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16. Abstract

This report presents a summary of the history and events pertinent to the Civil Aeromedical Institute's evaluation of the feasibility of providing smoke/fume protective breathing equipment for passenger use, including research undertaken, reports produced, and responses to requests for information. The report covers a period of November 1965 to February 1987.

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SUMMARY REPORT OF THE HISTORY AND EVENTS PERTINENT TO THE CIVIL AEROMEDICAL INSTITUTE'S EVALUATION OF PROVIDING SMOKE/FUME PROTECTIVE BREATHING EQUIPMENT FOR AIRLINE PASSENGER USE

Introduction

As a result of several accidents involving turbojet airplanes (1), particularly the accident involving a B-727 at Salt Lake City in November 1965 (2), the attention of the aviation industry focused upon smoke and toxic gases as causal factors of passenger incapacitation and failure to evacuate an aircraft before fire and heat rendered the environment uninhabitable. Under these conditions, providing passengers with a short-duration supply of breathable air sufficient to accomplish evacuation would enhance chances of survival.

Initial Development and Testing of Passenger Protective Breathing Equipment (PPBE)

The Federal Aviation Administration's (FAA) Civil Aeromedical Institute (CAMI) instituted work on this accident hazard in November 1965, when Mr. E.B. McFadden, the Supervisor of CAMI's Survival Research Unit at that time, fabricated the first two prototypes of a passenger smoke hood.

Subsequently, prototypes of a simple, light-weight, protective, bag-shaped hood incorporating a neck seal were fabricated under contract by the G.T. Schjeldahl (now spelled Sheldahl) Company using special techniques and high temperature adhesives. They were made of DuPont Kapton--a thin, pliable, high temperature-resistant, transparent, polyimide, plastic film. Prototype designs incorporated: (1) rebreathing; or (2) ventilation provided by a controlled flow from small disposable compressed gas cylinders. The polyimide film used had no melting point, but exhibited a tendency to char when a temperature of 1500 F was attained. A simple rebreather-type hood was tested by human subjects with a natural gas flame enveloping the facial portion of the hood for short durations. Attempts were made to standardize and evaluate this type of test. Rebreather prototypes were also evaluated for carbon dioxide accumulation during rest and maximal work conditions.

To reduce the heat transmission and increase infrared reflectivity of the hood, 21 types of metalized coatings (various

thicknesses of gold, silver, and aluminum) were applied to polyimide film. These samples were evaluated for heat transmission, reflectance, and optical transmission.

Ten experimental hoods were constructed using a silver coating which would provide maximum infrared reflectance and, at the same time, permit maximum visual acuity. Eleven subjects instrumented with thermocouples were exposed to high intensity infrared radiation for a period of 8 minutes while wearing non-metalized and metalized smoke hoods. Facial skin temperatures of 114-115 °F were recorded from subjects wearing the non-metalized smoke hoods. Under identical conditions, skin temperatures of the same subjects wearing the metalized hoods did not exceed 99 °F. These and other evaluations of the capability of the hoods to provide short-term and extended protection from smoke and flame inhalation in a fire environment are discussed in an Office of Aviation Medicine (OAM) Report (3).

Evolution and Growth of PPBE Program at CAMI

On April 12, 1967, the FAA Office of Flight Standards (AFS-700) was directed to secure smoke hoods for installation on FAA-owned aircraft. Installation was completed on the FAA aircraft N-1 and N-3, on which the hoods were available and appropriate briefings on their use provided prior to each flight.

On April 13, 1967, by memorandum, the Director of the Office of Flight Standards (AFS-1) requested the Federal Air Surgeon (AAM-1) to forward all information available on development and testing of smoke hoods.

On August 2, 1967, AAM-1 forwarded a report to AFS-1 which contained the results of tests which CAMI had performed in June and July of 1967. The report also contained an analysis of the smoke hood research and development program, performance standards for a smoke hood, and the cost and availability of the devices tested.

During the summer of 1967, U.S. Representative Dingell became interested in our smoke hood studies, and in a letter to the FAA Administrator dated October 11, 1967, inquired about FAA plans for use of smoke hoods. On November 9, 1967, the FAA Administrator informed Mr. Dingell that more tests and evaluations of the hoods should be conducted. Prior to that

time, the FAA had testified at the U.S. House of Representatives' Brooks Committee (Government Operations Subcommittee) Hearings (April 26-27, 1966) on the potential of the hoods as an air safety measure.

In July 1967, evacuation tests were conducted to determine the reactions of a naive group of subjects to the use of the protective smoke hoods in the presence of smoke. A total of 124 subjects were tested in the CAMI evacuation facility. Test results indicated that the presence of smoke was the primary variable influencing speed of evacuation, since evacuations with smoke were much slower than those undertaken without smoke. The use of the hoods alone did not seem to have a significant effect on evacuation rate (4, Chapter 6).

Amendment 25-15 to the Federal Aviation Regulations (FAR) was adopted September 15, 1967. This amendment dealt with evacuation standards, exits, exit conspicuousness, emergency lighting, protection from smoke and fumes, and other crashworthiness components. As a result of these amendments on crashworthiness and passenger evacuation standards, the Aerospace Industries Association (AIA) established a Crashworthiness Research Committee. Boeing, Douglas, and Lockheed aircraft manufacturing companies participated in the research work, most of which was carried out at Boeing facilities in Seattle, Washington. In AIA's study, eight different types of PPBE's were tested. An evaluation of the reports (5,6) indicated that the most pronounced difficulty with all the masks and hoods was the lack of adequate seal against smoke and fumes. Either the neck seals were not properly tightened or (on the Boeing mask) the mouthpieces were not properly used. Lack of sufficient visibility was also a deterrent in some prototypes. Many subjects were observed lifting their hoods to provide better vision in the darkness. In a crash fire situation, evacuating passengers might be expected to do the same when loss of visibility resulted from smoke. If hoods are lifted, the air inside the hoods becomes contaminated by the external environment. The report emphasized that simplicity of the hoods motivated more of the subjects to use them. The AIA report concluded that the masks and hoods evaluated in their study were shown to be unsatisfactory. Use of these prototype devices in low illumination decreased visibility and slowed evacuation. The report also concluded that further development was required to produce a device that would be simple to use, effective in providing protection, and not increase evacuation time.

On December 14, 1967, AAM-1, at the request of AFS-1, asked the Director of the FAA's Aeronautical Center (AAC-1) in Oklahoma City to conduct a full scale evacuation test on a typical airline jet in which smoke hoods were incorporated. The AFS-1 request stated: "These tests are necessary in order that the operational aspects associated with utilizing the hoods are properly formulated with respect to agency emergency escape procedures."

The emergency evacuation tests were conducted at the Aeronautical Center on February 17-18, 1968, using an FAA B-720 which was equipped with interior seating similar to that used on Braniff's B-720. Sufficient seats were leased from Braniff to provide a seating capacity of 124 passengers. Four Braniff stewardesses served as flight attendants. Six emergency evacuation tests were run; and tests were conducted both with and without smoke hoods.

A report of the results of the emergency evacuation tests was forwarded to AFS in March 1968. The primary conclusion in that report was: "There are indications that the use of smoke hoods during an emergency evacuation of a typical air carrier jet aircraft causes a small increase (approximately 8%) in the overall time required for naive passengers to evacuate." (7) The recommendation of the report states: "It is recommended that further study of the data of these tests and AIA data be made to determine whether or not an unequivocal conclusion can be reached regarding the effect of using smoke hoods on evacuation time."

After observing the smoke hood tests on February 27-28, 1968, Mr. Dougherty (AFS-301) prepared a memorandum for AFS-1 signature which was sent to AAC-1 on March 4, 1968, requesting clarification on several aspects of the smoke hood evacuation program. On March 19, 1968, AAC-1 replied to this memorandum after coordinating with CAMI, whose input addressed optical transmission, neck seal leaks, duration of wearing hood, noise production by crackling plastic hood, and claustrophobia.

On May 8, 1968, a joint memorandum from AFS-1 and AAM-1 to AAC-1 requested further study of the Schjeldahl smoke hood, including neck seal fit; tests in a noxious environment; more definitive studies of visibility characteristics; the effectiveness of passenger briefings; the feasibility of providing supplemental air supply; effects on communications; evaluation of the AIA data; and passenger acceptance. On May 31, 1968, the Aeronautical Center replied, but emphasized that only non-toxic smoke should be used.

In May 1968, tests were conducted at CAMI to determine the effects of the smoke hood on the vision of human observers (4, Chapter 3). Two types of smoke hood materials were used: one without aluminization (Type S); and an aluminized hood with a clear band (Type D). It was determined that Type S hoods have optical transmissions of approximately 75-80 percent. There was an approximate five percent difference between the uncoated samples and the clear areas from aluminized samples, probably due to the coating used to protect the aluminized surface. Vision in emergency illumination was so reduced with aluminized hoods (Type D) as to make them unusable. Visual capacity was reduced significantly by wearing clear hoods under emergency illumination, but a 20-25 percent increase in the level of emergency illumination would compensate for the transmission loss through the non-aluminized hoods.

In June 1968, tests were conducted at CAMI to determine the extent to which the smoke hood acts as a barrier to the transmission of sound (4, Chapter 4). The tests showed that the hoods do not interfere with the transmission of sound waves. At most, the threshold shift is three dB at 5,000 Hz, an amount that is barely detectable.

On June 19, 1968, a second joint memorandum from AFS-1 and AAM-1 to AAC-1 requested further information on smoke hoods. A reply was sent July 8, 1968. A final report from the Aeronautical Center was issued October 22, 1968, which contained a compilation of several of the individual studies cited elsewhere in this report.

In September and October 1968, CAMI conducted tests to evaluate leakage in protective smoke hoods in a hydrocarbon environment. Ten subjects participated--five males and five females. They were tested at rest and exercising in normal room temperature (25.5 to 27 $^{\circ}$C) and at high temperatures (56.5 to 60 $^{\circ}$C). It was concluded that the wearer of a Type S hood with an elastic polyurethane neck seal (original neck seal was of a drawstring type) was given excellent fume protection (4, Chapter 1).

On December 6, 1968, a project report, "Project 2355 - Smoke Hoods," was issued by the FAA Flight Standards Technical Division (AFS-40) which recommended the drafting of a Notice of Proposed Rulemaking (NPRM) to require smoke hoods on operations conducted under Part 121 and 123 of the FAR in accordance with recommendations made within the report.

In December 1968, additional tests were conducted at CAMI to study the effects of variations in safety briefings upon use of protective smoke hoods (4, Chapter 5). Results indicated that changes in briefing procedures to give passengers first-hand experience with safety devices should be considered.

On January 11, 1969, NPRM 69-2, "Protective Smoke Hoods for Emergency Use by Passengers and Crewmembers," was published in the Federal Register.

Responses to the docket for NPRM 69-2 are summarized below:

Neutral:

1. National Transportation Safety Board (NTSB).
2. Experimental Aircraft Association.
3. Ms. Prioleau (requested that protection be provided for the whole body).

Supported the NPRM:

1. Sprague Electric Company - support with reservations.
2. Schjeldahl - support with some recommended changes.
3. Flight Engineers International Association.
4. Air Line Pilots Association - support for passengers only. Requested more sophisticated protection for crewmembers.
5. Arthur C. Smith.
6. Donald E. Hackett - supported concept, but felt it should be combined with passenger oxygen mask.
7. Ralph H. Dawson, Jr.
8. Ralph L. Creel.
9. Simpson Drag Chutes/Safety Equipment.
10. Mrs. Julia Loscalzo.

Opposed the NPRM:

1. Jesse L. Wallace - concerned about suffocation and that briefing demonstrations would cause children to put plastic bags over their heads.
2. British Aircraft Corporation (Operating) Limited- increase in evacuation time.
3. Air Transport Association - negative safety benefit due to increased evacuation time and insufficient oxygen resulting in suffocation.

4. Aerospace Industries Association of America, Inc. - 30% increase in evacuation time, insufficient oxygen, and insufficient testing.
5. Flight Safety Foundation - suffocation.
6. Air Line Stewards and Stewardesses Association- increase in evacuation time and limited useful time without air supply.
7. Air Line Dispatchers Association - could lead to disorientation.
8. Scott Aviation - hood should be equipped with source of compressed air.

On August 11, 1970, NPRM 69-2 was withdrawn by the FAA citing the principal reason that the hood might cause a delay in evacuation. After the withdrawal of the NPRM, interest in PPBE's declined. This decline, combined with commitments to other research requirements, greatly reduced the research effort in this area at CAMI.

In late 1971, a comprehensive report relative to smoke hoods was reviewed by several members of the National Research Council (NRC). They rejected the viewpoint that the carbon dioxide accumulation in the hood and the accompanying hyperventilation would produce sufficient discomfort to cause removal of the hood. They suggested absorption of the carbon dioxide and addition of a source of oxygen to the hood in order to provide extended usage. The feasibility of using a small chemical oxygen source was then investigated.

It appeared that any form of protective equipment acceptable to the airlines must include a life support system (oxygen or breathable air). Systems using the polyimide smoke hood developed at CAMI, comparable to the Westinghouse mine-rescue unit and developed under contract to the Bureau of Mines, appeared to be too bulky, expensive, complex, and in providing 1-hour continuous use, far exceeded the requirements for escape from post-crash fires.

In 1974, tests were conducted at CAMI to evaluate the use of a passenger oxygen mask in combination with a smoke hood (8). Tests were conducted at ground level; 8,000 ft; and 14,000 ft with flow rates of 4.2 L/min and 5.5 L/min.

After emptying the oxygen reservoir of the continuous-flow passenger mask, the air drawn in was from the uncontaminated, oxygen-enriched air in the hood. Carbon dioxide remained at

acceptable levels and subjects were protected from inward leakage. It appeared it might be feasible to bypass the altitude-controlled regulator to achieve those flows; however, reliability and maintenance would have, in all probability, been a major problem.

In June 1980, the Federal Air Surgeon approved a request from the FAA Technical Center for a Research, Engineering, and Development (RE&D) effort to examine cabin fire PPBE's for passengers. The request read: "Survival and escape of passengers in a transport cabin fire may be impaired or prevented by smoke and toxic gases. Advancements in protective breathing devices and limited progress in the minimization of cabin fire hazards prompted the SAFER Technical Group on Compartment Interior Materials to recommend a reassessment of protective breathing devices for usage by passengers aboard Part 25 aircraft. The study should include the following: (1) reassessment of smoke hood concept, including review of objectionable comments to FAA NPRM; (2) testing of presently available hood devices; (3) testing of concepts as developed by industry and/or CAMI; (4) testing or modified TSO-C64-approved passenger oxygen masks; and (5) testing of other applicable devices. Items (2) though (5) should consider: (a) a dual-purpose device for use during decompression and for smoke/fume atmospheres; (b) use during in-flight fires; and (c) fume protection during emergency evacuations."

From July to September 1981, eight different devices were tested (9). Of those, CAMI researchers felt that a passenger oxygen mask modified to incorporate a controlled-use rebreather reservoir in addition to, but separate from the oxygen reservoir, offered the best approach to achieve the desired objectives. This device required a flow of approximately 5 L/min of sustaining oxygen for 15 minutes. Most of the current in-use, passenger-activated oxygen systems, either compressed gas or chemical generators, deliver approximately 3.1 to 6.0 L/min. Some of the lower flows, therefore, would have required an increase to meet the 5 L/min needed flow rate. During the subsequent 2 years, work in PPBE at CAMI was reduced to meet increased commitments to studies of crew protective breathing equipment and water survival.

Following the Air Canada DC-9 accident at Cincinnati, Ohio, on June 2, 1983, interest in PPBE again increased.

The NTSB Safety Recommendation A-83-76 issued October 31, 1983, recommended that research be expedited at CAMI to develop the technology, equipment standards, and procedures to provide passengers with respiratory protection from toxic atmospheres during in-flight emergencies aboard transport-category airplanes.

The U.S. Senate Subcommittee on Aviation for the Committee on Commerce, Science, and Transportation hearings on cabin air quality during November 1983 included discussions related to fire safety and breathing devices for emergency use by passengers. The FAA was urged by Subcommittee Chairman Elliott Levitas to take measures to provide additional passenger protection. In response, the FAA Administrator pledged to re-evaluate occupant protection against smoke and toxic fumes and stated that the FAA planned to take action in many areas to improve survivability in the cabin. During these hearings, testimony indicated that segments of the aviation industry were also interested in and already promoting the development of PPBE.

The FAA's Office of Airworthiness established a Passenger Protective Breathing Assessment Committee composed of representatives from the Office of Aviation Medicine (OAM), the Technical Analysis Branch of the Office of Airworthiness (AWS), the Technical Analysis Branch of the Office of Flight Standards (AFS), the Systems and Equipment Branch of the Northwest Mountain Region (ANM), and CAMI. The first committee meeting was held January 26, 1984, to discuss current problems and possible solutions. On April 2, 1984, CAMI was requested by the Director, AWS, and the Federal Air Surgeon to initiate a priority program to evaluate the performance of a passenger mask with the following requirements: (1) modification by addition of a rebreather bag; (2) testing at flight altitudes typical of airline operation (8,000 ft); and (3) with information on total oxygen requirements when used at this altitude. The FAA Administrator set September 30, 1984, as the deadline for a definitive report from the committee. In August 1984, a preliminary report of the CAMI study was forwarded to AWS for incorporation into the committee report. The results indicated that the device functioned well when respiratory minute volume was low (resting), but did not function for eight of 10 subjects when minute volume was high (with exercise).

On August 29, 1984, the Aircraft Engineering Division of AWS issued a position paper, "Cabin Fire Hazard Analysis for

Evaluation of Passenger Protective Breathing Devices." The Conclusion stated: "The position taken by FAA in the September 27, 1983, letter to Chairman Levitas is sound. The improvements resulting from FAA regulatory actions obviate the need to mandate passenger protective breathing devices. The use of fire-hard panel construction for walls, ceilings, partitions, and cabinets, and fire blocking for seat cushions, greatly reduces, and in many cases, eliminates the inflight fire potential of the vast majority of materials used in the cabin. Smoke detectors provide early warning in the more vulnerable areas. Improved Halon 1211 hand fire extinguishers and crew protective breathing equipment provide a far more effective fire suppression capability and protection for those fires which might occur."

In September 1984, AWS-100 issued a staff study which included material from the Passenger Protective Breathing Assessment Committee and reiterated the material in the AWS-100 position paper. The study indicated that an effective, practical breathing device suitable for use in commercial airliner cabins to protect passengers had not been identified and that the above-mentioned cabin fire hardening proposals would reduce the need to further develop PPBE for passengers. The study recommended FAA evaluation for any devices developed by industry that appeared promising. If evaluation by FAA proved positive, the results could be used to develop criteria for Technical Standard Order (TSO) approval. In addition, it was recommended that FAA should continue to evaluate the need for PPBE and participate in industry-sponsored meetings (such as Society of Automotive Engineers (SAE) S-9 and SAE A-10 committees) to discuss protective breathing issues.

In September 1984, Scott Aviation requested that CAMI evaluate a new design of the passenger mask with rebreather bag. Accordingly, testing was conducted with the redesigned device. The device provided protection for those individuals who had tidal volumes of 1.5 L or less. However, it did not function properly for those whose tidal volumes exceeded 1.5 L, in that either the carbon dioxide levels were too great or the rebreather bag collapsed (10).

On January 22, 1985, the FAA Administrator replied to the NTSB concerning their recommendation (A-83-76 cited above) and reiterated the findings of the staff study cited above, again indicating that if industry developed suitable devices that showed promise, the FAA would evaluate them and develop criteria for their approval.

International Involvement in CAMI PPBE Program

Interest was again stimulated by the British Airtours B-737 accident at Manchester, United Kingdom, on August 22, 1985. At the request of Mr. E.J. Trimble of the Accidents Investigation Branch, Department of Transport, United Kingdom Civil Aviation Authority (CAA), a conference convened at CAMI on March 17-18, 1986, to discuss PPBE.

A joint effort by CAMI and the CAA to evaluate the potential for PPBE was initiated by the CAA, with participation by the FAA, Transport Canada, and the French Direction Generale de L'Aviation Civile (DGAC). The first meeting was held in England from September 28 - October 2, 1986. A second meeting was held in Ottawa, Canada, in mid-November 1986.

As part of this cooperative effort, CAMI undertook a study to evaluate workloads, oxygen consumption, carbon dioxide production, and respiratory exchange rates for passengers during an evacuation in an effort to define possible qualification standards for a protective breathing device. The results of this study (11) were presented to the Passenger Protective Breathing Equipment Workshop held at CAMI February 3-5, 1987. During this workshop the need for an historical record of these facts was established and resulted in this summary report.

Summary

This report presents a history of events pertinent to CAMI's evaluation of the feasibility of providing smoke/fume PPBE for passenger use, including research conducted, reports produced, and responses to requests for information. The report includes the period November 1965 to February 1987.

REFERENCES

1. Hasbrook, A.H.; Garner, J.D.; and Snow, C.C. "Evacuation Pattern Analysis of a Survivable Commercial Aircraft Crash." Office of Aviation Report No. 62-9, May 1962.

2. Snow, C.C.; Carroll, J.J.; and Allgood, M.A. "Survival in Emergency Escape from Passenger Aircraft." Office of Aviation Medicine Report No. AM-70-16.

3. McFadden, E.B.; Reynolds, H.J.; and Funkhouser, G.E. "A Protective Passenger Smoke Hood." Office of Aviation Medicine Report No. AM-67-4, April 1967.

4. McFadden, E.B. and Smith, R.C. "Protective Smoke Hood Studies." Office of Aviation Medicine Report No. AM-70-20, December 1970.

5. Aerospace Industries Association Crashworthiness Development Program - 2. "Evaluation of Smoke Hoods and Masks for Fire Suppression." July 1968.

6. Aerospace Industries Association Crashworthiness Development Program - 3, "Lighting and Exit Awareness." July 1968.

7. Wullenwaber, G.E. and Herndon, D.F. "Smoke Hood Evaluation Program." Flight Standards Technical Division Special Project Report No. 01271. March 1968.

8. deSteiguer, D.; Pinski, M.S.; Bannister, J.R.; and McFadden, E.B. "Aircrew and Passenger Protective Breathing Equipment Studies." Office of Aviation Medicine Report No. FAA-AM-78-4, pp. 34-43. January 1978.

9. deSteiguer, D.; and Saldivar, J.T. "An Analysis of Potential Protective Breathing Devices Intended for Use by Aircraft Passengers." Office of Aviation Medicine Report No. FAA-AM-83-10. May 1983.

10. Higgins, E.A.; Saldivar, J.T.; Lyne, P.J.; and Funkhouser, G.E. "Evaluation of a Passenger Mask Modified with a Rebreather Bag for Protection from Smoke and Fumes." Office of Aviation Medicine Report No. DOT/FAA/AM-85-10. October 1985.

11. Higgins, E.A.; Saldivar, J.T.; Lyne, P.J.; and Funkhouser, G.E. "A Study of Passenger Workload as Related to Protective Breathing Requirements." Office of Aviation Medicine Report DOT/FAA/AM-87/2. March 1987.