physician on board and in many cases they are residents in a training program, although the skills of the physician were needed in 25 % of all flights [124]. The additional costs of the physician instead of the nurse are given in [125] with 7 % of the annual budget of the service provider of that study. The benefits of the physician would by far outweigh the additional costs.

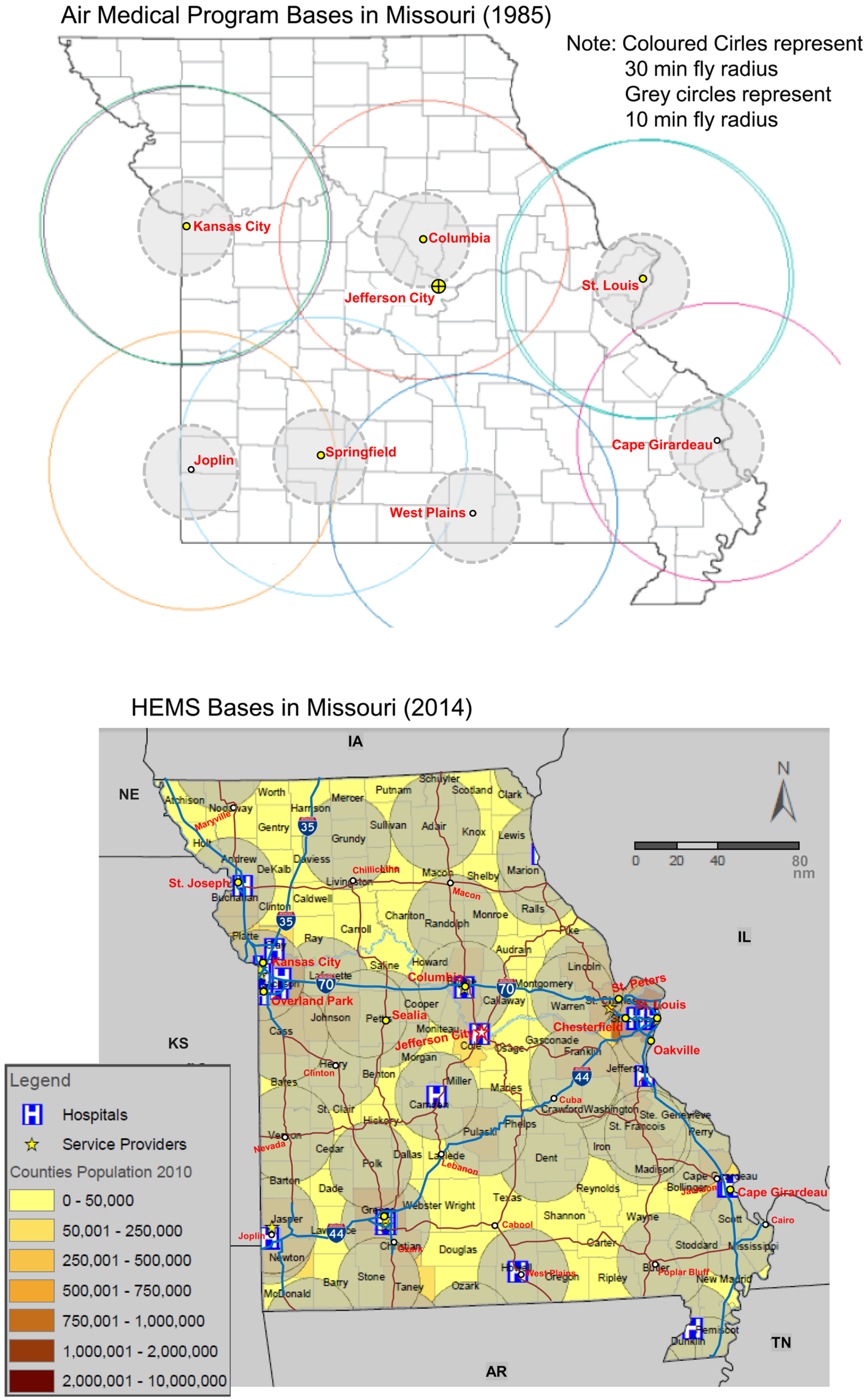


Fig. 26 EMS helicopter bases and population in counties of Missouri, Graphic based on information in [121] (*top*) and ADAMS [114] (*bottom*), *grey circles* in both figures represent 10 min fly radius

Table 4 Comparison of population and area per HEMS base for Nevada and Missouri

	Unit	Nevada	Missouri
Population	(–)	2,790,000	6,044,000
Area	(km^2)	286,351	180,533
	(nm^2)	110,561	69,704
HEMS bases	(–)	7	35
Population/base	(–)	398,571	172,685
Area/bases	(km^2)	40,907	5158
	(nm^2)	15,794	1992

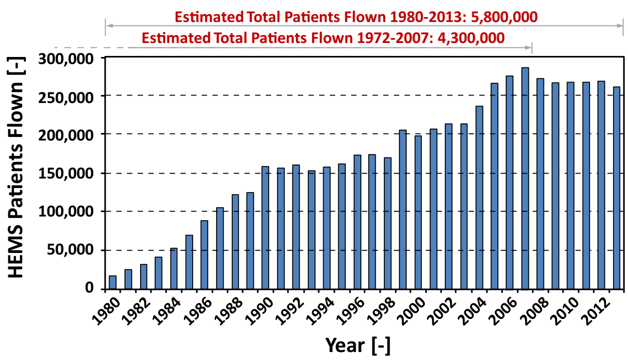


Fig. 27 Patients flown by EMS helicopters in USA from 1980 till 2007. Source: I. Blumen

Table 5 Top 10 US HEMS providers by fleet size

Provider	Helicopter
Air methods	306
Air Evac Lifeteam	110[a]
Omniflight	90
PHI Air Medical	82[a]
Metro Aviation	62[a]
Med-Trans	43[a]
EraMED	29
STAT MedEvac	21
Reach	16
EagleMed	12

Source: [46]

[a] 100 % NVG equipped and satellite tracked

Another difference to other HEMS systems might be the influence of the individual states on HEMS service providers. The large number of operators and EMS helicopters in the US imply a certain competition among the helicopter operators and a less organized structure of the various HEMS programs. This is being confirmed in [126] and [127]. In [128] a brief note refers to the Airline Deregulation Act of 1978. This act intended to allow competition among air carriers in general by removing government control over fares, routes, and markets. With respect to HEMS, the US states now cannot control anymore “where HEMS programs are located, when they fly, or where they deliver patients”.

Due to the cost considerations that are also outlined in the context of the Humboldt County in [118], many providers rely on single-engine helicopters. This is also documented in the ADAMS database [113] since 2004. This database also includes information on EMS helicopter models, maker, and whether a helicopter is a single or twin engine one. The number of single and twin engine EMS helicopters is shown in Fig. 28. Please note once more the difference in US HEMS helicopter numbers in the various sources.

Figure 28 shows that the total number of EMS helicopters increased within the last 10 years from 637 to 998 helicopters. While in the past the numbers of twin engine helicopters were higher than those for single engine ones, this trend reversed in 2013. Cost constraints might be a reason for this. A brief comparison on the impact on one and two engines might be worthwhile. The AS350 and AS355 aircraft might be a good choice for this comparison, since the AS350 is a very popular EMS helicopter in the US [113] and since the first is a single and the latter a twin engine aircraft while keeping the basis aircraft as far as possible similar. Two engines are usually used for helicopters with higher gross weights than these two aircrafts. The difference in costs is evident, while the AS355 shows even slightly less performances for the two given entries. On the other hand, twin engine helicopters have advantageous with respect to the dead man’s curve. Twin engine helicopters are advisably or even mandatory, for flights over sensitive or hostile terrain like offshore, urban areas or where simply higher performance classes, see [2], are required.

Finally, Fig. 29 shows the market share of the EMS helicopter makers. Airbus Helicopters has 55.3 % of the whole HEMS market. The most helicopter sales are

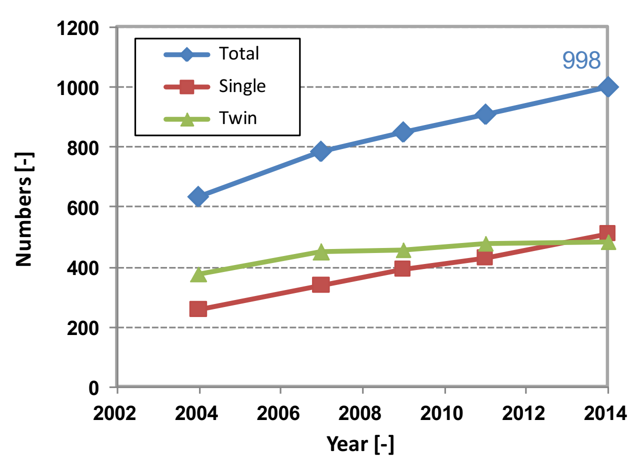


Fig. 28 Numbers of EMS Helicopters in USA for single and twin engine helicopters. Data source: [113]

apportioned on EC135 (180 units), AS350 (161), Bell 407 (150), and Bell 206 (119). Except for the EC135, all mentioned models are single engine helicopters.

The need for a further development of the US HEMS systems is still high. Large parts of USA are not covered by HEMS and many US citizens do not have rapid access to a trauma center in case of an emergency. The introduction of the ADAMS data base was motivated above by the high number of traffic accidents in the US. Regarding motor vehicle accidents, the loop now shall be closed to HEMS. In 2012, 33,561 people died in motor vehicle traffic crashes. This represents the first increase in fatalities since 2005, when 43,510 fatalities were recorded [110]. Regarding the economic impact, the situation even worsens. The economic costs of these crashes totaled $277 billion in 2010. This represents the equivalent of approximately 1.9 % of the US Gross Domestic Product in 2010 [129]. The benefit of EMS helicopters in this context has been analyzed in [111] for each US state. Using the ratio of fatalities per 1000 injuries as a metric, a "moderately strong" correlation between increased HEMS coverage and reduced fatality rates was found. The cause for this correlation was seen in the same reasons that have been also outlined at the end of Sect. 2: when a high percentage of a state's crash injured victims have access to fast medical response (i.e. EMS helicopter), the survival rate among the injured is higher.

3.10 Japan

As outlined above, Japan has a very young HEMS system that was established in 2001, but now has been enlarged to 43 HEMS bases [49]. The bases are shown in Fig. 30.

The shown circles resemble flying circles of 50 km (31 miles) radius, as usual in Germany. The stations are not distinguished between operators but between utilized helicopter models. Airbus helicopters with its EC135 and BK117 is the dominating manufacturer. Please note, the EC145 is named in Japan still BK117. It is therefore likely, since the HEMS system was built up from 2001 onwards, that all BK117 stations are modern EC145 ones. The helicopters are stationed at a hospital and are solely used for HEMS. The base hospitals are of a very high standard, i.e. a trauma center that can carry for critically ill patients and patients suffering from severe trauma [50]. This was called the "Munich model" in [47], see above. The EMS helicopter in Munich, Christoph 1, is stationed at the City Hospital Harlaching.

Unfortunately, there is not much information on the Doctor-Heli operators available, but is seems, that the helicopters are chartered for the Doctor-Heli program from commercial operators like Nakanihon Air Service [130] or Kagoshima International Aviation. Kagoshima International Aviation operates the Doctor-Heli in the Kagoshima Prefecture and has ordered another from AgustaWestland to enter service in early 2015 at the Hakodate Airport [131].

From the figure, a higher density of HEMS stations in the Tokyo area becomes evident. Tokyo with its 23 districts has about 9.1 million citizens today, the metropolitan region of Tokyo-Yokohama about 37.5 million, which is a little less than half of the number for Germany. From the figure it becomes also evident, that further stations are needed, to fully cover the whole surface of Japan. In [49] a number of 21 more bases are mentioned. This would sum

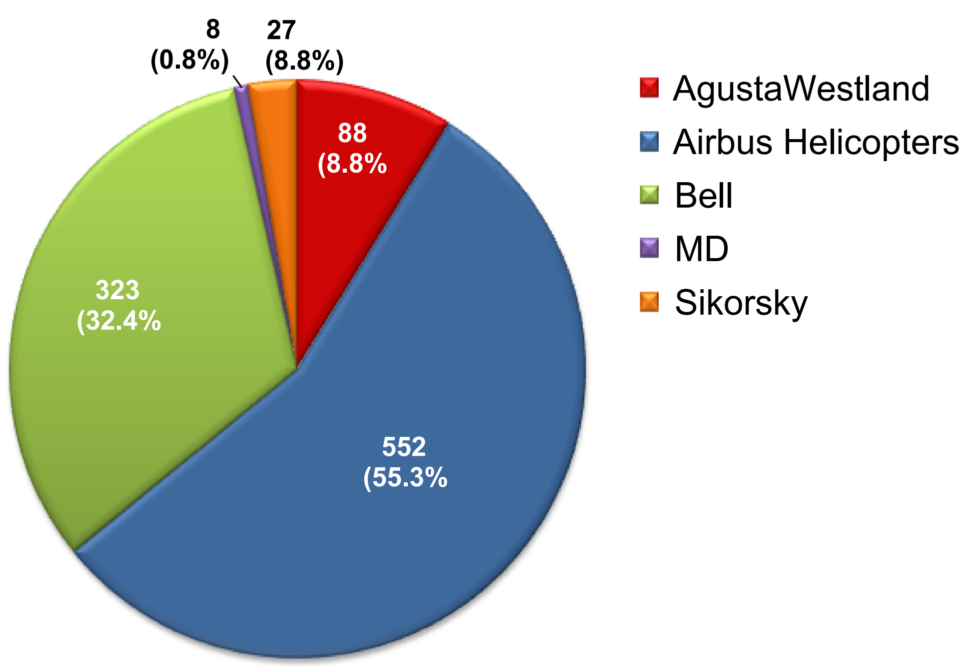
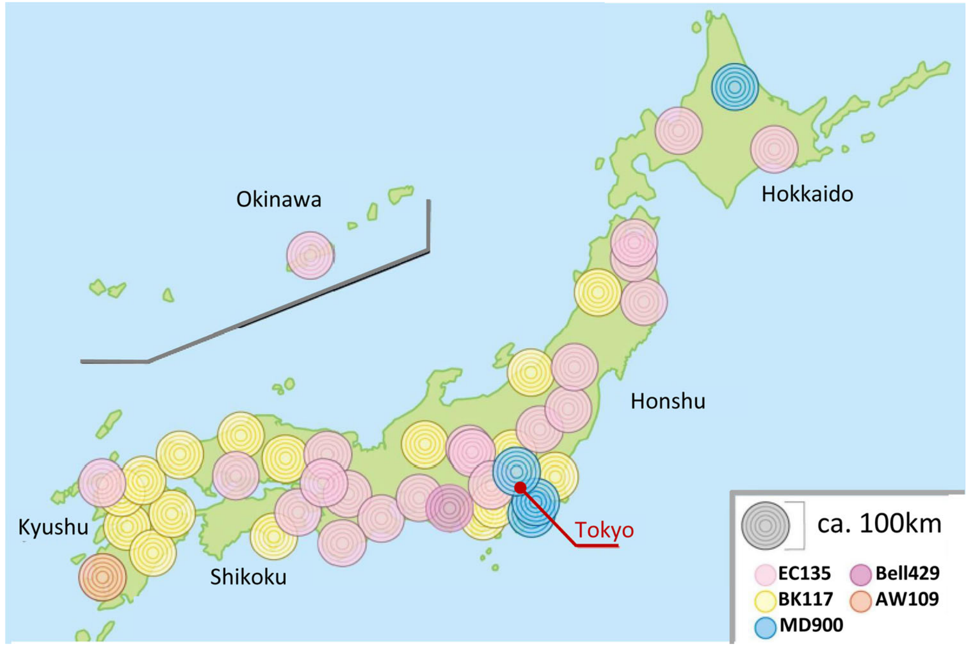


Fig. 29 Market share of EMS helicopter makers in USA, units and percent of market. Source: [113]

Fig. 30 HEMS stations in Japan, Source: [49]



up to 74 stations in total and would equal roughly the number of stations in Germany.

The number of HEMS missions flown in the period till 2010 is shown in Fig. 31. The number of missions per year is steadily increasing. Till 2010 45,450 deployments were counted, in 2011 12,923 [48]. This resembles an increase of 37 % compared to 2010. In principle, this curve follows the trend of the number of HEMS bases shown in Fig. 8. However, the number of missions grows faster than the one of stations (the increase of stations in 2011 was about 26 %).

The average number of flights per base was 488 in 2013. Between 2001 and 2010, this number was between 364 in 2001 and 448 in 2007. In Germany, these numbers are much higher, see above. In Germany, very few stations fly less than 1000 missions per year. Even at the beginning of the German HEMS program the number of missions was higher. Christoph 1 of Munich flew 853 missions in 1971 [63].

Trauma was the highest cause for a mission in Japan. Second highest was stroke (15 %) followed by cardiovascular emergency (12 %). From the trauma related deployments 45 % were caused by traffic accidents [48].

The goal in Japan as in other countries is to get the casualty into a trauma center within 1 h (golden hour). According to [48] this requires that EMS alerting takes less than 1 min with arrival at scene under 10 min, hospital admittance under 45 min and beginning of treatment within 60 min. In Japan EMS notification is not until the first 5 min. Another 15 min pass by till the EMS helicopter is alerted. It then takes 18 min before the helicopter arrives

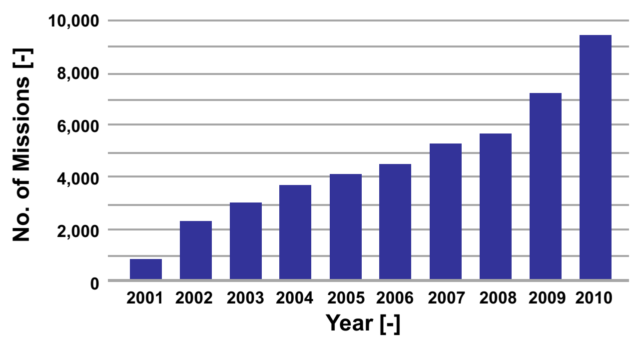


Fig. 31 Number of HEMS missions in Japan, Source: [49]

at the scene. In total, the time from crash to arrival at the hospital is 67 min [48]. One way to improve that interval could be to leave the HEMS notification to the dispatch personnel of the fire departments. On the other hand, the concept of the “safe landing spots” as discussed below, could hinder a reduction of the time till arrival at the hospital. Nevertheless, it definitively improves flight safety. Since traffic injuries are still a large cause for HEMS dispatch, an ACN is being developed, as in other nations with large automotive industry, too. Data to trigger such an automated call could include crash severity, direction of impact, air bag release, roll over, etc., [48]. This technology has already been pointed out in context with the US HEMS system.

The Japanese HEMS system is government funded (90 % central government, 10 % local responsible government). The operating costs are given in [49] and sum up to ¥210 million (about €1.41 million or $1.74 million in

2014 values) per year and per station. This is a major distinction from other HEMS systems like in Germany (financed by the health insurance companies) or USA.

Another difference from other HEMS systems is the composition of the crew. The medical crew comprises an EMS doctor and a flight nurse. According to Japanese law paramedics are not allowed to carry out certain medical procedures (even under the supervision of a doctor), that nurses are authorized to perform [50]. The helicopter crew makes up of a pilot holding an IFR license and a mechanic [48]. This latter crew member does not exist in other countries. This seems to be a compromise between a single pilot flight and a two pilot cockpit. The tasks of a mechanics are to contribute to save operation and assisting the medical team on the scene. On the scene, he co-operates with the doctor and the nurse in providing medical care or to load and unload the patient. Furthermore, he communicates with ground rescue forces to ensure safe take-off and landing. During flight he assists the pilot with navigation, external environmental obstacle monitoring or communication. Prior and after flight he is responsible to check the helicopter [50, 52]. This special Japanese feature is being motivated in [50] and is seen in the improvement of safety. To prove this hypothesis, a questionnaire was carried out and the results are summarized in [50]. 59 HEMS staff members from five HEMS operators took part in this questionnaire. This included 16 Pilots, 23 mechanics, 17 communication specialists, but just 3 business managers. A majority of the respondents (91.5 %) think that the presence of the mechanic is necessary for the Doctor-Heli program in Japan. 92.6 % of the respondents agreed that the aircraft mechanic can assist the pilot to ensure safe operations and 90.3 % that the mechanics can immediately tackle mechanical problems. 74.6 % of the respondents also agreed that other crew members cannot replace the mechanic during flight in assisting the pilot, but 22 % agreed that the paramedic could also assist the pilot to maintain safety. This strong favor for the mechanic on board the aircraft is astonishing, since the Japanese HEMS program was strongly influenced by the German one. But in Germany, the assistance of the pilot is being done by the paramedic. On the other hand, the paramedic cannot assist the EMS doctor during flight at the same time to care for the patient. And finally, 43 respondents agreed (i.e. 72.9 %) that the mechanic as a fourth crew member is not an economic burden. Compared to these numbers, the confidence of the respondents in the mechanic's capabilities to assist the medical crew on the scene is with 37 % much lower. Nevertheless, the questionnaire clearly shows the affinity of the Japanese HEMS staff members with the mechanic. It should be considered, that 39 % of the respondents were mechanics and 32 % pilots. This sums up to 71 % which might explain the positive outcome of the questionnaire. But this figure does not fully explain especially the three numbers (i.e. 91.5, 92.6 and 90.3 %) given first. On the other hand, since 5.1 % were business managers, only, it seems to be an explanation why the mechanic is not being viewed as a financial burden for the HEMS system in Japan in general.

Compared to other HEMS programs, the concept of a mechanic as fourth crew member on board the aircraft is so far unique. In USA, HEMS operations are usually carried out with a single pilot. This might be a consequence of the competing HEMS providers. However, especially from a Japanese perspective, this competition is one reason for the high number of EMS helicopter accidents in the US [49], see below. In Germany, as mentioned already above, the paramedic assists the pilot during normal daytime operations on land. In London or Moscow, see above, two pilots are on board the aircraft. The latter is felt in Japan as too costly for the operators [50]. The two pilots concept might be favorable or even mandatory, if the mission risk is higher than for "normal" operations during daytime hours over land. Over sea and during NVG operations, two pilots are definitively reasonable. And a similar argumentation could be true for operation over large cities.

According to [47], the Doctor-Helicopters have resulted in a tremendous success: Doctor Helicopters have raised patient survival rate by nearly 30 % compared to conventional emergency transportation by RTVs. The rate of patients who fully recovered rose by 50 %.

3.11 China and India

Finally, some remarks shall be spent on China and India. Airbus Helicopters has delivered an EC135 in EMS configuration to China [132]. This aircraft is the first EMS helicopters in China and is operated by the 999 Emergency Rescue Center, a subsidiary of the Chinese Red Cross based in Bejing. A second one will be delivered in 2015. The organization has also signed a declaration of intent to purchase two further EC145 T2, which shall be delivered in 2016, and at least two more shall be put into service till 2022. The aircraft will serve the Bejing city with its 27 million residents and the surrounding area, which even comprises 95 million people. It might be too early to speculate about this as the first step towards a HEMS system in China, but the benefit for such a system should be clear: like Russia, the country has very large distances and a poor infrastructure in the country side. On the other side, China has worldwide the largest population with about 1.37 billion citizens that would benefit from helicopter EMS. Especially the large cities could be a very important first target to cover by HEMS as in Russia. However, they represent a challenge on its own, not only due to the obstructed landing sides in case of an emergency, but also due to wires and the

Fig. 32 Air rescue helicopters

industrial air pollution that reduces visibility. It could be a worthwhile idea to consider specifically EMS helicopters that are tailored to such a need.

India, with the second largest population of slightly less than 1.3 billion people is a step ahead of China in the respect of HEMS. In 2013, an agreement was signed between Airbus Helicopters and Aviators Pvt Ltd. on seven EC135 EMS helicopters [133]. According to that note, Aviators intends to establish itself as a pioneering HEMS operator in India and as many as 50 EMS helicopters are being expected to be installed in India in the coming years.

4 Rescue helicopter statistics

A data base has been setup which aims as a basis to back up a preliminary helicopter design capability at DLR by statistical data [134, 135]. The know-how of this capability will be used in the context of the research concept the “Rescue Helicopter 2030”, which has been mentioned in the introduction and will be briefly outlined in Sect. 5.

Figure 32 shows helicopters that have been identified as air rescue helicopters capable of transporting casualties. The helicopters can be grouped in three classes depending on their MTOW: below 4000 kg (8818 lbs), between 4000 and 6000 kg (13,228 lbs) and above 6000 kg.

These classes can be designated as light, intermediate and heavy helicopters. The limits are somewhat arbitrary, but there is no firm definition of these designations. The helicopters shown in Fig. 32 in the heavy class are used as SAR helicopters and will not be included in the further statistics on EMS helicopters. For the statistics data have been taken as far as possible from manufacturer’s information. In addition data were partly taken from [66] and [136], if no other data source was available.

Some selected data of these helicopters are shown in Figs. 33, 34 and 35. These figures aim to give e.g. a brief overview on the dimensions and selected data for flight performances of the aircraft shown in Fig. 32, and identify outliers. The data shown here are data of the basis aircraft and not of the individual EMS equipped aircraft. The figures are shown in metric units only. Some data points have been labeled with the designation of the helicopter, but any model type identifier has been left off. They are shown in Fig. 32. For some of the data, linear or quadratic trend lines have been included as solid lines. Dashed lines refer to manually drawn lines.

Some fuselage parameters as width l_{FW}, length l_{FL} and cabin volume V_{cab}, are shown in Fig. 33. Height is not shown here in order not to overload the figure. The fuselage width data show a rather small band and a linear variation with MTOW. Some outliers are the S-76, the EC130, and the EC145. The fuselage cabin volume also shows a reasonably linear variation with MTOW with a slightly larger scatter. Some outliers towards larger cabins are, e.g. the EC145 and the Bell 429. Large cabin volumes are beneficial from a practical, operational point of view, especially for EMS helicopters to stow the extensive medical equipment, the patient and the physician or even further medical personnel. From a high-speed performance point of view one needs to take into account, that the so-called parasite drag of the helicopter causes large power requirements at

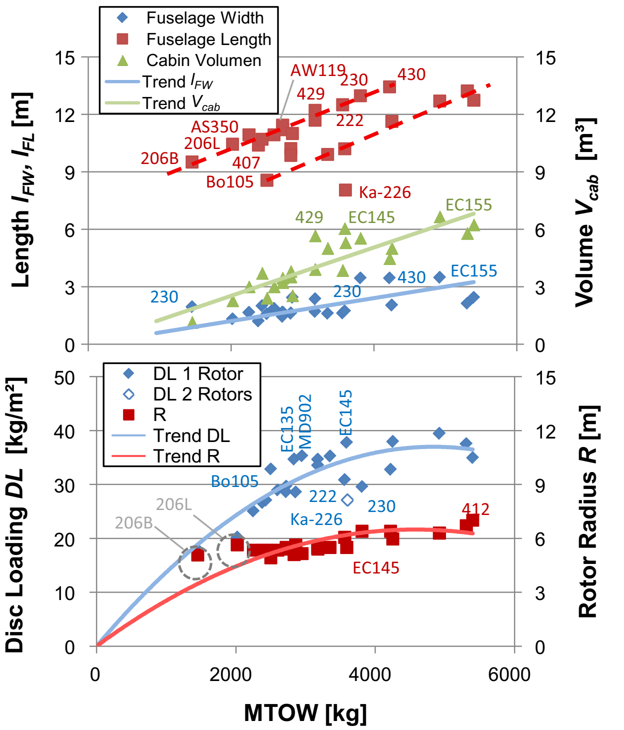


Fig. 33 Fuselage dimensions and cabin volume (*top*), disc loading and main rotor radius (*bottom*)

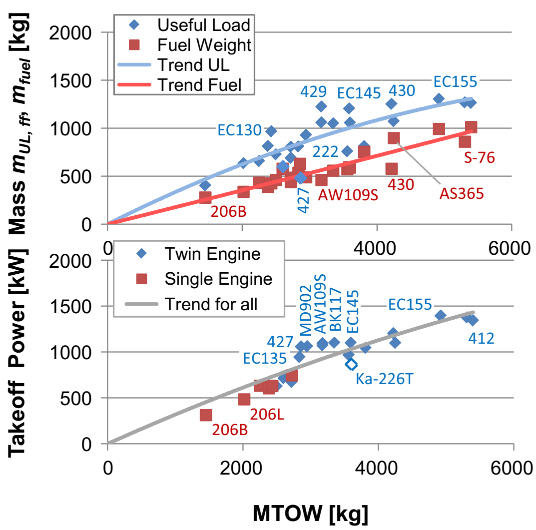


Fig. 34 Payload at max. fuel (*top*) and takeoff power all engines (*bottom*)

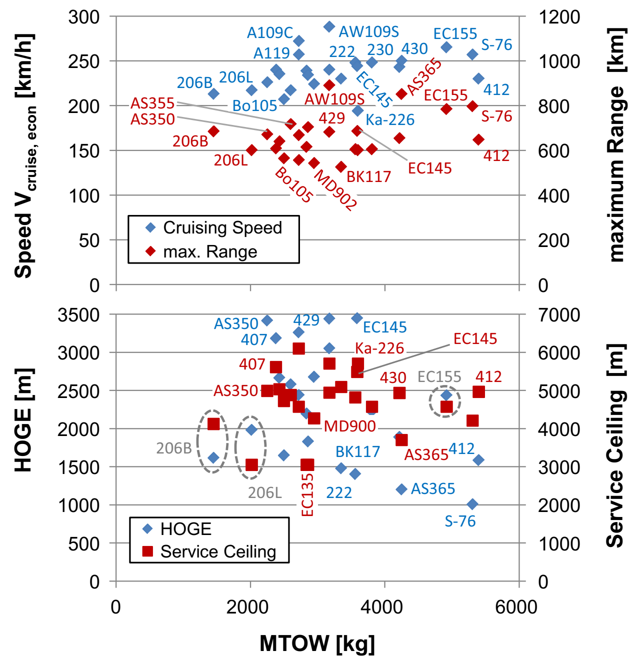


Fig. 35 Flight performances, economic cruising speed and range (*top*) and service ceiling and HOGE (*bottom*)

higher speeds of flight. The fuselage contributes significantly to this drag. Therefore, the shaping of the fuselage and the choice of its dimensions need to be carefully considered. The EC155 for example realizes as some other helicopters like the S-76 or the AW109 an aerodynamically well shaped fuselage. The effect of a "clean" helicopter drag versus unrefined designs and a discussion on drag minimization is included in [137]. In contrast, the cabin length shows a different behavior. It seems as if some helicopters feature longer fuselages than others for similar MTOW. This holds first of all for single engine helicopters and also for Bell twin engine ones. The advantage of a short fuselage is also evident for the co-axial rotor Ka-226.

Disc loading and rotor radius trend show a quadratic shape. The 206 models use rather large rotor diameters, while the one for the Ka-226 fits to the rotor radius trend. However, it shows the lowest disc loading due to the co-axial rotors (it has been assumed, both rotors are equally loaded). In hover and low-speed flight, the induced power dominates the power requirement and gets low for low disc loading. In high-speed flight, this effect diminishes, since the induced power reduces, but parasite and rotor blade profile power increase. The open symbol of the DL-values for the Ka-226 shall symbolize, that it has not been retained for the trend analysis. This is done for single rotor helicopters only. With respect to the disc loading, Bo105, EC135 and MD902 lie above the trend as some others, too. Low disc values are beneficial for good hover performance. On the other hand, larger rotor radii are limited by overall helicopter size, weight, gearbox torque, costs, etc. [137].

In Fig. 34 (bottom) take-off power is shown for both, single and twin engine helicopters. For twin engine helicopters, the power of both engines is added. The grey curve depicts the trend for both helicopter classes and is almost linear versus MTOW. The Ka-226 has again not been included in the trend analysis to omit the effect of the co-

Table 6 Comparison of AS350 and AS355, DATA: [66]

	AS350B3	AS355N
MTOW	2250 kg 4960 lbs	2600 kg 5732 lbs
Engine(s)	1× Turbomeca Arriel 2B	2× Turbomeca Arrius 1A
Max continuous power (each)	544 kW (730 shp)	302 kW (406 shp)
Fuel burn	176–195 L/h (47–51 gal/h)	209–231 L/h (55–61 gal/h)
Service ceiling	4987 m (16,360 ft)	4877 m (16,000 ft)
Economic cruising speed	226 km/h (122 kts)	217 km/h (117 kts)
2008 base price	$2 million	$2.9 million
Maintenance costs per hour	$215–230	$246–276

axial rotor from the power trend, but it fits quite well into the speckle pattern of the other aircraft. Both 206 models of Bell seem to be slightly underpowered according to that trend, but both are rather old designs. Some helicopters lie above the trend as EC135, Bell 427, MD902, AW109S, BK117 or EC145. The Bell 412 lies slightly below like the Ka-226. Therefore, one could expect for the Ka-226 with respect to the installed power and the low disc loading that this aircraft will show good hover performances, but low cruising speeds. Besides the impact of the installed power on performances, its impact on costs needs to be considered. Two engines cause higher maintenance costs due to more complex (e.g. transmission) and more systems (engines, fuel system, etc.). They also have a drawback in fuel consumption, when compared to a single engine operating at the same power, see e.g. Table 6. In addition, they have a severe impact on the purchase price. An analysis of helicopter base prices on the basis of 1994 Dollars has been performed in [138]. A correlation process with various parameters has been conducted. The resulting equation shows helicopter costs are more sensitive to installed power $P_{\mathrm{total,Engine(s)}}$ than to empty weight m_e:

$$\text{Base Price} = \$269 \times [H] \times [m_{\mathrm{e}}]^{0.4638} \times [P_{\mathrm{total,Engine(s)}}]^{0.5945} \times [N_{\mathrm{Bl}}]^{0.1643} \tag{1}$$

with N_{Bl} as blade number and the factor H given by:

$$H = H_{\mathrm{EngineType}} \times H_{\mathrm{EngineNumber}} \times H_{\mathrm{Country}} \times H_{\mathrm{Rotors}} \times H_{\mathrm{LandingGear}}. \tag{2}$$

Out of these five factors the engine and rotor related factors are of higher interest for the purpose presented here. The factor $H_{\mathrm{Engine\ Type}}$ distinguishes in principal between piston and turbine engines and becomes the highest with 1.794 for turbines and the lowest with 1 for simple piston driven helicopters. $H_{\mathrm{Engine\ Number}}$ considers the impact of one and more engines and becomes 1 or 1.344, respectively. The consequence on costs of one and twin main rotor designs can be considered with H_{Rotors}, but is small, 1 or 1.031, respectively. These simple equations show, how large the impact of engine number and installed power ($P_{\mathrm{total,Engine(s)}}$) on helicopter prices is. One the other hand, multi-engines offer increased safety. They show much smaller and less "avoid" areas in the dead man's curve [137] and are required in principle for EMS helicopters in the performance classes 1 and 2 [2]. In the future, avionics equipment might also become a high-cost driver, since it is increasingly utilized in helicopters.

The upper diagram in Fig. 34 shows the useful load of the helicopter at maximum filled fuel and the maximum fuel mass. The data for the fuel mass show a narrow scatter and a linear trend. The data for the useful load show a broader pattern and the trend is slightly quadratic. Some outliers towards smaller values are Bell 222, 230 (not labeled), 427, and AS355 (not labeled). Higher values are shown for some of the Airbus Helicopters aircraft and the Bell 229, and 430. The useful load at full fuel finally can be used to transport the crew, the medical equipment and of course the patient. High values are therefore beneficial. The useful load value for the Ka-226 lies almost on the trend curve. From its low disc loading and installed power, larger values could have been expected. The problem of the Ka-226 is its large empty weight. Its ratio of $m_{\mathrm{e}}/m_{\mathrm{TOW,\ max}}$ is about 0.62. Good helicopter designs like the EC145, which is in the same MTOW range, have a value of about 0.5.

Finally, Fig. 35 shows some selected flight performances. However, these data have to be taken with some care, since the flight performances like range depend on various parameters as altitude, weight, speed, etc. It is not always clear, if such and most notably consistent considerations for all included helicopters have been made while compiling the data especially in [66] and [136]. Detailed information is, e.g. not always given on the operating point for which the performance data are listed. Therefore, the individual performance data are not necessarily reached at MTOW. However, an own computation of these performances, e.g. from flight manuals would have been out of the scope of this paper. Nevertheless, the data give an overview on the performances of different actual EMS helicopters. The upper figure in Fig. 35 shows economic cruising speed at sea level and range at maximum internal fuel. Especially the range strongly depends on the mass of the aircraft, fuel volume and speed. This parameter therefore represents just one point of the payload range diagram. Both parameters show a broad scatter. However, there is a certain trend noticeable: especially the helicopters with a rather aerodynamically clean fuselage design and probably modern rotor blade profile designs do quite well in both parameters like AW109S, A119, EC155 or S-76. In contrast to that, older designs like Bo105, BK117, and Bell 412 or even MD902 show lower values. The problem of helicopters like Bo105 and BK117 is among others like old rotor blade profiles their fuselage shape with a blunt tail section of the cabin. Both aircraft feature so-called clam-shell doors which are very beneficial from an operational point of view. These clam-shell doors allow a very comfortable access of the cabin with the patient from the rear of the helicopter. However, they result in a relatively blunt section of the aft-cabin section which causes higher parasite drag than clean designs like that of the AW109S. As already anticipated, the cruising speed of the Ka-226 is on the lower end of the scale and its range (not labeled) is in-between the old and modern helicopter designs. In contrast to the BK117, the EC145 is showing superior flight performances although it also features clam-shell doors. There has been much refinement on the fuselage and the blades that results in better range and speed. Nevertheless, it shall be pinpointed, that higher cruising speeds for EMS helicopters are contradicted by the current reimbursement model which is based on costs per flight minute.

Finally, the lower part of Fig. 35 shows HOGE and service ceiling. Here, both parameters show even less structured patterns than before and is difficult to find potential relationships. However, it can be stated that very modern designs like the Bell 429, 407, and EC145 (values given at 92 % MTOW) do quite well. Now, the Ka-226 can show superior performances as indicated above. Its HOGE with 4100 m lies even out of the figure. The excellent HOGE capability of the AS350 was already mentioned above. Older helicopter designs again show lower values for both parameters, like the Bell 206B and 206L or BK117. Astonishingly, helicopters like AS365 and S-76 also show minor values. Both aircraft are widely used as offshore helicopters (e.g. SAR or oil rig supply), which does not require high ceilings limits.

5 Noise and safety aspects of rescue helicopters

Despite the undoubtedly increased maturity of helicopters since their emergence, some challenges still remain like high noise levels, high vibration levels, performance in hover in high-speed forward flight, but also safety. These aspects are not necessarily problematic to EMS helicopters only, but to all helicopters. However, EMS helicopters operate close to populated areas; they land on or next to hospitals in cities. This fact has a direct impact on the annoyance of the population in the neighborhood of especially landing helicopters caused by their high decent noise levels [139]. In contrast to that, high vibration levels and high fuel consumption are first of all problematic to the crew and the operator, but not to the public. On the other hand, especially the high accident rates of EMS helicopters especially in USA have become a concern of authorities and have been and are still discussed in the public. Therefore, this chapter aims to give a brief overview on noise and safety aspects of helicopters and EMS helicopters.

5.1 Noise

The origin of helicopter noise is for EMS and other helicopters the same. However, the field of operation differs between EMS helicopters and, e.g. those for aerial work or police services. EMS helicopters, as mentioned above, operate in close neighborhood to populated areas or in cities. They land and take-off from hospitals or emergency scenes which are located in the midst of populated areas. Especially, if EMS helicopter operation will be increasingly conducted during night, patients at hospitals and population in their vicinity will be disturbed. This will raise complaints, even if the benefit of helicopters is widely accepted. Therefore, low noise emissions of EMS helicopters are mandatory. The following noise sources contribute to the overall noise of helicopters [140]:

(i) main rotor:
  - thickness and loading noise,
  - blade vortex interaction (BVI),
  - high-speed impulsive noise,
  - blade wake interaction,
  - trailing edge noise,

(ii) tail rotor (same as for main rotor and in addition interaction with body and main rotor wakes),
(iii) engines, (compressor, turbine, combustion),
(iv) and airframe (fuselage, skids).

While BVI is of more concern during decent, thickness and loading noise are of general importance during all flight segments. Especially the BVI noise causes noise of impulsive character and at high levels. This is all the worse, since in this flight segment the helicopter gets closer to the ground and hence closer to the population.

Maximum noise levels of helicopters are defined by the International Civil Aviation Organization (ICAO) in [141] and helicopters have to keep below these levels for certification. Two different chapters specify maximum noise limits in dependence of the helicopter's MTOW, chapter 8 and 11. In chapter 8 three different segments are defined for certification: take-off, overflight (i.e. horizontal flight), and approach. The permissible noise limits distinguish between helicopters for which the application for the type

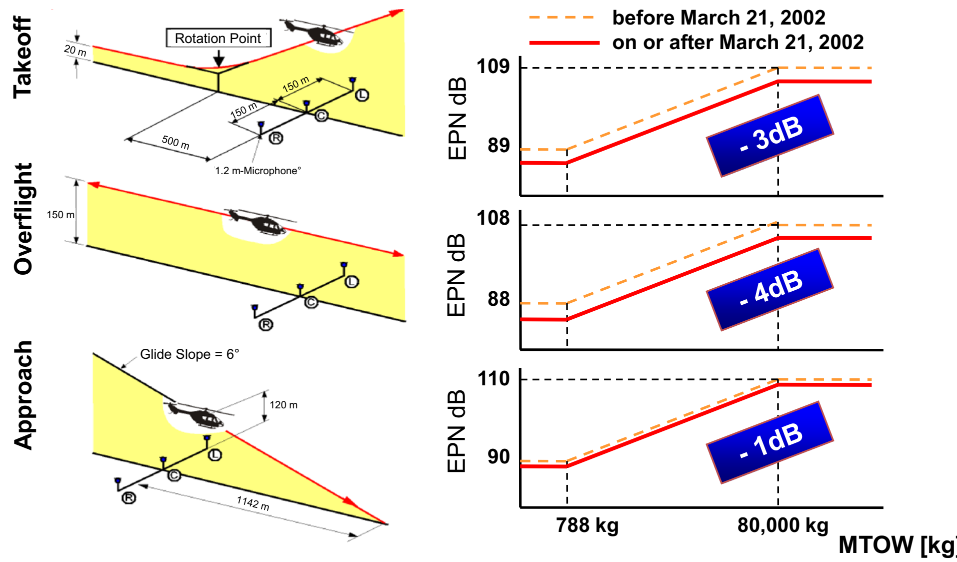


Fig. 36 ICAO noise certification limits of Annex 16, Volume I, Chapter 8. *EPN* Effective Perceived Noise Level

certificate was submitted on or after March 21, 2002 or before. For helicopters certified before January 1, 1985, no noise limits are specified in [141]. The noise certification levels of chapter 8 are shown in Fig. 36.

Chapter 11 is applicable to helicopters only, if they do not exceed 3175 kg (7000 lbs). Helicopters that fulfill this condition may alternatively be certified according to chapter 8, depending on the applicant's choice. In chapter 11, too, stronger noise levels are valid since March 2002, but overflight is required only. Most of the helicopters certified by EASA are certified according to chapter 8, see [142]. Certified helicopters are listed with relevant certification data, measured noise levels and relevant noise limits. For the helicopters shown in Fig. 32 and which were certified according to chapter 8 Fig. 37 shows noise values in approach in comparison to the permissible noise levels. Unfortunately, no data were found for the Ka-226. Both limits of Fig. 36 have been included in the figure. In contrast to those shown in Fig. 36, they are no straight lines, since a linear MTOW-axis has been used for Fig. 37 to fit to the figures of the preceding chapter while the axis of Fig. 36 is a logarithmic one. For the data points of Fig. 37 it has not been distinguished whether helicopters have to fulfill the strong new limits or the somewhat relaxed older ones. This difference is for residents in the vicinity of helipads actually of minor importance.

Nevertheless, it may be especially noted for EC135,[11] BK117, and AS365 that these helicopters have to keep to the limits valid before March 21, 2002. Two trends become

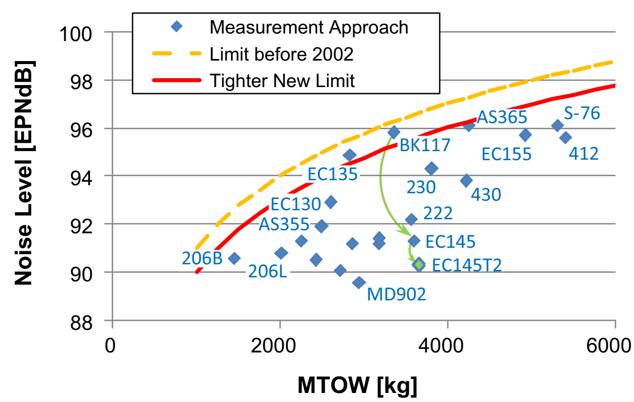


Fig. 37 Noise levels and of various helicopters during approach and noise limit. Data source: [141, 142]

evident from this figure: Heavier helicopters generate more noise what is also depicted by the permissible limits that solely depend on the helicopter's MTOW. Additionally, modern helicopters are significantly more silent than old designs. This is shown for the BK117 family (the EC145 is still recorded as BK117 at EASA). While the BK117 shows a noise value of almost 96 EPNdB, the EC145's value is 91.3 EPNdB, and for its successor, the EC145 T2 even 90.3 EPNdB despite increased MTOW. This is an excellent result. The same holds for the MD902 which is the quietest helicopter in the figure. Taking into account the mass effect, the EC145 T2 does equally well. One feature of the MD902, which is often mentioned as a significant contribution to noise reduction is its torque compensation device, the No Tail Rotor System (NOTAR).

A summary on helicopter-related noise issues and its relevance to a community is given in [143]. The reaction to helicopters is according to [143] dependent on several factors, some of which are completely unrelated to the

[11] Shown here is the T2 model. The P2 model shows a noise level in approach which is 2.2 EPNdB below the T2 [142]. In approach with its low power requirement, the engine should not have such an impact on noise. It is quite likely that flight certification of the T2 have been conducted under less optimal conditions than for the P2.

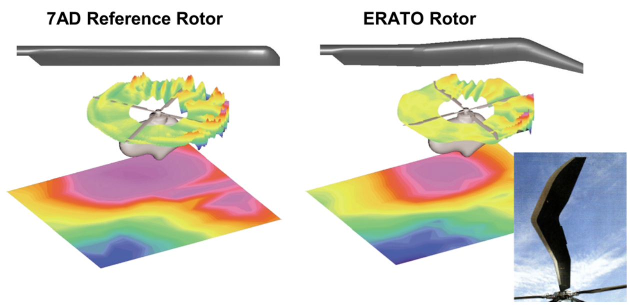


Fig. 38 Noise carpets of 7AD and ERATO rotor, $\mu = 0.165$, 6° decent angle and Blue Edge™ blade of Airbus Helicopters

maximum helicopter noise level. The subjective character of the sound is equally or more important than the absolute noise level itself, which seems to contradict the stipulation of maximum noise levels. Improvements should not only focus on the reduction of the noise level itself, but also on reducing the impulsive character of the noise. This would lead to greater acceptance in the public. Recommendations given in [143] include a reduction of main and tail rotor tip speeds to 215 m/s (705 ft/s) or less, usage of thin blade profile sections, low noise blade tips, increased number of blades, etc. For older helicopter designs it is being recommended to fly at higher altitudes and use noise abatement procedures for normal operations. Also, these helicopters should fly much slower than anticipate. Some of these aspects are already used at modern helicopters as shown by the EC145 T2 and are also in the focus of research projects. Two examples might be given on this below.

How well proper blade design can reduce noise has been demonstrated in a joint Onera-DLR research program called ERATO (Etude d'un Rotor Aéroacoustique Technologiquement Optimisé) [144]. Figure 38 shows the noise carpets of the 7AD reference rotor and the ERATO rotor as measured during a wind tunnel test campaign. Red spots symbolize high noise levels. As can be seen, the novel ERATO design has decreased the rotor generated noise significantly. Noise was reduced by 4–5 dB at the certification condition for landing approach and about 7 dB and more at high lift conditions. In addition, approx. 10 % less power required turned out at high speeds. This called Airbus Helicopters' attention to the ERATO design. Airbus Helicopters has shown a slightly modified ERATO blade as its Blue Edge™ design at the Heli-Expo 2010 in Houston.

Flight test results on noise reduction by flight path optimization using DLR's EC135 test aircraft are presented in [145]. It was found, that piloting at very low torque or at high torque allowed to avoid BVI noise. At a speed of 120 km/h (75 mph) and descent angles of below 3°or above 13° the noise became the lowest. However, very low decent angles are from an operational point of view not efficient and large descent angles are close to autorotation condition. Adding side slip angles (cabin nose oriented towards the retreating side of the rotor) further decreased the BVI noise. A maximum of about 10 dB SEL (Sound Exposure Level) was measured. However, such a flight procedure would increase the pilot's workload and assistance systems would be advisable to ease such a descent flight.

In addition to the above-mentioned passive noise reduction, active rotor control can contribute to a significant noise reduction (5–6 dB), but would increase system complexity of helicopters. It, too, can reduce vibrations or power consumption in high-speed forward flight. A survey on various technologies has been given in [140, 146].

Implementation of these technologies could further reduce the noise values in Fig. 37 and probably could further improve acceptance of EMS helicopter operation in the public, even if in the future more missions will be flown.

5.2 Safety

Besides the above-mentioned noise aspects, safety of civil helicopters in general has been of major concern in the preceding years. The long time accident rate has been much too high in the past in comparison to general aviation. The 5-year averaged accident rate (2001 through 2005) was in USA 9.1 accidents per 100,000 flight hours, worldwide in average 9.4 accidents per 100,000 flight hours [147, 148]. This initiated the foundation of the International helicopter Safety Team (IHST) in 2005. Goal of the IHST is to reduce the accident rate by 80 % till 2016. Basis is the averaged value for the years 2001 to 2005 [147].

Since the implementation of the IHST, many analyses of helicopter accident statistics have been undertaken especially in the US and Europe.[12] Since 2005, the accident trend in the US showed a saw tooth character with a slight downward trend. After a minimum of 129 accidents in 2011, the numbers increased back to 148 in 2012 and 147 in 2013 [149]. However, the fatal accidents were even worse: in 2013 fatal accidents peaked at 37, which denotes the worst year since 2004 [150]. The accident rates in the US are slowly improving, but fatalities are not. This motivated the US National Safety Board (NTSB) to add helicopter accidents reduction to its "Top 10 Most Wanted List 2014" [139]. A detailed analysis for the calendar years 2000, 2001, and 2006, covering 523 accidents, has been performed in [147] and [151]. The analysis revealed that personal/private operations resulted in 97 accidents of

[12] Numbers have to be taken with some care, since accident and fatal accident numbers or rates vary, depending on the report.

which 19 were fatal. HEMS ranked number four in the accident list. In those 3 years, 40 accidents were related to HEMS of which 10 were fatal. In Europe, the situation in this respect does not differ much. The roughly 6800 registered helicopters cause in average 100–120 accidents per year, of which in average 16 are fatal [152]. HEMS was listed in the EASA safety review, which covered the calendar years 2003 to 2012, as the operation type causing the second highest accident count (40 accidents) for this period [153].

Occasionally, accidents per 100,000 flight hours are being used as a measure instead of absolute accident numbers itself. For the calendar years investigated in [147] the captured HEMS accidents resulted in 3.9 accidents per 100,000 flight hours and the operation sector personal/private with 29.6 accidents per 100,000 flight hours [154]. Although the figure for the personal/private sector was more than seven times the value for HEMS, even the HEMS figure was still far above the IHST target of 1.8 accidents per 1000,000 flight hours in the US. Nevertheless, this figure has come down dramatically for the HEMS sector since 1982 when it peaked at almost 24.5 accidents per 100,000 flight hours. The number of fatal HEMS accidents per 100,000 flight hours has also decreased significantly and is almost constant since 2000 at about 1.5–2.2 fatal accidents per 100,000 flight hours with the exception of a dip for 2006 and 2007. However, the average fatal accidents rate for all helicopters is lying below the HEMS fatal accident rate since 1997 [155]. It should not be withheld that criticism on the accident rate as a indication value is raised in [156]. Inaccuracies in the statistics on allocated flight hours per helicopter operation and the importance of the fatalities themselves and not a rate are quoted for this.[13]

When looking at the accident rates for both sectors, personal/private and HEMS, the flight experience of the crashed pilots needs to be taken into account. Many of the US HEMS operators require 2000 flight hours before command of an EMS helicopter is conferred to the pilot [157]. HEMS pilots involved in a crash were indeed more experienced than the pilots for the personal/private operation sector. This is clearly shown in Table 7. Despite their experience, HEMS pilots are still involved in accidents. The figures for the personal/private sector might explain the high accident numbers in this sector. Both groups show less flight experience on the crashed helicopter model. Both trends for HEMS pilots are confirmed in [157]. Here, out of 106 accidents just one pilot showed 1432 flight hours, but 11 more than 10,000 flight hours. But the majority of the pilots that crashed showed less than 200 flight hours on the crashed aircraft model.

Table 7 Flight experience of pilots involved in accidents in USA

Value		HEMS	Personal/private
Flight hours	Min	1328	23
	Median	4628	384
	Average	5566	1184
	Max	11,876	16,550
Flight hours on model	Min	3	2
	Median	323	157
	Average	686	398
	Max	3000	5000

Data source: [151]

This finding fits also well to a European analysis. In 26 % of the accidents analyzed in [158], the pilots in general had less than 100 flight hours, 33 % less than 1000 flight hours experience. The highest number of accidents (20 % of all investigated accidents) fell into the dedicated category general aviation with less than 1000 flight hours experience of the pilot. This sector includes the above-mentioned personal/private operation sector.

Besides these numbers, it has been analyzed in which phases of flight helicopters crash and what causes an accident. The dominating phase of flight in which the accident sequence was initiated is shown in Fig. 39. Landing seems to be the phase with the highest accident occurrence. In combination with the approach phase it is dominating. However, the highest fatality number is caused while the helicopter is en route. This might be attributed to the higher speed at impact [147]. Additionally, it has to be considered that for helicopters the en route phase is conducted very often at low altitudes which exposes the helicopter to collision with objects (e.g. wire strike), inadvertent entry into instrument meteorological conditions, or controlled flight into terrain (CFIT) [158]. The same might be valid for the maneuvering phase. Again, these results fit reasonably to a European analysis done by the European Helicopter Safety Team (EHEST). Here, too, en route caused the highest fatality number. En route, maneuvering and approach/landing were the flight phases with the highest accident probability [159]. With respect to HEMS, a typical air medical transport operation, whether a primary rescue (accident scene to hospital transfer) or secondary rescue (hospital to hospital transfer), involves three take-offs, three en route segments and three landings: flight from base to scene, scene to hospital, hospital to base. Maneuvering is part of these segments. A typical HEMS mission therefore includes three times the flight profile of a normal mission.

[13] In this context it might be helpful to refer to other industry sectors like the automobile industry. The traffic fatalities have been reduced significantly, see e.g. Fig. 5, despite an enormous increase in registered motor vehicles and hence driving hours.

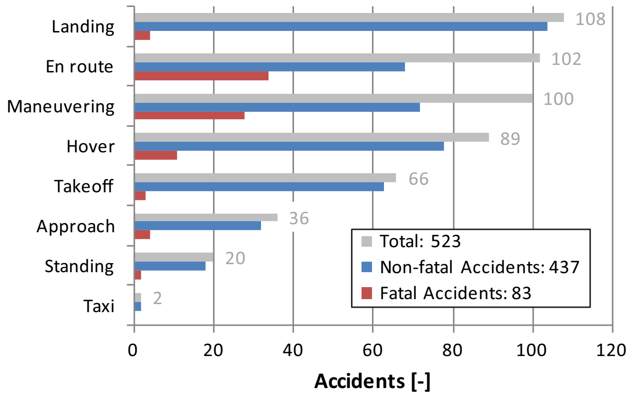


Fig. 39 Accidents by phase of flight for years 2000, 2001, 2006. Adopted from [147]

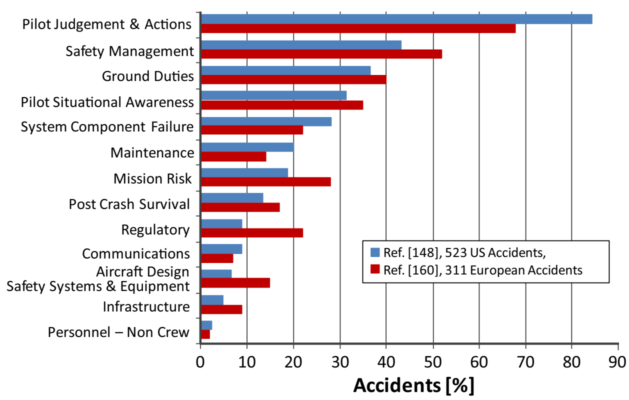


Fig. 40 Standard problem statement comparison for US and Europe. Adopted from [147, 159]

The causes of accidents are analyzed by IHST using the so-called standard problem statements (SPS) taxonomy. The SPS features over 400 codes in 14 different areas. The structure consists of three levels: the first level identifies the main area of the SPS, the others go into more detail. A single factor identified in the accident can be coded using more than one SPS. Figure 40 shows in comparison 13 of the 14 level 1 SPS taken form references [147] for USA and [159] for Europe. Both studies agree reasonably well in their findings, although they differ for some SPS categories in size.

Nevertheless, most helicopter accidents in both analyses include pilot-related factors in the list of causes, i.e. pilot judgment and actions, ground duties, and pilot situational awareness [147]. Pilot judgment and actions are less often quoted in the EHEST study, but this study therefore weights regulatory and mission risk causes higher than their US counterparts. The latter includes descriptions that also could be attributed to the decision-making of the pilot. A significant contribution to accidents can be also attributed to system component failures.

For the three calendar years investigated in [147], single engine turbine helicopters account for 45–51 % of all accidents, single engine piston helicopters varied between 39 and 45 %, multi-engine turbine rotorcraft varied between 8 and 10 %. Similar findings are reported in [157] and [156]. Although the analysis in [156] cover accidents in the period from 1964 till 1997 and hence include helicopter data which are not representative for modern helicopters, it is interesting since most of the engine-related accidents were not related to structural problems with the engine, but to incorrect fuel/air mixture including running out of fuel as the highest cause.

The accidents of single engine helicopters may not be attributed to engine malfunctions only. Single engine helicopters focus on a segment of the helicopter market that requires inexpensive helicopters. Many of these helicopters do not feature modern flight control systems that aim to reduce pilot workload. This aspect is again confirmed in [156]. Some single engine helicopters also utilize see-saw rotor types which lead to a tighter flight envelope and hence require more pilot attention for not violating the envelope with respect to, e.g. low gravity maneuvers. However, HEMS providers in USA use increasingly single engine turbine helicopters, see Fig. 28. From a safety point of view, this trend seems to point into the wrong direction. However, twin engine helicopters and especially modern ones with improved pilot assistance systems to reduce pilot workload, see EC145 T2 or AW109S DaVinci, are more expensive than single engine ones, but reimbursement of the operator remains the same.

Besides these general analyses of helicopter accidents and some remarks on HEMS given above, dedicated studies on HEMS accidents and safety have been conducted like [155] and [157] in the US and have been quoted already occasionally above. In [155] 146 HEMS-related accidents that occurred in the period from 1998 till 2008 were analyzed. Ref. [157] is a summary of various EMS aircraft accident reports published before 2002. A first report was published already in 1988 by the NTSB on EMS accidents (59 accidents analyzed that occurred from May 11, 1978 till December 3, 1986), but is not further quoted below. This report issued 19 safety recommendations to FAA which were turned into an advisory circular for FAR Part 135[14] HEMS operations.

A second report was released by the NTSB in 2006, investigating 41 HEMS aircraft accidents (helicopter and airplane) that occurred between January 2002 and 2005.

[14] Regulations allowed US HEMS operators to conduct work under FAR Part 135, Commercial Aviation Operations, or under Part 91, General Aviation Operations. Flights with patients on board have to be performed under Part 135, but without patients on board they were allowed to be operated under Part 91, which is less stringent than Part 135 [160]. The latter rule has been aggravated in-between, see below.

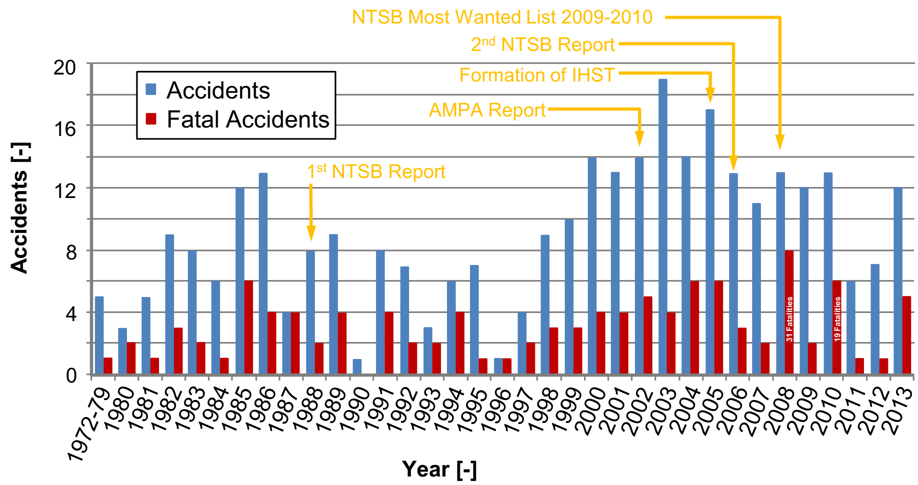


Fig. 41 HEMS accidents in USA. Adopted from a graphic for accidents and fatal accidents provided by I. Blumen

These 41 accidents caused 39 fatalities [160]. In this report, the NTSB expressed its concern, since the above-mentioned advisory circular had not been widely adopted by HEMS operators.

The reason for all these reports becomes evident from Fig. 41. This figure shows the recorded US HEMS accidents and fatal accidents from 1972 till 2013. They sum up to 315 accidents since the introduction of HEMS programs in USA of which 112 resulted in at least one fatality. In total, 941 persons were involved on board the crashed helicopters, 305 of them died. Two maxima in the fatal accidents statistics are clearly visible, the first in 1985 and the second in 2004/05. After a decline in 2006/07, another peak occurred in 2008 exceeding all other values before. In 2008, 31 people died in HEMS accidents, 19 people in 2010 [109]. Therefore, the NTSB put particular the improvement of EMS flight safety on its “Most Wanted List 2009–2010”.

Of the 146 accidents analyzed in [155], 49 (i.e. 34 %) were fatal. Probable causes were related in 77 % to human error (e.g. weather related causes or collision with objects). Mechanical problems were stated with 17 %. The remainder comprises other problems or undetermined causes. The collision with objects category included 33 in-flight collisions with objects (3 fatal) and 21 CFIT accidents (19 fatal). Weather related accidents accounted for 19 % of the accidents and result in 56 % of all cases in fatal accidents. In principal, this finding is being confirmed by a study quoted in [157]. Here, 107 EMS rotorcraft accidents that occurred from 1978 to 1998 were analyzed. Pilot error (weather, spatial disturbance, hit obstacle, loss of control etc.) caused 69 accidents (about 64 %), mechanical problems (engine, flight controls, improper maintenance) were identified for 26 accidents (about 24 %). The remainder could not be specified. The highest cause for accidents and especially fatal accidents in one category was related to weather: 23 accidents of which 17 were fatal. These 17 fatal accidents resemble 40 % of all fatal accidents. According to [157], weather related difficulties in flight can result in general in CFIT, loss of control, and collision with obstacles. In another study outlined in [157], 25 HEMS accidents were analyzed that were related to collision with objects. The majority of 64 % of these accidents occurred during primary rescue missions at or near the landing zone. Nine out of these 25 accidents were related to wire strike. Wires were mentioned to be the most common objects with which helicopters collide. Although not specifically related to HEMS, findings in [156] with respect to the category collisions with objects shall be briefly quoted. Here, about 16 % of all analyzed accidents were related to this category, whereas collisions with wires, poles and tress were the dominating causes. The above quoted statistics did not consider multiple reasons for a crash as for Fig. 40.

Finally, it should be mentioned that 49 % of the HEMS accidents analyzed in [155] happened during night. Of the 27 fatal HEMS accidents mentioned, in [160], for the period from 1998 till 2004, 21 occurred during night operations, just six during day operations. However, since NVGs have been introduced to the US HEMS market and many operators utilize these devices in-between, see Table 5, this number might have gone down for recent years.

The fatality rate of dedicated HEMS crews in comparison with other occupations is shown in Fig. 42. The figure is based on the above-mentioned HEMS accident analysis [155]. These 146 accidents caused 131 fatalities of which 105 were dedicated HEMS crew members, 6 dual-purpose helicopter[15] crew members, 16 patients and 4 others fatalities. The fatality rates of the other occupations are based on a statistic of 2007. Even if the numbers for the

[15] Dual-purpose helicopters in the US are helicopters combining dedicated EMS with other services. This differs from the definition given above.

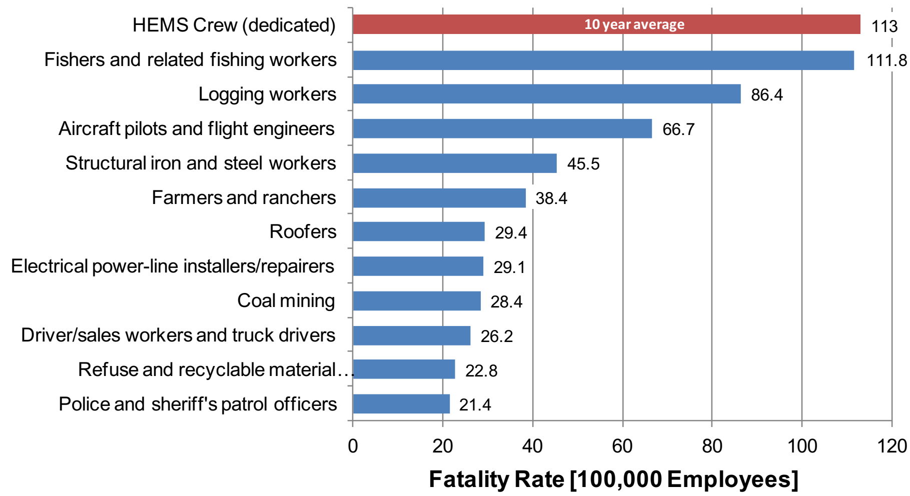


Fig. 42 Fatality rates of various occupations in USA. Source: [155]

dedicated HEMS crew is averaged over a period of 10 years, HEMS crew members show the highest fatality rate of all occupations in USA. This is confirmed by [157].

Besides the tragedy of lives lost, it should be mentioned, that accidents cause as significant financial burden. Based on 1991 Dollars, each accidents costs about $1,000,000 in average [156].

Motivation to reduce accidents, may it be for helicopters in general and HEMS in particular, is more than high. Five typical HEMS accidents are outlined in [160] to provide examples of the safety issues involved. Following the various accident analyses, of which some have been quoted above, recommendations were released in various reports to improve helicopter safety in general. The HEMS industry would benefit from such improvements. Such recommendations predominantly focus on training/instruction (e.g. advanced maneuver training, safety training or mission specific training), data/information (installation of cockpit and data recording devices, satellite monitoring), and safety management interventions (e.g. risk assessment, awareness of accident causes, or standard operating procedures for pilot and management). The training/instruction aspect is, e.g. directly addressed by ADAC's HEMS Academy, an integrated training center for helicopter pilots, emergency doctors and rescue paramedics in air rescue services. From an aircraft design point of view, especially the recommendations related to systems and equipment are interesting. They can be summarized on an upper level as situational awareness enhancers, cockpit indication/warning or post-incident survivability. Locking into more detail, the situational awareness enhancers comprise recommendations for NVGs, HTAWS, radar altimeters tail rotor strike protection, rearward cameras, proximity detection systems, wire detection systems, auto hover recovery function, etc. The cockpit indicator/warning includes recommendations for external load meters, low rotor speed warning, hover drift indicators, power available versus power required indicator, etc. For the post-incident survivability, especially crash-resistant fuel tanks seem to be of importance. Further aspects include shoulder harness for all occupants, emergency locator transmitters or personal location devices (e.g. emergency position-indicating radio beacon) [147, 151].

Even further go the clues given on safety equipment in [156]. Here, a low price "spherical cocoon" sensor suite with audio warning about wires, poles, and trees is mentioned to enhance safety. Another recommendation addresses low cost flight control systems, first to improve yaw damping and maybe even heading hold. Later further axes could be addressed. A suggestion pointing far in the future is to replace current flight control systems with technology utilized in unmanned aerial vehicles.

In response to the high number of helicopter accidents in general and HEMS accidents in particular, FAA has implemented a new rule to improve helicopter safety on April 22, 2014, [161]. Indeed, this rule was initiated by the recommendations given in [160]. Some of the requirements shall be mentioned here. Within 60 days, all US helicopter operators were required to use enhanced procedures for flying in challenging weather, at night, and when landing in remote locations. All Part 135 helicopter operators were required to fit their helicopters with radio altimeters and for offshore operations with emergency locator transmitters. Furthermore, pilots should be tested to handle flat-light, whiteout and brownout conditions, etc. Part 135 air ambulance helicopters operators are now required to conduct flights with medical personal on board under FAR Part 135. Part 135 air ambulance operators need to equip their helicopters with HTAWS within 3 years and flight data monitoring systems within 4 years. Operators with 10 or more EMS helicopters shall establish an operations control center. HEMS pilots should hold an instrument rating.

EHEST has recently published a report on technologies that have the potential to reduce the number of accidents [162]. From a research and development point of view, this report contains both, technology that is mature and ready for integration in aircraft, but also technology that is more pointing into the future. The latter is by nature less mature, but has the potential to even more prevent accidents. The five most promising technologies of the first category are: enhanced ground proximity warning systems/HTAWS, digital range image algorithms for low-level guidance aids for helicopter low-level flight (i.e. set of algorithms for terrain following or contour flights computing a reference contour line to prevent CFIT or wire strike etc.), digital moving maps, laser radar obstacle and terrain avoidance systems (see e.g. HELLAS, Fig. 12), deployable voice and flight data recorder (recorder get deployed shortly before the crash to prevent it from being buried within the wrack). The first four technologies primarily aim to improve SPS pilot situational awareness, the first three also pilot judgment and actions. Except for the second, the other three address SPS mission risk, too. The fifth technology targets SPS part system failures, maintenance, and regulatory. These suggestions agree reasonably with the above technologies required by FAA, but even go a step further. In addition to these technologies suggested by EHEST, technologies are listed, which are not mature enough for utilization in helicopters yet, but are very promising. Among these technologies are such that incorporate several sensors (based on different technologies e.g. laser, radar, cameras) and fusion of the sensor signals. These data then can be used for enhanced or synthetic vision, but also for collision-free flight path computation for display (e.g. tunnel in the sky). In the far future the latter aspect can be also used to fly segments of the flight path or even the whole flight path partly or even fully automatically. Another listed technology concerns helicopter slung load stabilization or high resistant helicopter windshields. In all three fields, DLR is active.

Quite astonishingly, none of the recently published recommendations quoted above mention sophisticated flight control systems as one aspect to reduce pilot workload. The only exception is [156]. However, in military norms like ADS-33, the usage of higher control modes is outlined as an important solution to guarantee excellent handling qualities even in deteriorating vision cues.

6 Conclusions and outlook

The presented paper has outlined the motivation and origin of civil HEMS. Last year, aeromedical evacuation by helicopter celebrated its 70th anniversary. Today, a modern society with a high standard in health care cannot be imagined without HEMS. The origins of HEMS lie in military AE, although HEMS was in many countries later on also motivated by civil needs, e.g. the high number of traffic fatalities in Germany or USA. The tremendous benefits of HEMS have been outlined at the end of Sect. 2 and in Sect. 3, and cannot be better summarized as by one more quotation of Igor Sikorsky: “It would be right to say that the helicopter’s role in saving lives represents one of the most glorious pages in the history of human flight.” [163].

As outlined in Sect. 3, the EMS helicopter market is steadily increasing. Very many Nations have established effective HEMS programs as part of their national health care system like Switzerland, Japan, USA, Germany or many others. Today, HEMS is among the four largest applications for civil helicopter utilization. In the future, this could even be increased. New markets emerge like in Asia or even in Europe and for countries that feature already well established HEMS systems, still new operators show up to offer EMS by helicopters or simply new stations are set up by established operators to cover areas, which have not been covered before as in Japan and especially in USA. For other countries like Switzerland or Germany, there are already very advanced HEMS systems in operation and the market for new stations has almost reached a saturation. This holds true, if no further assignments are delegated to HEMS that may derive from further mission scenarios. Nevertheless, especially the operators in these latter mentioned countries have a continued demand for modern helicopters like REGA, ÖAMTC, ADAC, or DRF Luftrettung.

New HEMS applications as discussed with respect to the PrimAir project or offshore rescue missions as outlined within the context of German HEMS may be such new assignments. Such missions require new EMS helicopter designs or enhanced capabilities like full 24 h all-weather operation. Such scenarios could further increase the demand for new EMS helicopters, featuring better technical equipment, but probably even new designs.

From a technical point of view, modern helicopters still suffer in general from many problems that limit their efficiency and acceptance in the public. Limited speed, range, and high noise levels are reasons for this. The high level of vibrations furthermore aggravates this situation. Vibrations are problematic for crew and passengers, but also give rise to an increase in maintenance costs. Another drawback of helicopters is their high fuel consumption in high-speed forward flight. This further increases operating costs. Motivation for improving helicopters or even EMS helicopters with respect to noise and safety might come more and more from governmental side. References [2, 141 or 161] might be first clues for such requirements on noise and safety. Requirements for vibrations have been established for military helicopter in ADS-27A, for civil helicopter there are no comparable standards, but the European Directive 2002/44/EC of the European Parliament defines vibration requirement which might be extended in the future also on aircraft.

The increasing HEMS market and further fields of operation resulting from newly emerging missions offer tremendous chances for the helicopter industry and research establishments. Especially manufacturers with a more civil orientation of its products could benefit when compared to helicopter manufactures that focus more on the military market. As pointed out in [139], the global defense market will decrease from just under $20 billion today to $14 billion in 2019. This corresponds to a drop of 30 % after the military market has increased within the past 10 years from $4.3 billion in 2004 to the mentioned $20 billion (all numbers in 2014 values). In contrast the civil market might compensate that loss of defense market. After an increase from $3.1 billion in 2004 to $7.8 billion in 2008 and a cutback during the global economic crises it is estimated, that the value of all new produced helicopters will recover to a value as high as $8.3 billion this year. In 2019, however, this value might peak at $11.2 billion in 2019. And EMS helicopters will form a large part within that civil growth. All this should be motivation for industry as well as research establishments to focus research and development on EMS rotorcraft designs that are no longer multi-purpose helicopters as shown in Sect. 4, but specifically tailored for HEMS needs.

This background and the tremendous benefit of EMS helicopters to the public have motivated DLR to focus civil research on a particular lead concept called the "Rescue Helicopter 2030". It is one out of six lead concepts (two on fixed wing aircraft, one on unmanned freighter aircraft, one on air traffic management and one on virtual aircraft technology). In this context, a lead concept is being defined as an integration platform, which aims to focus DLR's civil institutional aeronautic research across technical disciplines and institutes on a product. This shall establish and maintain the premise for an evaluation capability and hence a systemic innovation skill at DLR.

The idea of the lead concepts is being visualized in Fig. 43. First, components and technologies will be developed in the course of the lead concept. These components or technologies then will be integrated into the helicopter, and their impact on the overall aircraft than needs to be analyzed. The improved aircraft finally needs to be integrated within the air transport system. An example, illustrated in Fig. 43 might explain this philosophy better: One possible technology for the "Rescue Helicopter 2030" is the usage of new sensors and sensor fusion technologies for enhanced/synthetic vision or different levels of flight path automation. Main purpose of such a technology would be to improve the flight envelope beyond today's limitations (e.g. VFR limitations). Next, this technology will be integrated into DLR's Active Control Technology/Flying Helicopter Simulator (ACT/FHS). Flight tests than shall demonstrate impact on pilot workload, handling qualities etc. Finally, it needs to be discussed, how EMS helicopters could benefit from such technologies. It would be e.g. of interest how the VFR requirements could be attenuated and which certification requirements need to be fulfilled to benefit from such technology. This research chain will be accompanied by DLR's research infrastructure (e.g. test stands, ground-based simulators), tools (computational capabilities), and procedures (e.g. certification process for getting a permit to fly).

Some of DLR's computational capabilities and large-scale facilities that will be used within this lead concept are shown in Fig. 44. The list is, however, not complete, and aims to depict DLR's know-how in the field of rotary wing

Fig. 43 Research idea of the lead concept "The Rescue Helicopter 2030"

aircraft. Shown are (1) pre-design capabilities for layout of various rotorcraft concepts; (2) noise optimization capabilities of blade profiles, tips, flight path etc.; (3) rotorcraft interactional aerodynamics including comprehensive and computational fluid dynamics; (4) sensor data fusion and helmet mounted display for pilot assistance; (5) EC135 ACT/FHS with fly-by-wire/fly-by-light control system, experimental system to run various experiments, sensors suite, active side sticks, etc.; (6) air vehicle simulator including fixed and motion base; (7) rotor test stand for model scale wind tunnel test of whole rotary wing aircraft; (8) transonic wind tunnel and blade segment test stand for unsteady airfoil measurements; (9) crash test stand, and (10) microwave autoclave symbolizing manufacturing know-how especially for composite materials, etc. Not shown are structural mechanics and dynamics capabilities, know-how in aviation medicine, and finally know-how in physics of the atmosphere.

DLR has set up a definition project, which aims:

(i) to analyze the status quo of HEMS, which countries run HEMS systems, what are the specific characteristics of the various HEMS systems, and are there imperfections in the systems that could be addressed in the lead concept "The Rescue Helicopter 2030" (see Sect. 3),

(ii) to work out, what are coming missions in 2030 which are currently not served by HEMS and have not been captured by (i),

(iii) to find out, what are the technological drivers to develop new EMS helicopters, and what are the needs,

(iv) to define a set of requirements for the "Rescue Helicopter 2030",

(v) to identify, which technologies with respect to the "Rescue Helicopter 2030" should be explored in more depth, and which rotorcraft configurations might be suitable for an identified reference mission in 2030.

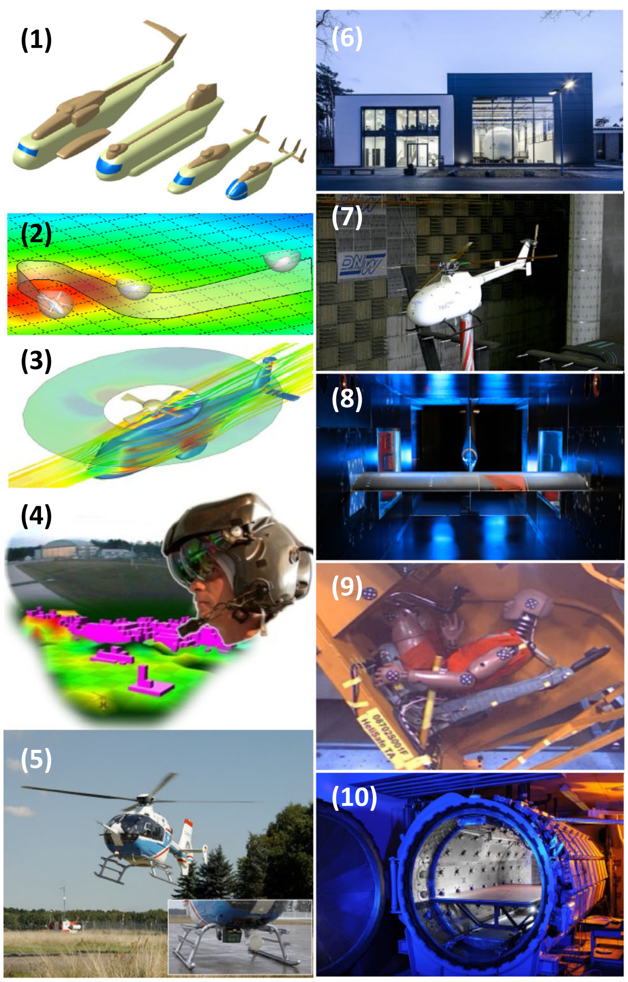


Fig. 44 Computational capabilities and large-scale test infrastructure at DLR

A major step within this definition phase is to select a reference mission 2030. Talks with HEMS operators and manufacturers have been conducted to address this question. As a result of these talks and the descriptions given in Sect. 3, two scenarios are currently discussed in more detail which also have been mentioned above: the first is motivated by the PrimAir idea and would comprise somewhat larger flight distances than covered today, and true all-weather capability including, e.g. icing, and increased number of flights per day. This would include the prediction of local weather phenomena, since there will be certainly a tradeoff between hazards caused by weather phenomena and economic aspects. Special attention would have to focus on fatigue problems of especially pilots during shift service. The second scenario would be one requiring flights over longer distances at much higher speeds than today. This might be motivated by offshore scenarios or simply by the need to provide residents in remote areas with HEMS as for example in rural areas in USA, Canada, China etc. A third scenario might become of higher interest in the future and would require needs opposing the ones for the second scenario: short distances but obstacle rich environment. This could fit to HEMS in mega-cities as they emerge in increasing numbers in Asia. However, such a helicopter-based rescue system would be in strong competition to ground-based solutions. Helicopters would only be beneficial, if in such cities traffic problems could not be sufficiently solved.

With the end of the above-mentioned definition phase, a project phase will be initiated which first addresses predesign of a rotorcraft configuration according to the requirements set up in (iv) and for the chosen reference mission 2030. This step will be limited to helicopters and

Fig. 45 Banner in Germany "Stroke? Please wait … Ambulance Car has to take a detour. Please be appreciative."

hybrid concepts like compound helicopters as mentioned in the introduction, since other concepts can be excluded due to cost and compactness constraints [164]. The data base presented in Sect. 4 will suit as a base, but may have to be enlarged, if necessary. Secondly, for the pre-designed configuration, the technologies identified under (v) will be investigated in detail, e.g. new blade designs for excellent hover capabilities and high-speed performance, low vibrations, and noise level to mention just one technology. These technologies will be matured in the course of the project till demonstration on test stands, some of them even in flight.

The duration of both phases totals 10 years. This shall allow sufficient maturation of ideas and technologies, before results are being handed over to industry, operators and other stakeholders.

Today, the rescue systems in every country, even the ones with excellent health care systems, still have gaps. This is illustrated by Fig. 45. The banner, seen in a small village in Germany, illustrates worries of the residents to be excluded from rapid medical supply due to a problem preventing ground-based EMS from taking the fasted route towards the village. If weather permits, rescue helicopters could prevent severe consequences for the patients. Especially in case of a stroke rapid medical care is the key to a full recovers of the patient. DLR's lead concept the "Rescue Helicopter 2030" aims also, to fill such gaps.

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Comments

Where possible, English literature has been quoted. However, much of the literature on German and Swiss HEMS have not been published in English and it was not always possible to refer to international publications. The author is aware, that the quotation of web pages bears some problems. Web pages may be withdrawn ore may contain unproven content. Regardless this issue, some web pages have been included in the literature list. The contents of each web pages has been cross-checked with other web pages to prove the quality of the quoted web page. The author felt that the reader might be interested to study also the quoted web pages and some material has simply not been published elsewhere except in the web.