Engineering Notes

Presence of Ozone in Cabins of High-Altitude Aircraft

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OZONE is present in significant quantities in the atmosphere at high altitudes. When such ambient air is compressed and supplied to an aircraft cabin, it could exhibit potentially harmful effects on man and in some aircraft materials. An analysis of ozone at high altitudes and its presence in aircraft cabins was undertaken in order to assess the nature of the ozone problem in the cabin of the planned supersonic air transport (SST) and to resolve the question of potential toxicity of ozone to flying personnel in current jet aircraft at altitudes in the range of 40,000 ft.

Ozone is found to exist in meaningful concentrations between altitudes of 50,000 and 120,000 ft. The ambient concentration increases from small amounts below 50,000 ft to an average peak concentration of 5–10 ppm by volume between approximately 70,000 and 90,000 ft. It varies with geographical latitude, season of the year, and meteorological factors. Figure 1 illustrates these variables compositely with the ambient ozone concentrations expressed in parts per million by volume. High ambient ozone concentrations of 5–10 ppm are found at altitudes of 65,000–80,000 ft, the range through which the planned SST will cruise.

Several papers have called attention to the probability that modern jet aircraft are traveling at altitudes where they might encounter appreciable concentrations of ozone[1–3] in the aircraft.

In order to develop data concerning the need, if any, for protection of air crews and passengers, the Aviation Medical Service, Federal Aviation Agency, sponsored two independent studies of precise ozone measurements in the cabins of current commercial jet aircraft. In the first study, the Weather Bureau measured the ozone content in the cabin of a KC-135 at altitudes of 25,000 and 41,000 ft, respectively. Little ozone was detected at 25,000 ft. At 41,000 ft, two broad ozone maxima were observed with maximum values at 33 parts/hundred million by volume. In a second flight at 41,000 ft, two maximum values of approximately 50 parts/hundred million (50 pphm or 0.5 ppm) by volume were recorded. The latter values coincided with an upper atmospheric trough where the aircraft traveled well above the tropopause.

The relationship of high ozone content to the tropopause is also disclosed by Bennett[4] in his study using the British Comet and Boeing 707 aircraft in North Atlantic crossings. In the Comet, where air for pressurization is taken from engine compressor tappings at about 240°C no ozone was detectable in the aircraft cabin at altitudes below the tropopause (see Fig. 2). Above this level, however, the concentration increased steadily to an average of 0.065 ppm at 41,000 ft. Approximately 90% of the ambient ozone taken in was dissociated by heating before entering the passenger cabin. In the 707, air for pressurization is taken from engine-driven turbocompressors at an outlet temperature of 150°C. As shown in Fig. 2, the ozone content in the cabin was higher than the Comet, ranging up to 0.12 ppm at 39,000 ft. Here, only about 75% of the ozone was destroyed before reaching the aircraft cabin. Bennett, in subsequent correspondence with the authors, stressed the relative height above the tropopause rather than the actual altitude above sea level as the important factor which is correlated with high ambient ozone content.

In the second study, the Armour Research Foundation measured the ozone content in the fuselage of a number of types of commercial jet aircraft, including the 707, 720, Caravelle, Convair, 880, and the DC-8, flying across parts of the continental United States at various altitudes and latitudes over a period of a full year. Some of the preliminary findings, as well as a detailed review of the process of ozone formation and its vertical distribution in the atmosphere, and a resume of the biomedical effects of ozone in various concentrations on man and animals, are contained in a comprehensive paper by the authors.[5]

The preliminary data acquired by Armour Research Institute personnel indicate that little or no ozone was detected below the tropopause. At or above the tropopause the internal cabin ozone concentration was usually at or slightly above 0.05 ppm. During 11 months of the 1-year study, the internal ozone cabin concentration during transcontinental domestic flights ranged from negligible values to 0.1 ppm. In April the cabin ozone content readings of 0.2–0.3 ppm occurred for relatively short periods of peak exposure, which represented a small fraction of the total flying time. Considering that the threshold limit value of 0.1 ppm for ozone established by the American Conference of Governmental Industrial Hygienists is based upon an occupational exposure of a 40-hr, 5-day week, a cabin level of 0.2–0.3 ppm does not appear to be unreasonable as a maximum concentration for intermittent short exposures as may be experienced in jet aircraft during flights at high altitude. It appears that the problem of ozone exposure in current jet aircraft is not of physiological significance in current jets flying below 40,000 ft over continental United States, primarily because the concentrations of ozone, even when they reach a level of 0.2–0.3 ppm, are of short duration.

The precise amount of ozone which may be present in the pressurized cabin of the SST will depend upon a number of factors: 1) the amount of ambient ozone present at the specific altitude range, 2) the degree of heating of the air passing through the turbocompressor and subsequent destruction of ozone by this heat, and 3) destruction of ozone by contact with various materials including metal surfaces. By extrapolation of the data presented in Fig. 1, wherein the

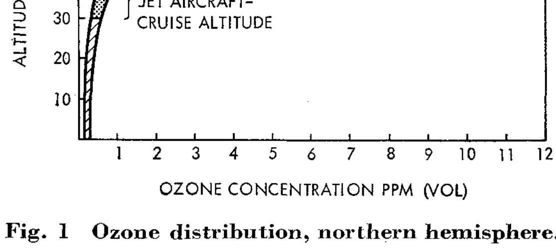

Fig. 1 Ozone distribution, northern hemisphere.

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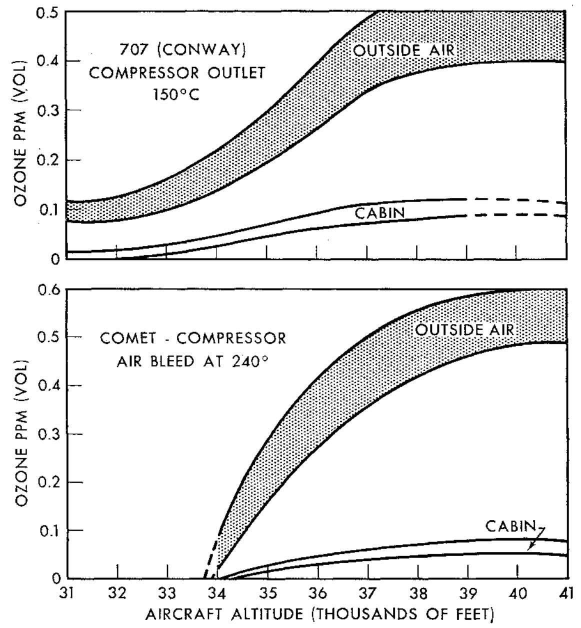

Fig. 2 Ozone concentration.[4]

ambient air for pressurization purposes of the SST contains 5–10 ppm, and using the 75–90% degree of destruction of ozone shown by Bennett[4] in Fig. 2 in passage to the cabin, the projected predictable cabin ozone content in the SST would probably fall within the range of 0.5–2.25 ppm, unless special means were to be taken to destroy or reduce this high concentration to a tolerable level.

It is believed that the heat generated in the high-speed compressor necessary to maintain cabin pressure at altitudes of 70,000–80,000 ft would destroy a large portion of the ambient ozone. Unfortunately, the very efficiency of these compressors depends on their speed, thus reducing the contact time of ambient air with the heat. It is probable that the ozone concentration present in the planned SST will reveal an environmental health hazard unless some means is used or an adequate dwell time is engineered in the compressor system to destroy or reduce the ozone to an acceptable level.

There are a number of ways of destroying or substantially reducing the ozone level in an aircraft, including the use of manganese dioxide-cupric oxide, cobalt, nickel wool, silver or other metal or metallic oxide types of catalytic filters, and other gas phase thermal decomposition methods.[6] Military aircraft have successfully used catalytic filters to destroy cabin air contaminants which include aldehydes, ketones, and ozone. A lighter weight filter to destroy ozone alone can no doubt be developed. Consequently, although ozone may represent a potential environmental health hazard, its control does not impose serious difficulties for engineers in design of the SST.

References

[1] Clamann, H. G. and Bancroft, R. W., "Toxicity of ozone in high altitude flight," *Ozone Chemistry and Technology* (American Chemical Society, New York, 1959), p. 352.

[2] Ernsting, J., "Physiologic aspects of the significance of ozone in pressurized cabins." I.A.M Memo. 8–20, Royal Air Force, Inst. Aviation Med., Farnborough (September 1959).

[3] Young, W. A., Shaw, D. B., and Bates, D. V., "Presence of ozone in aircraft flying at 35,000 feet," Aerospace Med. **33,** 311 (1962).

[4] Bennett, G., "Ozone contamination of high altitude aircraft cabins," Aerospace Med. **33,** 969 (1962).

[5] Jaffe, L. S. and Estes, H. D., "Ozone toxocity hazard in cabins of high altitude aircraft, a review and current program," Aerospace Med. **34,** 633 (July 1963).

[6] Boberg, J. E. and Levine, M., "Catalytic filtration of ozone in airborne application," J. Eng. Ind. (Trans. Am. Soc. Mech. Engrs., Ser. B) **84,** 42 (1962).

Structural Energy Absorption

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Introduction

VARIOUS target drones (Ryan Firebee) and escape capsules (Mercury) have in the past been recovered by parachute systems. Many of them have been using decelerating devices, such as inflated impact bags (Radioplane XQ-4), nose spikes (Lockheed X-17), or spring and shock absorbers. These impact absorbers have been designed to absorb the kinetic energy of descent (K.E. $= \frac{1}{2}mV^2$), with minimum loads transmitted to the vehicle itself. In this paper an inquiry is made into the best material to use for a vehicle structure (the airframe) which does not have any shock-absorption device. The best structural shapes to use for this purpose are not investigated here.

Discussion

The criterion for the best material is the amount of energy that can be stored in the material within the elastic limit. It is assumed that the vehicle is undamaged upon touchdown and may be used again, perhaps even for 20 flights, without any permanent set in the material. Within the elastic limit, the stress-strain diagrams are essentially linear, and the energy absorbed (or rather stored) by the structure is equal to $P\delta/2$, where δ is the maximum deflection of the airframe. By equating energies, $mv^2/2 = P\delta/2$ and $P = mv^2/\delta$. This simple equation can be used to compare the structural load developed by, for example, an impact-bag ($\delta = 10$ in.) system vs no impact bag ($\delta = \frac{1}{4}$ in.).

It is shown here that the absorbing device reduced the structural load about 40 times. However, it is not the purpose of this paper to compare systems but only to compare materials. It is nevertheless pointed out that the best energy-absorbing material, either in combination with other available shock-absorbing devices or without, can be used for the airframe structure.

Comments on Shape

Stress concentrations at notches in a structure subject to impact will tend to fail the material at the notch before the full energy-absorption capability of the remaining volume of material is attained. The shape, the length L, and the volume of the material are important in the design of impact-absorbing structures:

1) A larger volume can absorb more energy.

2) A longer part can absorb more axial energy because at the same *strain* ($\epsilon =$ in./in.) it has a larger *deflection*, $\delta = \epsilon L$, and the external energy absorbed is $P\delta/2$.

3) Notches tend to absorb too much energy.

4) Constant cross sections are best for columns. This is another way of saying that the most efficient energy storage is obtained by maintaining a high constant stress throughout.

Plastic Energy Absorption

The material inelastic range may be used for "one landing only" designs. Here, in the plastic range, there is available a large energy reservoir of ductile materials, which may prove to be superior to the brittle ones. Also, energy-absorbing sandwich cores may be used. In either case, the parts are permanently deformed or crushed and must be replaced.

Elastic Energy Stored

The strain-energy density is defined as the strain energy per unit volume. Below the elastic limit, this is sometimes referred to as the modulus of resilience.[1]

Typical materials are chosen in order to compare their elastic-energy contents, using the uniaxial elastic-energy[2]

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