ANALYTICAL CONSIDERATIONS CONCERNED WITH CEPHALAGIA ON THE DC-10

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20 February 1973

Summary

Since the DC-10 has been put into operational airline service, initially with United Airlines and American Airlines, a number of complaints of cephalagia (headache) have been made by the Cabin Attendants (C.A.'s) of both airlines. Associated complaints have been received describing "disagreeable, sour, irritating, acrid and pungent" odors in the cabins and lower galleys of the DC-10. The odors have been ascribed variously as being due to spilled and decomposing food, carbon monoxide, carbon dioxide, hot metal, and other causes. CO and CO_2, being odorless, could not be responsible for "odors" as described above. Therefore, odors present must be due to some other contaminant(s) in the cabin environment.

The time of onset and severity of odors was examined and compared with the time of onset, duration and disappearance of headaches. In brief, there appears to be a correlation between these phenomena. A thorough correlation was not possible, however, because of the lack of definitive records relating to onset times. A significant portion of the information was obtained by word of mouth, once or twice removed from the original sources within the airlines. However, similar reports, in the form of trip reports by DAC personnel and records of discussions with DAC personnel are among the data reviewed. These inputs are essentially the same as those obtained from airlines personnel.

In reviewing the problem in an effort to gather leads as to the cause(s) of headaches in Cabin Attendants, the factors considered were: 1) engine bleed air source for cabin pressurization and possible sources of contamination associated with this air supply, 2) possible sources of contaminants taken aboard during flight preparation and servicing, 3) interiors materials subject to degradation after installation, 4) faulty operation of installed equipment leading to 3) above.

After preliminary examination of these possible sources, it appeared to be quite probable that the source of the headaches could be contaminants derived from the engine bleed air source for cabin pressurization. This report is limited to consideration of this aspect, and the analysis of the report quoted in the introduction of this report. The contaminant, from its odor and description by personnel affected, would appear to be an irritant gas, although it may well be accompanied by asphyxiants such as CO or CO_2. This report elaborates on this premise.

Introduction

In the report of a meeting on April 6, 1971 attended by representatives of the FAA, Douglas and ESSO/ENCO Research Laboratories, and Humble Oil and Refining Company, concerning DC-10 Compliance with FAR 25.831(c) Propulsion Bleed System, it is stated that the "thermal decomposition products (of the turbine oil??) are carbon monoxide and aldehydes, such as acrolein." It states also that these were detected in concentrations below the TLV's established for "8-hour work period, day after day as established in industrial hygiene." It states further that decomposition products do not occur below 450°F, which indicates either other factors present, or that the engine temperature was higher, and sufficiently high under the test conditions to cause breakdown of the oil, since these breakdown products were, in fact, detected. The report also states that "in a few cases, detection was made but the concentrations were very low." In no instance is the level of any contaminant given a numerical value to be able to make a judgment as to its significance. Nor does the report state the source for comparison of the "TLV established in industrial hygiene", or the date of that source. This is of some importance because of year-to-year revisions of the TLV's by the American Conference of Governmental Industrial Hygienists (ACGIH), which, it is assumed, is the reference cited.

In the next paragraph the report describes in part the actions of and symptoms produced by aldehydes. However, it neglects to mention the pulmonary effects which aldehydes produce; i.e., pulmonary edema. Also, it states that the odor is detectable early by the nose, and that haze is visually detectable, and that these early "numerous indicators" are available to passengers and crew to suggest that "action be taken to isolate, and not use, air from the offending bleed source". Also, that "these warnings are given long before the carbon monoxide reaches a level that would cause degradation of crew performance". (It is not clear what the passengers could do to "isolate and not use air from the offending bleed source" or what the crew could do if indeed they are even informed of the problem during flight).

The statement about passenger/crew action appears to assume that CO is the only possible contaminant capable of causing degradation of crew performance, when in truth, other contaminants, including acrolein, may be of as much or more significance. The TLV of 50ppm for CO is 500 times higher than that for acrolein (0.1ppm).

Sources of Data

The presence of a pungent, acrid, sour, disagreeable or irritating odor has been described as beginning immediately after engine start by various airlines' Cabin Crews, by Douglas engineering, flight test and product support personnel during flights they have made aboard the DC-10 at various times. United and American Airlines have both raised the question as to the cause of headaches in Cabin Attendants (C.A.'s) on board the DC-10. United Cabin Attendants have made statements that their passengers have requested more aspirin for headaches during DC-10 flights than on other United aircraft. One Douglas man on a DC-10 flight to Tulsa developed a moderately severe headache, and when the C.A. discovered he was from Douglas, railed at him for the headaches caused by the DC-10.

In all the reports gathered to date, common factors are evident - the description of the odor, irritation of the eyes, nose and throat, headaches beginning a few minutes after engine start and lasting until after the flight is over, in some cases, or until aspirin is taken for relief. The description of the odor and the symptoms produced are generally in agreement and are entirely compatible with those caused by aldehydes, particularly acrolein, but can be caused by many other contaminants of the irritant class. Carbon monoxide and carbon dioxide are both odorless and colorless gases do not produce a haze under "normal" conditions, but nevertheless could be present along with whatever contaminant(s) is odoriferous.

Further Discussion of the Referenced Report

"Assumed failure" (p.2) appears to consider that the only possible failure could be a crack in the casting where "the pressurized oil supply approaches the compressor inlet wall at the base of the #8 strut at the compressor inlet." A simulated failure test to evaluate this possibility was run by G.E. There appear to be other possibilities of oil leakage which were not discussed. These include leakage from deteriorating seals, in combination with failures of temperature control sensor, the valves they control, and possible over-heating within the compressor stages. It would appear that, whatever other failures might occur, it is necessary for seals to fail to permit oil or its breakdown products to enter the bleed air system.

Other possible reasons for breakdown products of the turbine oil and which should be analyzed include: 1) high pressure (8:1 at the 8th stage, and 16:1 at the 16th stage) providing compressed air with high pressure oxygen, 2) higher temperatures, 3) possibility of ozone in air, all of which would tend to change the breakdown point of the oil, 4) possible presence of atmospheric contaminants which would act as catalysts, and 5) presence of peroxides and/or catalysts as products of early oil breakdown.

It appears questionable as to whether the tests performed in the laboratory to determine breakdown temperatures of oil, do involve testing under increased pressure with higher partial pressures of O_2, and the possibility of catalytic or accelerated reaction in the breakdown process.

Another question raised in the process of this analysis is, in the thermal cracking of the oil, whether the CO or the acrolein evolves at a lower temperature than the other, or whether they evolve at the same time and temperature in the reaction. Should the CO evolve at lower T° than acrolein, headaches could be produced by the CO. If the acrolein evolves first, the primary mechanism of headache may be the production of pulmonary edema (fluid in the lung) which in turn would act as a mechanical barrier to the diffusion of O_2 into the blood and to CO_2 out of the blood. Thus, the acrolein and all other irritants become mechanical asphyxiants, resulting in hypoxia, and accumulation of CO_2 in the body, both of which are common causes of headache.

Further Discussion of the Referenced Report (Continued)

Throughout this report the descriptions of tests and equipment used for tests, reliabilities and sensitivities of instruments seem to leave one in considerable doubt as to accuracy and specificity. If numbers were provided; i.e., ppm of contaminants detected, tests used, and the accuracy of the tests and instruments used, it would be extremely helpful in this analysis.

Physiological Effects

The statements related to physiological effects and toxicity are also rather vague. An analysis needs to be performed on the combined effects of the contaminants discussed above (or those eventually identified by air sampling and analysis) and workload of the Cabin Attendants. It is quite possible that the physical workload of the C.A.'s imposed in the presence of such contaminants could make the difference in the higher incidence of headache in C.A.'s than that among passengers. Of course, due to lack of good data collection, the incidence in either C.A.'s or passengers is unknown.

Additives

The problem of additives in the oil is also treated lightly in the report. Even though the "additive package is a very small percentage of the total formulation" and perhaps "not detectable by laboratory equipment", we know that additives are there and it is possible that, under engine conditions, some of these or their degradation products could serve as catalysts in thermal degradation of the oil.

Typical additives include: methacrylate and butylene polymers for improving viscosity; alkylated naphthalene as a pour-point depressant; organic compounds of sulfur, phosphorous and nitrogen such as amines, sulfides, hydroxy sulfides, and phenols as oxidation inhibitors; more of the latter plus metal salts of thiophosphoric acid as corrosion preventives or "catalyst poisons" (which implies the presence of catalysts); tricresyl phosphates as Extreme Pressure (E.P.) and anti-wear agents; certain alcohols, aldehydes, phenols and mercuric-and chlorine-containing compounds as bactericides; nitro-benzol for odor control; plus a multitude of other complex, high-molecular weight molecules as dispersants, detergents, oiliness improvers, rust prevention, metal deactivators, emulsifiers, water repellents, stringiness and tackiness agents, dyes, color stabilizers and foam inhibitors.

Since many of these additives are for different purposes, but have similar components or structure, the additive package may not be insignificant. The complexity of compounding synthetic turbine oils, and the variety of chemicals added for this multitude of purposes, makes it very difficult to formulate so that these chemically-active components do not have adverse effects on each other, on the oil base itself,

Additives (Continued)

or on the lubricated parts. The human toxicity is still another consideration, either from the point of view of the intact additives, their breakdown products, or from the oil base stock, which in the case of turbine oils, are usually: (1) dibasic acid esters for the earlier 3 cSt and the 7-1/2 cSt oils, and, (2) for the newer Type 2 (5 cSt oil), hindered esters which are made from alcohols based on neopentane, are usually the base stocks.

Oil Testing

Another sticky problem involved in the evaluation of turbine oils is that there are few standardized tests to which new oils are subjected. Each manufacturer and specifying authority has his own pet method, and often where evaluation test procedures in different specifications are based on similar principles, good performance in one test will not necessarily guarantee good performance in another. In addition, the philosphies of oil evaluation are different in different countries. The United States places greater emphasis on rig tests (those conducted in mechanical apparatus; e.g., Erdco Bearing Rig, designed to simulate engine components and conditions on a small scale) whereas in Great Britain, the use of glassware testing (example - the Rolls Royce blown oxidation test) and a fundamental approach to the chemical behavior of oils in the engine environment, is favored. All these tests in use try to assess the behavior of the oil as related to engine function. Consideration of the toxicological implications, is given little emphasis until one is literally "hit in the head".

Oil Oxidation

High temperature is probably the most important factor in oil oxidation. Non-catalyzed oil oxidation rate approximately doubles for every 18-20°F. increase in temperature. Oxidation rate of motor oil may be increased one hundred fold by exposing it to metals, dust, fuel combustion blow-by products or other catalysts usually found in an engine.

It is generally theorized that organic peroxides are among the first oxidation products formed, and these are formed when an oil is oxidized even slightly. Peroxides are highly reactive and may act as catalysts to accelerate further oxidation of hydrocarbons (including seals), involving a set of reactions, which, if continuing, are akin to a chair reaction. They are also known to be corrosive to certain bearing metals.

Oil Oxidation (Continued)

Free radicals are also formed in the breakdown of the peroxides. From these a variety of potentially toxic compounds - aldehydes, ketones, acids - can be formed. These reactions can become self-propagating, possibly at an ever-increasing rate. Both the initiation and propagation reactions may be activated or accelerated by presence of metal ions, heat, increased pressure, or light. Termination of the oxidation reactions may result from exhaustion of the oxygen supply, exhaustion of reactive fragments, the formation of stable molecules as end products, or the formation of free radials too stable to participate in further chain reactions (but perhaps not too stable for production of biological effects).

Aldehydes can also react violently when exposed to O_2, particularly those with lower molecular weights (including acrolein).

Comparison of Acrolein With Similar Contaminants

The importance of the presence of small amounts of acrolein in the cabin air becomes evident when a comparison of TLV's (ACGIH, 1971) are made with othe strong irritants and asphyxiants.

CHEMICAL	TLV	OTHER
Acrolein	0.1 ppm	Was 0.5 ppm in 1961. 0.25 ppm may cause irritation. 1.0 ppm is practically intolerable.
Phosgene	0.1 ppm	
Ozone	0.1 ppm	
Fluorine	1.0 ppm	Notice of Intended Change (from 0.1 ppm)
Chlorine	1.0 ppm	
Nitrous Oxide (N_2O)	C5.0 ppm	C = Absolute Ceiling for any exposure time
Formaldehyde	C5.0 ppm	
Ammonia	25.0 ppm	Notice of Intended Change (from 50.0 ppm)
Carbon Monoxide	50.0 ppm	
Carbon Dioxide	5000.0 ppm	

From this it can be assumed that acrolein has a toxicity comparable with phosgene and ozone, 10X that of fluorine and chlorine, 50X that of nitrous oxide and formaldehyde, and 250X that of ammonia and 500X that of carbon monoxide. Yet these others would not be permitted in the cabin environment.

Conclusions and Recommendations

From the foregoing comments and analysis, it is apparent that the possibility of turbine oil or fuel could be the source of some odors and headache-producing contaminants which may enter the cabin environment through the bleed air system. In view of the number of complaints of headaches aboard the DC-10's in operation, it would seem wise to sample the cabin air and analyze it for a number of possible contaminants in both the asphyxiant and irritant classes of contaminants. This can best be done by use of gas chromatography or mass spectrometry or both, unless the contaminants can be identified closely enough to be able to use simpler techniques. The test program proposed by R. W. Maddock and D. O. Englebrecht, C1-253, Environmental Control, in August, 1972, would be an excellent start in the identification of the offending contaminants, particularly if the analysis were to include aldehydes, esters and halogenated hydrocarbons, as well as those already suggested in the F&LD Test/Work Request. Both identification and quantification of each contaminant are required.

Should contaminants of the types discussed be found through such an analysis, engine components mentioned, particularly the seals, should be inspected and tested for possible failure(s). The fact that the odors and the headaches both begin shortly after engine start suggests that the seals may be leaking when the engine is not running.

A theoretical chemical analysis could be performed to determine the effects on oil breakdown temperatures under 8:1 and 16:1 compressor pressures, ozone and peroxides effect, and other potential catalysts.

Should these steps fail to reveal the causes of headaches, it is suggested that the complete program recommended in Memorandum, C1-253-JGG-169, dated 17 November 1972, be accomplished.

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