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

An Executive Summary

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

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.

The FAA's Civil Aeromedical Institute (CAMI) instituted work on the problem in November 1965, when Mr. E. B. McFadden fabricated the first two prototypes of a passenger smokehood.

Subsequently prototypes of a simple, light-weight, protective, bag-shaped hood incorporating a neck seal were fabricated under contract by the G. T. Schjeldahl* Company utilizing special techniques and high temperature adhesives. They were made of Du Pont Kapton, a thin, pliable, high-temperature resistant, transparent, polyimide, plastic film. Prototype designs incorporated: (1) rebreathing or (2) ventilation as provided by a controlled flow from small disposable compressed gas cylinders. The polyimide film used has no melting point, but exhibits a tendency to char when a temperature of 1500°F is 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.

In order to reduce the heat transmission and increase infrared reflectivity of the hood, twenty-one 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

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*Now spelled Scheldahl

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 hood did not exceed 99°F. These and other evaluations of the capability of the hood 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).

On April 12, 1967, FAA Flight Standards (FS-700) was directed to secure smoke hoods for installation on agency aircraft. Installation was completed on agency aircraft N-1 and N-3, where the hoods were available and appropriate briefings given prior to each flight.

On April 13, 1967, by memo, the director of Flight Standards (FS-1) asked the Federal Air Surgeon (AM-1) to forward all of the information they had with respect to development and testing of smoke hoods.

On August 2, 1967, AM-1 forwarded a report to Flight Standards which contained the results of tests which CAMI had undertaken 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 device tested.

During the summer of 1967, Congressman Dingell became interested in our smoke hood studies. In a letter to the Administrator dated October 11, the Congressman inquired about the FAA's plans relative to the use of smoke hoods. On November 9, 1967, the Administrator told Congressman Dingell that more tests and evaluations of the hoods should be conducted. Previously, the FAA had testified on the potentialities of the hoods as an air safety measure at the Brooks Committee Hearings, April 26-27, 1966, U.S. House of Representatives (Government Operations Subcommittee).

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. 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 Air Regulations (FARs) was adopted September 15, 1967. This amendment dealt with evacuation standards, exits, exit conspicuity, emergency lighting, protection from smoke and fumes, and other crashworthiness components. As a result of these amendments

on Crashworthiness and Passenger Evacuation Standards, the Aircraft Industries Association (AIA) established a crashworthiness research committee. Boeing, Douglas, and Lockheed participated in the research work, most of which was carried out at Boeing facilities in Seattle. In their study, eight different types of passenger protective breathing devices were tested. An evaluation of the reports (5,6) indicated that the most pronounced difficulty with all of 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 mouth pieces were not properly used. Lack of sufficient visibility was also a deterrent in some prototpyes. Many subjects were observed to lift their hoods to see better in the darkness. In a crash fire situation, evacuating passengers might be expected to do the same when the loss of visibility was caused by smoke. If hoods are lifted, the air inside the hoods would become 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. It 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, AM-1, at the request of FS-1, asked the Director of the Aeronautical Center (AC-1), in Oklahoma City to conduct a full scale evacuation test on a typical airline jet aircraft in which smoke hoods are incorporated. FS-1 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 27-28, 1968, utilizing 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. Four Braniff stewardesses served as flight attendants. Six emergency evacuation tests were run; tests were conducted both with and without smoke hoods.

A report of the results of the emergency evacuation tests were forwarded to Flight Standards in March 1968. The primary conclusion in that report is as follows: "There are indications that the use of smoke hoods during an emergency evacuation of a typical air carrier jet aircraft causes a small increase (approximatley 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 (FS-301) prepared a memo for the signature of FS-1 which was sent to AC-1 on March 4, 1968, asking for clarification on several aspects of the smoke hood evacuation program.

On March 19, 1968, AC-1 replied to the FS memo of March 4, with coordinated CAMI responses concerning optical transmission, neck seal leaks, duration of wearing hood, noise production by crackling plastic hood, and claustrophobia.

On May 8, 1968, a joint memorandum to AC-1 from FS-1 and AM-1 requested further study of the Schjeldahl smokehood, 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 provided a positive reply to that memorandum, 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 the other aluminized with a clear band (Type D). It was determined Type S hoods have optical transmissions of approximately 75-80 percent. There was an approximately 5 percent difference between the uncoated samples and the clear areas from aluminized samples, which was 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 3 dB at 5000 Hz, an amount that is barely discriminable.

On June 19, 1968, another memorandum to AC-1 from FS-1 and AM-1 requested further information in regard to smoke hoods. A reply to that memorandum was made July 8, 1968. A

final report from the Aeronautical Center was issued October 22, 1968 which contained a complilation of several of the individual studies, which are each cited elsewhere in this Executive Summary.

In September and October 1968 tests were conducted at CAMI 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°C) and at high termperatures (56.5 to 60°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 Flight Standards Technical Division (FS-40) which recommended the drafting of an NPRM (Notice of Proposed Rule Making) to require smoke hoods on operations conducted under Parts 121 and 123 of the FARs 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.

Below are summarized responses to the docket for NPRM 69-2:

Neutral:

1) The National Transportation Safety Board.
2) Experimental Aircraft Association.
3) A Ms. Prioleau who asked 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 - supports concept, but feels 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 the principal reason cited being that the hood might cause a delay in evacuation.

After the withdrawal of the NPRM, interest in passenger protective breathing equipment 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. 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 utilizing a small chemical oxygen sources was then investigated.

It appeared that any form of protective equipment acceptable to the airlines would have to 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, developed under contract to the Bureau of Mines, appeared to be too bulky, expensive, complex, and, in providing one-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 might be feasible to bypass the altitude-controlled regulator to achieve these flows, however, reliability and maintenance would, in all probability, be a major problem.

In June 1980 the Federal Air Surgeon accepted a request for an R, E, and D (Research, Engineering, and Development) effort from the FAA Technical Center for CAMI to examine cabin fire protective breathing devices 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 of modified TSO-C64-approved passenger oxygen masks; and (5) testing of other applicable devices. Items (2) through (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."

In July - September 1981 eight different devices were tested (9). Of the various devices tested, it was 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 about 3.1 to 6.0 L/min. Some of the lower flows, therefore, would have to be increased to meet the 5 L/min needed flow rate.

During the ensuing two years, work in passenger protective breathing at CAMI had to be reduced due to increased commitments to studies of crew protective breathing equipment and water survival.

Following the Air Canada DC-9 accident at Cincinatti on June 2, 1983 interest in passenger protective breathing equipment increased again.

The National Transportation Safety Board (NTSB) Safety Recommendation A-83-76 issued October 31, 1983, recommended that research be expedited at the Civil Aeromedical Institute 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.

Hearings during November 1983 on cabin air quality before the Subcommittee on Aviation for the Committee on Commerce, Science and Transportation, included discussions related to fire safety and breathing devices for emergency use by passengers. The FAA was urged by Chairman Elliott Levitas to take measures for additional passenger protection. The FAA Administrator, in response, pledged to reevaluate 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 also were interested in, and were promoting the development of passenger protective breathing devices.

The FAA's Office of Airworthiness established a "Passenger Protective Breathing Assessment Committee" with representatives from the OAM, Technical Analysis Branch of Airworthiness, Technical Analysis Branch of Flight Standards, Systems and Equipment Branch of the Northwest-Mountain Region, and CAMI. The first meeting was held January 26, 1984 to discuss current problems and possible solutions. On April 2, 1984 CAMI was requested by the Director of Airworthiness and the Federal Air Surgeon to initiate a priority program to evaluate the performance of a passenger mask, modified by the addition of a rebreather bag, at flight altitudes typical of airline operation (8000 ft), with information on total oxygen requirements when used at this altitude. The FAA Administrator had set September 30, 1984 as a deadline for a definitive report from the committee. In August a preliminary report of the CAMI study was forwarded to the Office of Airworthiness so that it could be incorporated in the committee report. Results indicated that the device functioned well when respiratory minute volume was low (resting) but did not function for 8 of 10 subjects when minute volume was high (with exercise).

On August 29, 1984, the Aircraft Engineering Division of the Office of Airworthiness (AWS-100) 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 above cited 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 protective breathing equipment for passengers. The study recommended FAA evaluation for any devices developed by industry that were shown to have promise. If the evaluation proved positive the results could be used to develop criteria for TSO approval. In addition it was recommended that the agency should continue to evaluate the need for protective breathing equipment, and that the agency should participate in industry- sponsored meetings (SAE S-9, SAE A-10 committees) to discuss protective breathing issues.

In September 1984 Scott Aviation requested an evaluation of 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. 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 recommendation A-83-76 cited above. He 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.

Interest was again stimulated by the British Airtours B-737 accident at Manchester on August 22, 1985. At the request of Mr. E. J. Trimble of the Accidents Investigation Branch, Department of Transport, U.K., a conference was convened at CAMI March 17-18, 1986, to discuss passenger protective breathing equipment (PPBE).

A joint effort to evaluate the potential for PPBE was initiated by the CAA, with participation by the FAA, Transport Canada, and the DGAC. The first meeting was held in England, Sep. 28 - Oct. 2, 1986. A second meeting was held in Ottawa in mid-November 1986.

As a 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. This study was undertaken 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 Feb. 3-5, 1987. It was during this workshop that the need for this summary was established.

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