Continuous Recording of Oxygen, Carbon Dioxide and Other Gases in Sealed Cabins

By Hans Georg Clamann, M.D.
Department of Physiology, USAF School of Aviation Medicine, Randolph AFB, Texas

A SUITABLE CABIN environment must be provided in any aircraft carrying passengers into the upper atmosphere. The maintenance of a proper oxygen partial pressure is first in importance. Maintenance can be accomplished at lower atmospheric pressure—beginning at 6,600 feet—by increasing the oxygen percentage in the inspired air until 100 per cent oxygen at one-fourth sea level pressure (that is, 3.7 psi, 190 mm. Hg), or an altitude of 34,000 feet, is obtained. In emergencies, somewhat higher altitude may be attained by pressure breathing. However, at all altitudes higher than 34,000 feet, adequate respiratory conditions can be maintained only by compressing ambient air in a pressure cabin or by means of a pressure suit. But the application of this principle has its limits. The atmosphere eventually becomes so rare that even by the use of the most effective compressors it will not yield the desired results. These shortcomings were also apparent in the power plants of an airplane, where engines—based on external combustion—must be replaced by rocket motors that carry their own oxydizers. A sealed cabin is the only solution for the passengers. This cabin can be designed to carry sufficient oxygen in some form to provide the necessary partial pressure of oxygen for the entire flight.

The sealed cabin—in contrast to the open system pressure cabin affording constant ventilation—calls for some means of elimination of excess water vapor, carbon dioxide and other waste gases which accumulate during flight. It is comparable to a submerged submarine in this respect. Figure I shows a comparison between the open cockpit, the pressurized cabin and the sealed cabin in regard to gas exchange with the surroundings. It emphasizes the fact that in the sealed cabin the passengers rely entirely on the oxygen in store for supply, and on absorbers for elimination of waste gases.

The question now arises as to the need for controlling the composition of this atmosphere. In answering this question some physiological data should be considered. The oxygen consumption of a normal individual depends upon the extent of muscular activity. In terms of liters per hour (STPD) the oxygen consumption is at a minimum of 15 during sleep; it rises to 47.5 at light work (as walking 2.8 mph.), and can reach as much as 322 liters per hour at record heavy work.[4] Assuming a constant exchange ratio of CO_2/O_2 of .82, the CO_2 output is 12.3, 39, and 264 respectively.

If, at the start of a flight, a cabin

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volume of 70 cubic feet (1.98 m.^{3}) of air at sea level pressure were available to each passenger, the oxygen consumption during light exercise would reduce—after two hours and six minutes—the partial pressure of oxygen in the cabin to a level corresponding to an altitude of 6,600 feet. This level would be attained, during heavy work, in only nineteen minutes. During the same time the CO_2 would reach a concentration of 4.1 per cent. The literature shows that 5 per cent could be tolerated for a few minutes only.[5] Although rocket craft can be expected to cruise at 1,000 to 2,000 mph., under operational conditions, the duration of flight will probably be as long as from one to two hours. Consequently, the fast accumulation of CO_2 within a sealed cabin must be watched. In view of this wide range of variability in gas exchange during prolonged flights, a continuous regulation of oxygen replacement and CO_2 elimination is mandatory. Only by measuring the composition of cabin air, through constant surveillance, can a regulating system be made effective.

In addition to the principal respiratory gases aforementioned, other gases or vapors generated by the occupants and the machinery in the cabin, must be considered. Here, organic solvents, hydro-carbons and sulfur compounds must also be reckoned with. Harmless though they are in small amounts, after some time they may reach a toxic level, if there is not an all-efficient absorbent. A device, giving at least a qualitative indication or detection of any such gases, would be of great help.

Regarding the choice of proper instruments for controlling oxygen and carbon dioxide, those based chiefly upon physical principles, would be most suitable. This is because they permit rapid continuous reading and

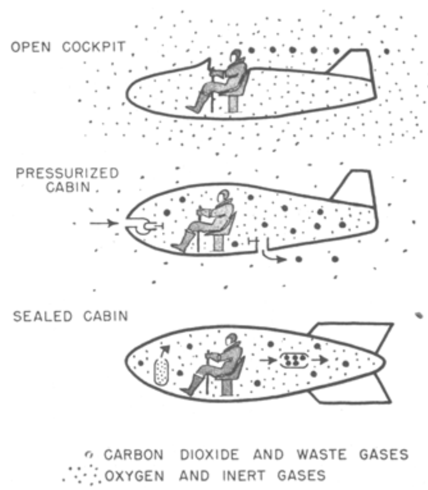

Fig. 1. Respiratory conditions existing in three types of cabins, showing supply of oxygen and elimination of carbon dioxide or waste gases. (The density of the spots simulates the concentration of molecules or the pressure.)

lend themselves to automatic control. Physical gas analyzers can be divided into two groups; namely, non-specific and specific. The measuring principle for the non-specific group utilizes physical properties that are common to all gases contained in the sample; they are distinguished only by being present in different amounts. This group comprises methods based on thermal conductivity, refractive index of light and velocity of sound. Specific methods utilize a property that is unique to an individual component in a gas mixture. Such properties are, for instance, an absorption band in the spectrum or the mass/charge ratio of ions, or the magnetic susceptibility of the particular gas.

Many of these instruments would meet the requirements for the purpose of laboratory gas analysis; however, the airplane designer would have to meet additional requirements such as light-weight, no-bulk, low-energy-consumption, and a certain ruggedness.

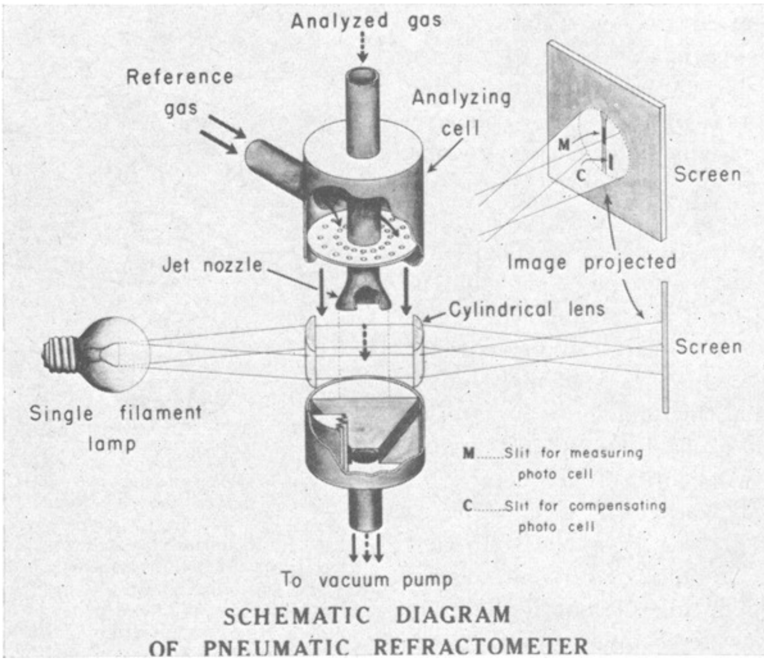

Fig. 2. The perforated disk shown in the analyzing cell, directs the reference gas to a laminar flow. The use of two photo-cells—arranged in a bridge-circuit—eliminates influence of changes in brightness of the illuminating lamp. (See text for further details.)

Under these conditions, the mass spectograph—one of the most valuable instruments—in its present laboratory form cannot be used with its weight of 1700 pounds, its 60 by 70 inch cabinet and 2800-watts power consumption, disregarding water for cooling and refrigerants.[2] If it could be simplified, this instrument would be capable of quantitative and qualitative analysis of cabin gases. Several types of infrared analyzers for CO_2 analysis have been developed but they are not rugged enough for operational use in aircraft. The oxygen analyzer, based on the principle of magnetic susceptibility, is a very reliable instrument for oxygen.

An instrument, called the pneumatic refractometer,[1] has been recently developed, from the standpoint of simplicity and flexibility (Fig. 2). Its principle is based on the fact that the refractive index of a gas is proportional to its density, or, in a mixture of gases with different refractive indices, is proportional to its concentration. The gas to be analyzed emerges from a slit-like nozzle and forms a flat band which is embedded in the reference gas. Both gases flow through the analyzer cell in a laminar stream produced by a small vacuum pump. A light beam from a single filament lamp traverses the analyzer cell, directed by two cylindric lenses as windows, and finally forms an image on the screen. The brightness of the image changes, depending upon the difference in the refractive indices of the reference and analyzed gas. These changes are transmitted by photocell to a recording device or microammeter. For the purpose of checking the efficiency of a CO_2 filter, for instance, the cabin air entering the filter can be used as reference gas, while the gas having passed through the filter is analyzed gas. The latency time is limited mainly by the dead space of the connecting tubes. In the present model, the latency time is in the range of one-tenth of a second, which allows respiratory studies on tidal air (Fig. 3). For CO_2 in air, the accuracy will be about 0.1 per cent. The principle is not limited to carbon dioxide, but is applicable to other gases, depending upon their optical qualities while eliminating disturbing components.

Summarizing, it can be concluded that in order to keep these gases within their physiological limit, some kind of monitoring of oxygen and carbon dioxide in a sealed cabin, will be necessary. The longer the flight and the smaller the volume of the cabin, the greater the probability of sudden changes in percentage of the vital oxygen and carbon dioxide will be. As for instruments, simplicity, quick response and ruggedness will be preferable to accuracy. The occurrence of unpleasant gases, which may accumulate to a toxic level in prolonged flight, must also be considered.

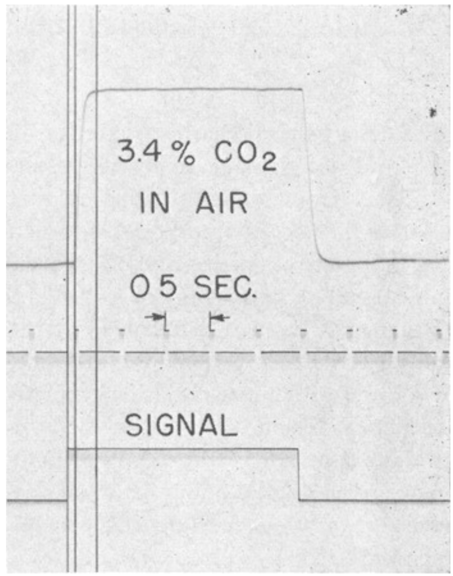

Fig. 3. Calibration curve of pneumatic refractometer. Beginning and end of signal indicates flow of the calibration gas mixture. The distance between the first vertical line (at left) and the second line marks the latency time.

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