National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: May 25, 2001

In reply refer to: A-01-14 and A-01-15

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20581

On April 29, 1998, about 9:00 p.m. central daylight time, a Douglas DC-8-51 cargo airplane, N507DC, was taxiing to take off at the Brownsville/South Padre Island International Airport in Brownsville, Texas, when all four occupants (three flight crewmembers and a jumpseat rider) became short of breath.[1] All occupants donned oxygen masks, and the captain taxied the airplane back to the ramp. The crewmembers and the jumpseat rider were transported to a hospital where they were examined and released. There was no damage to the airplane, which was registered to Agro Air Associates of Miami, Florida, and operated by Fine Airlines per contract with Burlington Air Express. Visual meteorological conditions prevailed, and an instrument flight rules flight plan was filed for the Title 14 *Code of Federal Regulations* (CFR) Part 121 nonscheduled cargo flight to Laredo, Texas.

According to documents provided by Fine Air, two shipments containing hazardous materials were loaded on the airplane, and the captain was made aware of the nature, quantity, and location of these items. One shipment consisted of 5,482 pounds of frozen shrimp packed in 198 packages with each package containing 4.85 pounds of dry ice, for a total of 960.3 pounds of dry ice. The other shipment consisted of 180 pounds of paint, a Department of Transportation defined flammable liquid. The packages containing the dry ice and the paint were located in the main cargo compartment.

Fine Air's Director of Training interviewed the flight crewmembers and reported that the first officer boarded the airplane first and was in his seat for about 30 minutes before engine start. The flight engineer arrived shortly after the first officer, and the captain arrived about 10 minutes before engine start. After the engines were started with an air start cart and the airplane was pushed back with a tug, there was an instrument failure on the first officer's side necessitating a return to the ramp. The engines were shut down, the electrical power cart was reconnected, and a mechanic boarded the airplane to assess the situation. After approximately 10 minutes, the problem was resolved and another engine start was initiated. During the engine start sequence, both sliding cockpit windows were open. The airplane was again pushed back for taxi, and the sliding cockpit windows were closed.

[1] Additional details are contained in the National Transportation Safety Board's narrative of incident FTW98IA196 available at <http://www.ntsb.gov/aviation/FTW/lnarr_98A196.htm>.

In written statements, the three flight crewmembers described the symptoms they experienced following the second push back. The captain reported that during the initial portion of the taxi, he "felt a few hot flashes and some heart beat increases. As [the] taxi proceeded, [he] began to feel short of breath, increased hot flashes." The first officer stated that during the taxi, he "started to feel very hot, and started to breathe very heavy. After a few moments [his] vision blurred and [he] started to see stars in [his] field of vision." The flight engineer reported that he "felt short of breath, and [his] chest felt tight." As the airplane neared the runway, the first officer told the captain that he did not feel well, and the captain acknowledged that he also felt ill. The flight engineer then said that he "felt the same way." The captain instructed the crewmembers to put on their oxygen masks, set them to 100-percent oxygen, and open both sliding cockpit windows for fresh air. After donning his oxygen mask, the flight engineer assisted the jumpseat rider in putting on his mask. The flight engineer reported that after putting on his mask, he "began to feel more alert." After taxiing back to the ramp, the flightcrew shut down the engines and exited the airplane. The captain stated that he needed help to exit the airplane and "felt dizzy." The flight engineer stated that "upon standing and walking, [he] felt dizzy."

At the request of an agent with the Federal Aviation Administration's (FAA's) Civil Aviation Security Office in Houston, Texas, all the airplane's doors were closed at about 9:45 p.m. The doors remained closed until about 1:00 a.m. the next morning, when a hazardous materials response team contracted by the Brownsville Fire Department entered the airplane via the crew entry door and took readings with air monitoring equipment. The measured oxygen levels in the cockpit, galley, and at two positions in the main cargo compartment were 20.2, 19.3, 18.6, and 18.5 percent, respectively (normal oxygen level is 21.0 percent). The Brownsville Fire Department's report on the incident noted that the hazardous materials team concluded that "maybe the dry ice displaced the oxygen in the cabin."

The section in Fine Air's *Flight Operations Manual* entitled "Dry Ice Shipments" explains that sublimation of dry ice (solid carbon dioxide) to the gaseous state occurs constantly and that carbon dioxide (CO_2) gas is heavier than air, "displaces air, and in high enough concentrations, can cause hypoxia and asphyxia." The section describes the symptoms of high concentrations of CO_2 gas as "headache, dizziness, muscular weakness, shortness of breath and ringing in the ears" and states that "removal from exposure results in rapid recovery. Such removal can be accomplished by donning an oxygen mask and selecting delivery of 100 percent oxygen."

With regard to the atmospheric levels of CO_2 typically associated with symptoms, the Fine Air Manual states, in part:

> No symptoms occur from inhalation of the gas if the air contains only slightly more than normal amounts of CO_2 (0.035%). When the concentration reaches 2%, depth of respiration increases so that the amount of air brought into the lungs with each breath increases up to 30%. Above 4%, breathing becomes rapid and very deep, to the point of becoming extremely labored and almost unbearable in some individuals. The most that can be tolerated is 7% to 9%. More than 10% can cause ataxia and unconsciousness.

U.S. Army Technical Manual 38-250 (which describes military specifications for the transportation of dangerous goods by air) provides the following information regarding CO_2 concentrations:

> If the carbon dioxide concentration in the aircraft is over 0.5 percent, crew personnel may suffer shortness of breath. Carbon dioxide concentrations of 3.0 percent are endurable from 1/2 to 1 hour. Concentrations of 5.0 percent are dangerous from 1/2 to 1 hour and concentrations of 9.0 percent are fatal from 5 to 10 minutes.

FAA Advisory Circular (AC) 103-4, dated May 1, 1974, entitled "Hazard Associated with Sublimation of Solid Carbon Dioxide (Dry Ice) Aboard Aircraft," states that "the rate of carbon dioxide release varies with the degree of insulation used in packaging, crushed or solid form, temperature, and atmospheric pressure. Experience during flight shows that as a rule, a sublimation rate of one pound per hundred pounds of dry ice per hour can be expected." The AC recommends use of this 1-percent-per-hour sublimation rate "for calculation of CO_2 concentration in aircraft spaces." Additionally, the AC states that "CO_2 concentration in the aircraft generally should not be allowed to exceed 0.5%" and provides a formula for calculating the maximum dry ice load that can be carried in a particular aircraft without exceeding the allowable CO_2 concentration.

Douglas Aircraft Company's report No. DAC 66729, issued December 15, 1967, and revised April 22, 1980, entitled *Transportation of Dry Ice by Air* states that "flight tests, conducted by Pan American World Airways and others, indicate that approximately one pound of gas is released every hour for each 100 lbs. of dry ice carried." The report further states that this sublimation rate "is associated with a quantity [of dry ice] being transported as a bulk shipment and not for use as a refrigerant. If the dry ice is being used to refrigerate cargo, there is a possibility that the sublimation rate will increase over that determined for bulk shipment." Contained within the report is a table giving the maximum dry ice load in the main cabin for various Douglas airplanes based on the recommendations in AC 103-4 (allowable CO_2 concentration of 0.5 percent and sublimation rate of 1 percent per hour). For the DC-8-50, the table lists the maximum dry ice load in the main cabin (main cargo compartment) as 11,148 pounds under normal airflow conditions and 5,574 pounds under minimum airflow conditions.

An article published in *Aviation, Space, and Environmental Medicine* in 1977[2] describes the results of a test in which "dry ice was permitted to sublimate within paper bags at room temperature of 72 to 73 degrees F." Over a 4-hour period, a single 2248-gram (5-pound) block of dry ice decreased in weight from 2248 grams to 1000 grams for an average sublimation rate of 14 percent per hour. Using the formula in AC 103-4 and substituting a sublimation rate of 14 percent per hour for the 1 percent per hour recommended by the FAA, the maximum dry ice load that could be carried in the main cargo compartment of a DC-8-50 without exceeding a CO_2 concentration of 0.5 percent would be 794 pounds under normal airflow conditions and 397 pounds under minimum airflow conditions.

[2] H.L. Gibbons, "Carbon Dioxide Hazards in General Aviation," *Aviation, Space, and Environmental Medicine* Vol. 48, No. 3 (March 1977): 261-263.

The Douglas report points out that the formula for computing the allowable dry ice load in AC 103-4 "is based upon uniform mixing of air and carbon dioxide. Whether this represents the actual situation or not is questionable because the carbon dioxide is cold and heavier than air." The Douglas report suggests that the CO_2 gas "may quickly drop to the floor and flow horizontally."

Fine Air's Director of Training reported that when the DC-8's doors are closed and the airplane is ready for taxiing, air flows forward from the main cargo compartment through a louvered vent near the bottom of the cockpit entry door. The air moves forward to the instrument panel, back along the sides of the cockpit, up into the top of the radio rack, and is then drawn down through an opening in the floor of the radio rack and exhausted into the forward belly compartment. Additionally, the incident airplane was equipped with an air conditioning unit mounted in the cockpit ceiling just inside the cockpit entry door. The unit recirculates cockpit air, which is drawn in from the rear of the unit and blown forward and down.

According to the aircraft manufacturer, the volume of the DC-8 cockpit is about 700 cubic feet. At sea level and 70° F (incident conditions were 23 feet mean sea level and 66° F), 0.4 pounds of CO_2 gas produces a CO_2 concentration of 0.5 percent in the DC-8 cockpit and 1.6 pounds produces a concentration of 2 percent. In 10 minutes, at a sublimation rate of 1 percent per hour, the 960 pounds of dry ice carried in the main cargo compartment of the incident airplane would produce 1.6 pounds of CO_2 gas; at a rate of 14 percent per hour, it would produce 22.4 pounds.

An article published in *Aviation, Space, and Environmental Medicine* in 1990[3] includes a report of symptoms experienced by an Air France transport crew, in which

> . . . twenty tonnes of perishable goods were preserved in dry ice in an aircraft on the apron; doors were closed for 40 min before engine start-up. Headaches and tachypnea [rapid breathing] occurred among crew members due to both the CO_2 released by the dry ice and to the nonfunctioning ventilation. Rapid use of oxygen masks made the symptoms disappear immediately, and start-up of the engines resulted in the proper ventilation of the cabin.

A review of the Safety Board's aviation accident database from 1983 to 1996 did not reveal any occurrences of crewmember incapacitation or impairment due to carbon dioxide exposure. However, the symptoms experienced as a result of exposure to high levels of carbon dioxide, particularly during critical phases of flight, might result in sufficient distraction to result in loss of aircraft control. The FAA guidelines for calculating expected CO_2 concentrations are based largely on aircraft manufacturer data that are nearly 40 years old and do not take into account the use of a large number of small pieces of dry ice as a refrigerant or ventilation designs that could increase crew exposure.

[3] A. Martin-Saint-Laurent, J. Lavernhe, G. Casano, and A. Simkoff, "Clinical Aspects of Inflight Incapacitations in Commercial Aviation," *Aviation, Space, and Environmental Medicine* Vol. 61, No. 3 (March 1990): 256-260.

The Safety Board is concerned that the current FAA guidelines for the carriage of dry ice aboard aircraft, as documented in AC 103-4, may be inaccurate with regard to the actual sublimation rate of dry ice as typically loaded aboard commercial cargo aircraft. Evidence suggests that the sublimation rate will vary widely depending on the amount of dry ice and the manner in which it is packaged, and may be an order of magnitude higher than current guidelines would suggest. Additionally, there is no guidance in the AC regarding the possibility of increased CO_2 exposure because of certain ventilation patterns. Without clear data regarding the in-flight sublimation rate of dry ice under a variety of common packing and ventilation conditions and in a variety of current cargo aircraft, the actual likelihood of aircrew exposure to high levels of carbon dioxide cannot be reliably estimated.

Because AC 103-4 represents a primary source of information for those carriers involved in the transport of goods requiring dry ice for refrigeration, carriers may substantially underestimate the potential exposure of flight crewmembers to carbon dioxide. The symptoms of exposure to carbon dioxide at high levels may result in substantial distraction or impairment of flight crewmembers, which could prove disastrous during critical phases of flight.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Conduct testing during all phases of ground operation and flight using varying quantities and forms of dry ice as typically loaded aboard commercial cargo aircraft to determine appropriate sublimation rates for the calculation of acceptable dry ice loads and the potential effects of various aircraft ventilation conditions on crew exposure to carbon dioxide. (A-01-14)
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> Revise and reissue Advisory Circular 103-4 to reflect appropriate dry ice sublimation rates and various ventilation conditions, as determined from the tests described in Safety Recommendation A-01-14. (A-01-15)

Acting Chairman CARMODY, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

Original Signed

By: Carol J. Carmody
Acting Chairman