Cabin Air Contamination Problems in Jet Aircraft

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AIR or atmospheric pollution problems have increased many fold during the past few decades. Air pollution and its control have grown to become factors of tremendous importance to the economy and health of many industrialized and urbanized communities. Air pollution has been defined as the excessive concentration of foreign matter in the air which adversely affects the well being of the individual or causes damage to property.[3] This pollution may not always cause injury to health when it is intolerably annoying and disagreeable. Health hazards need not be demonstrated to establish the need for air pollution correction.

Both the military aviation services and the aircraft industry have recently become aware of similar if not the same problems in newly developed high speed aircraft. In the Air Force test pilots complained of obnoxious odors, eye and nasal irritations, and headache associated with the presence of smoke in the aircraft cabin during flight operations. Preliminary investigations revealed that the smoke, including fumes and gases, were a result of the thermal decomposition of engine oil which had leaked into the compressor of the gas turbine engine (Fig. 1).

In turbo-jet and turbo-prop engines, compression of the intake air is necessary to provide for efficient combustion of the fuel. In addition to this function air is bled from the compressor to satisfy other requirements, two of which are pressurization and air-conditioning of the cabin. The temperature of the air will vary with the site or stage of the compressor from which it is bled. Consequently, engine oil which has leaked through a bearing seal may be subjected to varying temperatures (200° - 700° F.) and pressures. Temperatures sufficiently high will pyrolyze the oil, producing chemical substances which contaminate the air entering the cabin. Chemical analyses of these pyrolysis products have been successful only in identifying classes of chemical materials and includes aldehydes, keto-acids, peroxides and carbon monoxide. Engine tests and other reports revealed that the production of smoke and chemical irritants was variable and unpredictable. In some instances, smoke appeared in

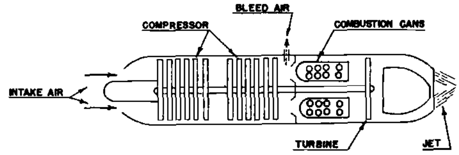

Fig. 1. Cross section of turbo-jet engine.

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the cabin without eye irritation being effected. Almost always an obnoxious odor was evident.

The increased performance characteristics of new aircraft have increased the requirements in the gas turbine engines. Temperatures have risen in the compressor section of the engine, and engine oils have been developed to meet these demands. These lubricating oils (Military Specification MIL-L-7808) are mixtures of several organic chemical materials, and are often referred to as synthetic oils. Almost all of them consist of a base stock, anti-wear agent, oxidation inhibitor, anti-foam agent, and viscosity improver. The base stock is usually an ester derivative of sebacic acid, adipic acid, and pelargonic acid. Di-2-ethylhexyl sebacate and tri-cresyl phosphate are examples of a base stock and anti-wear agent, respectively.

The contamination of the bleed air from these new type engine oils and their thermal decomposition products has prompted an extensive study of their toxicologic properties. Although more work has been performed with the base stock di-2-ethylhexyl sebacate and on engine oil containing it, the toxicity of the various esters and their formulations is essentially the same. On the basis of animal experimentation,[1,6] these materials may be classified as almost non-toxic when in contact with skin or eyes. Prolonged and continuous contact with the skin did effect some cutaneous damage. Inhalation of mists of either the formulation or of its chief component, generated at room temperature, were tolerated by all animals subjected to exposure to concentration of approximately 1.0 mg. per liter; however, fatalities occurred among rabbits and rats exposed for only seven hours to the fog produced by heating this concentration of either the formulation or its principal ingredient to the temperature of 700° F. (Table I).

TABLE I. COMPARISON OF TOXICITY OF MISTS GENERATED BY ASPIRATION AT ROOM TEMPERATURE AND OF FOG FORMED IN INCONEL FURNACE AT 700°F. (371°C.). (After Treon et al[6])

MATERIAL	TEMPERATURE	CONCENTRATION OF DI-2-ETHYHEXYL SEBACATE MG/L	DURATION OF EXPOSURE HOURS	NUMBER OF FATALITIES/NUMBER OF ANIMALS EXPOSED			
				CATS	GUINEA PIGS	RABBITS	RATS
FORMULATION	ROOM	1.14 (1)	10 X 7	0/1	0/2	0/2	0/2
DI-2-ETHYLHEXYL SEBACATE	ROOM	0.40 (1)	10 X 7	0/1	0/2	0/2	0/4
FORMULATION	700°F	0.95 (2)	7	—	0/2	2/3	3/4
DI-2-ETHYLHEXYL SEBACATE	700°F	0.94 (2)	7	—	0/2	2/4	3/4

(1) FOUND BY ANALYSIS OF SAMPLE COLLECTED FROM CHAMBER.
(2) RATE OF DROPPING LIQUID INTO FURNACE DIVIDED BY RATE OF AIR-FLOW (31.8 L. PER MIN) THROUGH FURNACE.

The toxic effects on animals were found to be dependent on the rate of decomposition of the material, the time of exposure, and the temperature of decomposition (Table II). Almost all animals survived when exposed for two hours to the fog formed by dropping 56 to 60 mg. of the sebacate or formulation per minute into an Inconel tube furnace, heated to 700° F., through which air was passing at the

TABLE II. COMPARISON OF TOXICITY OF FOGS FORMED IN INCONEL FURNACE HEATED TO 700°F. (371°C.) FROM DI-2-ETHYLHEXYL SEBACATE AND ENGINE OIL (After Treon et al[6])

MATERIAL	RATE OF DELIVERY MG/MIN (3)	DURATION OF EXPOSURE HOURS	NUMBER OF FATALITIES / NUMBER OF ANIMALS EXPOSED		
			GUINEA PIGS	RABBITS	RATS
DEHS (1)	223	2	2/2	3/3	4/4
E O (2)	207	2	0/2	2/2	2/2
DEHS	121	2	1/2	4/4	2/4
E O.	129	2	0/2	3/3	2/2
DEHS	56	2	0/2	0/4	1/4
E O	60	2	0/2	0/3	0/4
DEHS	61	7	1/2	3/4	4/4
E.O	61	7	1/2	3/3	4/4
DEHS	37	7	0/2	2/4	4/4
E O	43	7	0/2	3/3	4/4
DEHS	20	7	0/2	0/4	1/4
E O	20	7	0/2	0/3	1/4
DEHS	7.4	24	0/2	0/4	0/4
E.O	7.4	24	0/2	0/2	0/4

(1) DEHS- DI-2-ETHYLHEXYL SEBACATE
(2) E.O.- ENGINE OIL FORMULATION
(3) RATE OF AIR FLOW THROUGH FURNACE WAS 31.8 L/MIN

TABLE III. RELATIONSHIP OF TEMPERATURE TO TOXICITY OF THERMAL DECOMPOSITION PRODUCTS OF DI-2-ETHYLHEXYL SEBACATE. (After Treon et al[6])

FURNACE TEMPERATURE °F	RATE OF DELIVERY MG./MIN.	DURATION OF EXPOSURE HOURS	NUMBER OF ANIMALS THAT DIED/NUMBER OF ANIMALS EXPOSED		
			GUINEA PIGS	RABBITS	RATS
900	82	2.0	1/2	3/4	2/4
700	85	2.0	1/2	3/4	0/4
700	61	7.0	1/2	3/4	4/4
600	58	7.0	0/2	4/4	3/4
700	37	7.0	0/2	2/4	4/4
550	42	7.0	0/2	0/4	0/4
400	36	7.0	0/2	0/4	0/4

rate of 31.8 liters per minute. As the rates of delivery increased from 85 to 223 mg. per minute, while other factors were held constant, the incidence of mortality in other like groups increased. In seven hours exposure, all of the animals survived the fog formed at the rate of 20 mg. per minute. Increases in the rate to about 40 to 60 mg. per minute caused sharp increases in the incidence of mortality among rats and rabbits. All animals survived exposure to pyrolysis products obtained from rate of delivery of 7.4 mg. per minute.[6]

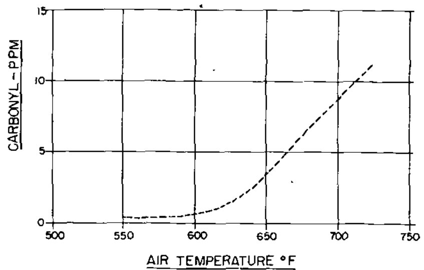

Fig. 2. Carbonyl production vs. air temperature. (From Gutowski et al[2]).

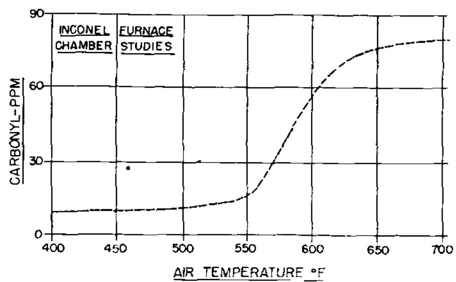

Fig. 3. Carbonyl production vs. air temperature (inconel furnace chamber studies).

The temperature of decomposition was found to be critical (Table III). The fog formed at 900° F. was slightly more toxic than that formed at 700° F., whereas fog at 600° F. differed little in toxicity from that at 700° F. However, when the Inconel furnace was maintained at 550° or 400° F., no fatalities occurred. Analysis of the fogs demonstrated an increase in total aldehyde content. The critical relationship of temperature to oil breakdown can again be shown by the studies of Gutkowski, Page and Peterson.[2] In specially constructed equipment referred to as a "smoke simulator," carbonyl production versus temperature was evaluated (Fig. 2). At a temperature of approximately 640° F., the increase became very rapid. This temperature is probably lower in the engine where high pressures are encountered, but is higher than the break point in the animal studies, probably because of slightly changed conditions. The break point for the animal studies was found to be 550° F. (Fig. 3).

It was clearly demonstrated why these problems of contamination of the bleed air arose with new engines having higher compression ratios, and hence higher temperatures, and why it is to be expected to increase in severity in the future if oil leakage occurs. It should be mentioned that carbon monoxide was found in the fog formed in the animal chamber studies in concentrations varying with the rate of decomposition and the temperature. Little carbon monoxide, however, was found in the fog formed in the smoke simulator or as a result of in flight or static engine tests. In none of these engine tests did the concentration of contaminants approach that which produced definite toxic reactions in test animals, but contaminants were present in high enough concentrations to cause eye tearing, nasal irritation, and objectionable odors.

Because high concentrations of these chemical materials resulting from the thermal decomposition of engine oils have never been found in the cabin air of aircraft, health hazards to crew personnel are not anticipated. Nevertheless, pilots have reported eye and throat irritation, dizziness, nausea, odor, and smoke. Respiratory distress has also been experienced in static tests after exposure of one-half hour or longer.[4] In these tests, oil was sprayed into the air intake of the engine to demonstrate that smoke or odor cannot be used as criteria because, at moderate leakage rates (0.5 to 1 gallon per hour), no smoke or fog was observed nor did the odor level increase. Eye and nasal irritation occured after one-half hour exposure with slight pulmonary and gastric distress. Excessive oil leakage (3 to 6 gallons per hour) produced considerable smoke. Severe eye and nasal irritation followed immediately. However, remission of symptoms and recovery were rapid and without sequelae.

In industry these problems are known as air pollution. As mentioned earlier, pollution need not cause injury to health but, when intolerably annoying and disagreeable, the well being and efficiency of the individual may be affected. Health hazards need not be demonstrated to establish the requirement for correction of air pollution. The importance of contaminants in the cabin air of an airplane must be considered in light of the purpose and function of the military aircraft, namely, the accomplishment of its mission[5] and: (1) the hazard to Air Force personnel; (2) smoke and fumes that may obscure electrical or fuel fires and hinder visibility; and (3) the potential detriment to aircraft materials and sensitive instrumentation.

No materials can be tolerated in the breathing air of those responsible for the operation of complex and costly aeronautical equipment which would interfere in any way with their efficiency of operation and performance. The materials resulting from the decomposition of the engine oils can be detrimental to the health of air crews if the concentrations are high and the duration of exposure long; even the minimum effects of eye and nasal irritation may be intolerable. Smoke in the cabin area is always a critical problem because it generally indicates the presence of an electrical or fuel fire. Smoke produced by conditions other than fire may cause confusion with unnecessary abandonment of the mission. Particulate matter derived from the thermal decomposition of engine oil, hydraulic fluid, or other materials may obscure true fire hazards that require emergency action and which may become dense enough to interfere with instrument visibility. Finally, the substances that constitute the smoke and the corrosive nature of the fumes may be detrimental to the operating efficiency of sensitive electronic instruments and to the rubber, plastics, and paint of the aircraft.

SUMMARY

Air pollution problems have been encountered in new turbo-jet aircraft.

Air, bled from the compressor section of the engine to pressurize and ventilate the cabin area, may become contaminated with chemical materials resulting from the thermal decomposition of engine oil which has seeped past the bearing seals. The engine oil itself is relatively non-toxic; however, the decomposition products were found to be toxic to laboratory animals. The effects were proportional to the rate of decomposition, the time of exposure, and the temperature of decomposition. Health hazards to aircrew personnel are not anticipated unless excessive oil leakage into the compressor and prolonged exposure are obtained. Eye and nasal irritation and obnoxious odors have been reported as objectionable. Smoke, fumes, and physiologically active chemical materials cannot be tolerated in the cabin air of high speed aircraft and may constitute a flight hazard by: (1) affecting the efficiency of the aircrew; (2) obscuring in-flight conflagrations; (3) hindering instrument visibility; and (4) affecting sensitive instrumentation and other aircraft materials.

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Anthropology and the Aviator

Are there any physical traits associated with success in military flying? If so, what are they; how strong is the association; and what techniques are most likely to disclose the relationship? Answers to these questions have implications beyond the practical utility of any positive findings. They may throw light on the body-behavior relationship, an area of traditional and currently renewed interest in constitutional anthropology. . .

Specific elements in the observed associations should be isolated. With what factors in flying success is physique associated? With temperament and personality; muscular co-ordination, strength, speed of reaction; perception; or with all of these? And to what extent with each? The greater size and mesomorphy of pilots as against co-pilots may be a function of strength needed to handle bomber controls as well as the confidence which such men inspire. . .

All of these problems . . . bear not only on flying ability but also on the larger problem of the relation between man's physique and his behavior.—ALBERT DAMON: *American Journal of Physical Anthropology,* 13:217, June 1955.