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Oxygen System Installation Cited In Fire Aboard Bell 206L-3

The pilot was seriously injured, and the emergency medical services helicopter was destroyed, by a fire that occurred on the ground when the pilot repositioned a valve on a medical-oxygen cylinder. The accident investigation revealed deficiencies in the control, design, construction, installation and maintenance of medical-oxygen systems in helicopters operated in Australia.

FSF Editorial Staff

On May 2, 1997, a Bell 206-L3 LongRanger helicopter operated by Sunshine Coast Helicopter Rescue was flown from Rockhampton to Tartrus Station, both in Queensland, Australia, to evacuate the injured occupants of an ultralight aircraft that had been involved in an accident. In preparation for the return flight to Rockhampton, the pilot slowly opened the valve on the medical-oxygen cylinder installed in the baggage compartment.

The pilot recalled that, after opening the valve, he was blown violently from the helicopter onto the ground. He received damage to his left lung, internal bruising and a punctured eardrum. The helicopter was destroyed by fire.

The Australian Bureau of Air Safety Investigation (BASI), in its final report on the accident, said that the blast was caused by a fire that ignited in the high-pressure flexible hose between the oxygen-system regulator and the oxygen-pressure gauge.

The investigation revealed the following significant factors:

- "There were no regulatory controls or guidelines concerning medical-oxygen systems for use in Australian-registered aircraft;
- "The level of knowledge within the Australian aviation industry of medical-oxygen-system design standards, operation and hazards was low;
- "The design of the oxygen system was inadequate, and inappropriate components were used; [and,]
- "The oxygen system had not been adequately cleaned."

The Australian Civil Aviation Safety Authority (CASA) published information and guidance on the design and installation of supplemental-oxygen systems. The information and guidance, however, did not apply to medical-oxygen systems.

"CASA had no involvement in the [installation of medical-oxygen systems] other than the requirement that an authorized person holding approval for design of modification or repair under Civil Aviation Regulation (CAR) 35 approve the installation," said the report.

The operator purchased the helicopter in 1995 and equipped it for emergency medical services (EMS) operations. A medical-oxygen cylinder, which was the same type commonly used in automotive ambulances, was installed behind the cabin in the forward upper corner of the helicopter's baggage compartment.

"The oxygen cylinder was installed in accordance with Engineering Order HEO-18, which was purchased from a CAR 35 delegate," the report said. "The order specified the method of mounting the oxygen cylinder inside the cargo compartment at the rear of the helicopter. … The engineering order contained no other detail concerning the design or plumbing for the system.

"However, the general notes concerning the system installation stated that the system was to be installed in accordance with the standard procedures of a major industrial gas company."

The aircraft maintenance technician who supervised the installation of the oxygen system told the operator that he did not have the expertise to install the system himself; the operator hired a medical-plumbing contractor to perform the installation.

The contractor installed a copper line between the oxygen-pressure gauge in the cabin and the high-pressure outlet on the regulator mounted on the oxygen cylinder.

"The medical-plumbing contractor stipulated that the copper line be replaced at every 100-hour inspection of the helicopter," the report said. "This was because the line could develop cracks due to fatigue, as a result of either bending during cylinder removal/replacement or movement during service.

"To overcome this difficulty, the helicopter-maintenance organization asked the medical-plumbing contractor to provide a flexible hose that could remain in the helicopter as a permanent fixture."

The copper line was replaced with a flexible hose in March 1997.

"The flexible hose supplied was an industrial-brand thermoplastic hose of 3/8-inch (9.5-millimeter) inner diameter, consisting of two steel-braid sheaths, polyester lines and cover," the report said. "The oxygen system was not cleaned [when the flexible hose was installed], nor had it been cleaned previously.

"No other maintenance was conducted on the system up to the time of the accident, other than routine cylinder replacement."

Postaccident examination of the helicopter's medical-oxygen system revealed the following:

- "[An] oxygen fire was initiated in the high-pressure flexible hose situated between the oxygen-system regulator (in the rear baggage compartment) and the pressure gauge (in the helicopter cabin);

- "Although the exact cause of the ignition was not established, particle impact or rapid compression of gas within the flexible hose were likely factors, with particle impact being the more likely [factor];

- "The design of the oxygen system was not consistent with best design practice for high-pressure oxygen systems. In particular, the use of a long polyester-lined nonmetal flexible hose, rather than a Teflon-lined hose, running to a dead end (the cabin-mounted gauge), was inappropriate;

- "The adapter connecting the flexible hose to the regulator system appeared to be of poor quality. Fissures in the inner surface of the adapter would have made thorough cleaning of this component difficult. This may have contributed to the ignition within the hose; [and,]

- "All other parts of the fixed oxygen system were suitable for use with oxygen, and there was no evidence that they contributed to the ignition."

Discussions with EMS helicopter operators in Australia showed that they had limited knowledge of the hazards associated with oxygen systems.

"While most were aware of the dangers posed by oil and/or grease, and of the necessity to open valves on oxygen cylinders slowly, there was little other knowledge," the report said. "Only a few of these operators had in place written instructions concerning system operation, maintenance or cylinder-changing procedures."

The operators also showed little awareness of information regarding the design and installation of medical-oxygen systems that was available from sources outside Australia, such as the U.S. Federal Aviation Administration (FAA) and the American Society for Testing and Materials (ASTM).

"Of particular interest to this occurrence are [FAA Advisory Circular (AC)] 43.13-2A [*Acceptable Methods, Techniques and Practices (for) Aircraft Alterations*] Chapter 6, 'Oxygen System Installations in Nonpressurized Aircraft,' and AC 135-14A, *Emergency Medical Services/Helicopter*," said the report.

AC 27-1A, *Certification of Normal Category Rotorcraft*, contains information that supplements the information in AC 43.13-2A.

ASTM has published the following information on oxygen-system design:

- *G-88 — Standard Guide for Designing Systems for Oxygen Service*;

- *G63 — Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service*;

- *G94 — Standard Guide for Evaluating Metals for Oxygen Service*; and,

- *G93 — Standard Practice for Cleaning Methods for Material and Equipment Used in Oxygen-enriched Environment*.

The report said, "A U.S. manufacturer of oxygen systems listed its criteria for medical-oxygen systems as:

- "Oxygen bottles are no longer removable for filling. A fill bottle or cart is taken to the aircraft. This lowers the possibility of leaks developing due to repeated loosening and tightening of the regulator assembly;
- "No high-pressure oxygen is ever routed to the passenger compartment. Transducers are utilized for oxygen-quantity monitoring with digital quantity gauges in the medical area;
- "Soft or flexible oxygen lines are no longer used. Hard metal lines should be used throughout the aircraft on permanently installed items;
- "Blowout pressure protection is provided at the fill port to protect against overcharging;
- "Separate analog gauges are provided on each bottle for filling purposes;
- "A mechanical, positive shut-off cable is located in the cabin area to provide positive shut-off at the bottle in the event of an oxygen fire; [and,]
- "A fill-port flow limiter is installed in line with the oxygen bottles to prevent heat buildup from filling too fast."

The manufacturer said, "All of these features add to the cost of medical systems, but oxygen is a very dangerous gas to deal with in a closed environment like a helicopter, and we feel every precaution should be taken."

Oxygen is nonflammable but will support the combustion of most materials when sufficient heat exists for ignition. One source of ignition is contamination particles, which can be accelerated to sonic velocities in high-flow portions of an oxygen system.

"The reactivity of oxygen increases with increases in pressure," the report said. "At very high pressures, it becomes extremely reactive. The successful design, development and operation of a high-pressure oxygen system require special knowledge of materials, design practices, testing, manufacturing and operational techniques."

The medical-oxygen systems in some EMS helicopters operated in Australia were installed according to FAA supplemental type certificates issued in the United States.

"These systems were apparently fitted in the [United States] before the helicopters were brought to Australia, and their design and construction appeared to accord with best industry practice," the report said. "For example, hard metal tubing was used throughout, cylinders were not removable but were refilled 'in situ,' and an emergency shut-off valve was positioned in the cabin. Systems fitted in other local aircraft had deficiencies similar to those identified in [the accident helicopter]."

The report said that the investigation revealed significant deficiencies in the control, design, construction, installation and maintenance of aircraft medical-oxygen systems in Australia.

"The lack of specifications and requirements at the regulatory level resulted in the CAR 35 delegate and the helicopter owner deferring to nonaviation industrial sources for guidance and expertise," the report said. "As a result, the design and construction of the oxygen system in [the accident helicopter] did not meet international aviation industry best standards in a number of areas.

"The absence of specific regulatory control for these systems within Australia may also have contributed to a culture within the industry which did not place an appropriate level of importance to design standards for, and hazards associated with, these systems.

"There was appropriate information available from overseas sources on medical-oxygen systems in aircraft. However, the level of awareness of this information within the local aviation industry was low."

Based on these findings, BASI made the following recommendations to CASA:

- "(i) Conduct an audit of all [EMS] oxygen-equipped aircraft to determine the equipment standards in Australian-registered aircraft;
- "(ii) Issue design standards for [EMS] oxygen-equipment installations;
- "(iii) Issue maintenance requirements for [EMS] oxygen equipment;
- "(iv) Provide surveillance requirements for [EMS] oxygen equipment in the Aviation Safety Surveillance Program [ASSP];
- "(v) Ensure [that] flight crew are provided with appropriate instructions in the use of [EMS] equipment in aircraft flight manuals or company operations manuals; [and,]
- "(vi) Provide educational material to the aviation industry on the installation, operation and maintenance requirements of [EMS] oxygen systems."

On Aug. 6, 1998, BASI received the following response from the director of CASA:

> "This incident has clearly revealed some deficiencies in current CASA procedures regarding medical-oxygen systems used in aircraft. These deficiencies require correction.

"[Regarding recommendations ii and iii,] role equipment, such as that installed in EMS aircraft, is installed on the basis of 'no hazard, no interference.' There are at present two Australian standards [that] relate to oxygen systems: [Civil Aviation Order (CAO)] 20.4, *Provision and Use of Oxygen and Protective Breathing Equipment* [and] CAO 108.26, *Systems Specifications — Oxygen Systems.*

"Neither of these standards is directly applicable to EMS oxygen systems, addressing instead supplemental oxygen for high-altitude flight. However, [FAA AC 27-1A] contains a section on EMS oxygen systems. Unfortunately, this U.S. AC has no legal standing under Australian law.

"Thus, while much information is available, it is not clearly presented, is fragmented and, in some cases, is out of date. I therefore intend to expedite the [issuance] of a [civil aviation advisory publication (CAAP)] providing integrated design guidelines for this type of installation. This CAAP, expected to be issued by September 1998, will cover the design, installation and maintenance of [EMS] oxygen systems. [FSF editorial note: In August 1999, CASA said that a draft of the CAAP was being reviewed and that publication was pending.]

"[Regarding recommendation iv,] the ASSP program does not at present specifically address surveillance of aircraft internal-role equipment, such as medical-oxygen systems. This deficiency will be addressed, and the ASSP amended as necessary to include this type of equipment.

"[Regarding recommendation i,] because there is at present no readily available standard against which to audit existing EMS oxygen installations, and because very few CASA (or industry) people have the knowledge or experience of oxygen systems necessary to conduct such an audit, I do not believe that an audit is appropriate at this stage.

"[Issuance] of the CAAP and clarification of ASSP requirements are expected to have a beneficial effect, resulting in improvements and upgrading of existing systems. However, should routine surveillance reveal widespread problems or raise further concerns, additional action will be taken to overcome the problems.

"[Regarding recommendation vi,] CASA is planning to conduct an educational seminar in the latter part of this year involving CASA staff and industry personnel, including designers, operators and other interested parties. Your assistance in conducting this seminar would be much appreciated, including a presentation on this incident and the BASI finding. The CAAP will also assist in this regard.

"[Regarding recommendation v,] EMS systems are normally installed in aircraft as modifications, under the auspices of CAR 35. An important part of any such modification is the provision of the necessary amendments or supplement to the aircraft flight manual. The CAR 35 authorized person who approves the modification should ensure that such data are available and included in the modification package. This requirement will be reinforced in the CAAP."♦

[Editorial note: This article, except where specifically noted, is based entirely on the Australian Bureau of Air Safety Investigation's *Air Safety Report: Bell Helicopter VH-CHP, Tartrus Station, Qld, 2 May 1997*, Investigation Report 9701421, November 1998. The 40-page report contains color photographs, diagrams and an appendix.]

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