A REVIEW OF THE ADAPTION OF THE RESPIRATORY SYSTEM

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ABSTRACT:

The main objective of this paper is to consider the analysis of the block diagram representation of the respiratory system. It considers a review of the adaptive structure of the lung and the pulmonary ventilation. The discussion reviews the nature of the adaptive mechanism of the system when the environmental pressure increases or decreases around the normal pressure. Several models of the adaptive structure have been discussed to show the engineering sense of the adaptive respiratory system.

Part (I):

INTRODUCTION

The most important function of the lung and of pulmonary ventilation is to supply tissue cells with enough O_2 and to remove excess CO_2. To accomplish this, pulmonary ventilation must increase the partial pressure of O_2 in the alveoli well above that in the venous blood flowing through the alveolar capillaries. This loads the blood flowing to tissue cells with O_2. It must also lower the partial pressure of CO_2 in the alveoli below that in venous blood. This unloads excess CO_2 from the blood destined for tissue cells. Gases move between alveoli and their capillary blood and between tissues and their capillary blood because of a difference in their partial pressure. In the lungs, the gases are O_2, CO_2, N_2 and H_2O

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(as water vapout); at 37°C. Their partial pressures are 104, 40, 569 and 47 mm Hg. respectively [1]. These are average values for healthy resting man at sea level; values of PO_2 PCO_2 and PN_2 fluctuate from breath to breath and during a single breath. Total ventilation is the volume of air entering or leaving thenose and mouth during each breath (tidal volume) [1]. Alveolar ventilation is the volume of fresh air entering the alveoli each breath. Alveolar ventilation is always less than total ventilation. The discrepancy between alveolar and total ventilation depends on the anatomic dead space, tidal volume and fequency of breathing.

There is a high partial pressure of N_2 in blood and in tissues because man breathes 79% N_2 and is surrounded by 79% N_2. Since N_2 is not used in metabolic processes, it acts as an inert gas and simply dissolves in blood and body tissues. Henery's law states that such gases dissolve in liquids in direct proportion to their partial pressure.

If man ascends to a high altitude, the PN_2 decreases in inspired air and alveolar gas, but is still high in tissues and blood. Dissolved N_2 must then diffuse from tissues to blood and from blood to alveolar gas until tissue and blood and air tension of N_2 are again equal. If the ascent and resulting decrease in ambient PN_2 occur slowly, nitrogen gradually leaves the tissues and blood by diffusion and no symptoms occur. If however, the ascent is abrupt, the dissolved N_2 in tissues and blood comes out of solution too rapidly to be carried away by diffusion, and gas bubbles form (just as when water that has been equilibrated with air is exposed to a vacuum). If O_2 bubbles form, these can be used locally in tissue metabolism, CO_2 is not involved, since these is very little CO_2 in ambient air. Thus the problem is largely one of N_2 bubbles, which can be removed only by diffusion.

When man breathes air at 3 atmospheres, his alveolar PN_2 rises about 3 fold. This causes 3 times as much N_2 to dissolve in pulmonary capillary blood, and the blood distributes this to body tissues. But blood volume is only 8% of the body volume, and considerable time is needed for blood to carry enough N_2 to tissues to saturate them at new PN_2. Some tissues that have a rapid blood flow and dissolve little N_2 comes to the new PN_2 quickly other tissues, such as fat cells full of fat droplets, have less blood flour per gram of tissue but dissolve 5 times as much N_2 per gram; these come to the new PN_2 much more slowly. If man goes to 3 atmosphere pressure for brief periods, he adds little N_2 to his tissues and will not suffer if he ascends rapidly. If he stays long enough for his tissues to load up more N_2, he must come up (decompress) slowly. A diver can escape the bends and chokes by breathing O_2 for several hours before diving; this eliminates dissolved N_2 from the tissues. If after N_2 elimination, he dives, breathing air at high pressure, he will accumulate N_2 but the total body N_2 will be much less because his tissues started near zero level of N_2.

Part (II):

THE ADAPTIVE STRUCTURE OF THE RESPIRATORY SYSTEM.

The respiratory center in the brain is responsible for the adaptation or regulation of breathing due to any changes of respiratory parameters. The informations go to brain by neural pathways. Regulation depends on:

1) Local gas pressures and PH in blood and in brain tissue (cerebrospinal fluid), allowing for direct "chemical" control.

2) Neural information "feed-back" from chemosensitive nervous structure in the carotid body and aortic arch, which allows for "neurochemical" control.

3) Afferent neural informations from stretch receptors in the tissues of the lung, airways, and chest wall, allowing for "neuromechanical" control, (Fig. 1).

A schematic representation of the human respiratory system is shown in (Fig. 2). [11]. Respiration is dependent upon neural impulses which originate in the lower brain (medulla) and are transmitted to the chest cavity (thorax) and diaphragm to govern both the rate and depth of breathing. Control of both rate and depth of breathing is governed primarily by neural signals initiated at central and peripheral sites in the body and transmitted to respiratory center, (Fig. 1). Because of the importance of the chemoreceptors in the automatic feedback control of respiration, it is customary to distinguish between chemical control and nonchemical control and to refer to the latter as neural. As indicates in (Fig. 1), the neural control can be reflex in nature, as are the signals arising from stretch receptors in the lungs, etc., or it can be at the conscious level, associated with vocalization, emotion, or exercise anticipation.

Chemoreceptors involved in respiration are located centrally at or near the respiratory center and peripherally in the carotid body, the aortic body, and with less importande, in other locations. The central chemoreceptors are responsive primarily to carbon dioxide and hydrogen ion concentration. Their location in the medulla, perfused with blood and bathed in cerebrospinal fluid, suggests that these chemoreceptors are responsive to chemical changes in both cerebral blood and cerebrospinal fluid. The carotid chemoreceptor is located in the neck near the bifurcation of the common carotid artery. The aortic chemoreceptors are situated in the arch of the aorta, the main blood vessel leaving the heart. Information about the oxygen concentration of the blood comes primarily from these peripheral chemoreceptors, although they are also sensitive, to a lesser extent, to carbon dioxide and hydrogen ion concentration.

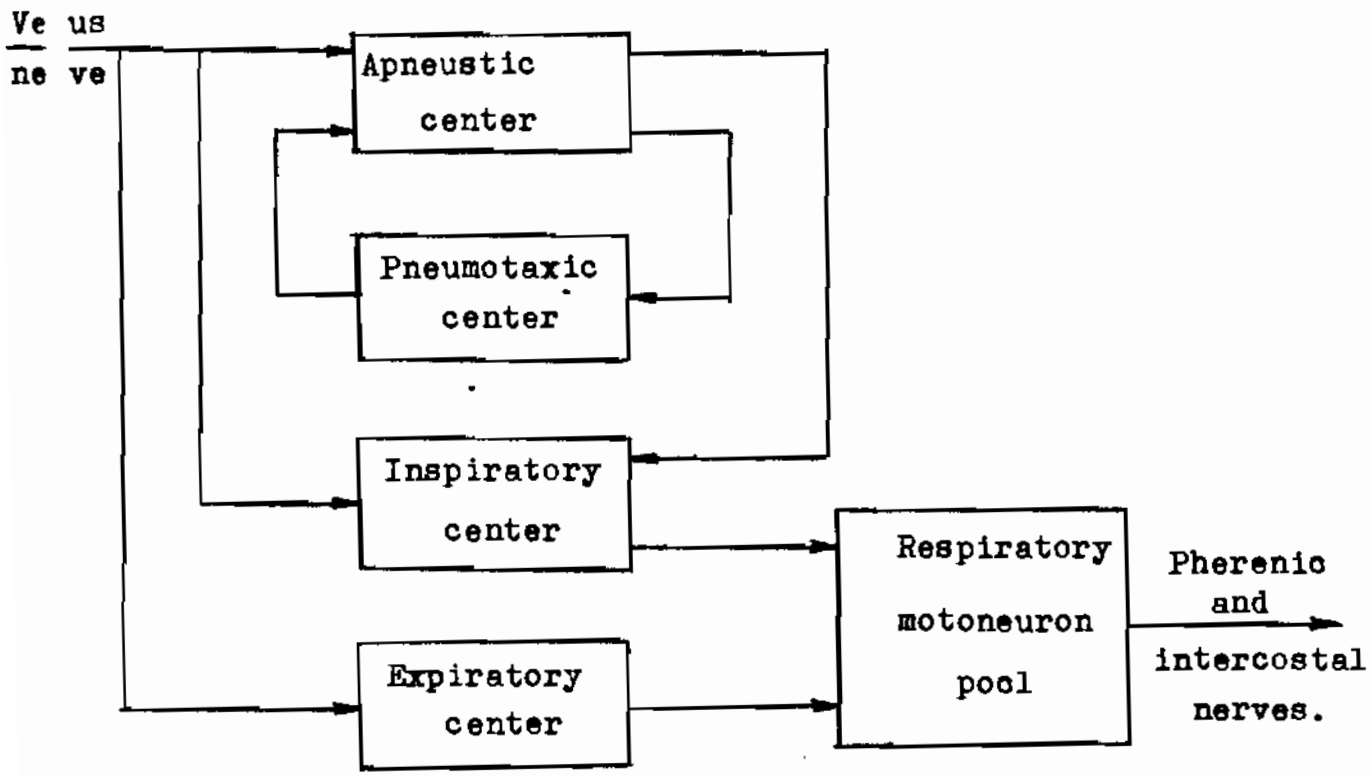

Fig. (1): Signal flow of respiratory center.

P t (III):

P VIOUS TESTS ON RESPIRATORY CONTROL SYSTEM.

A number of tests, both chemical and experimental, have be n devised to elict information about the human respiratory sy tem. The discussion here will emphasize only those which re ate to the control aspects of respiration.

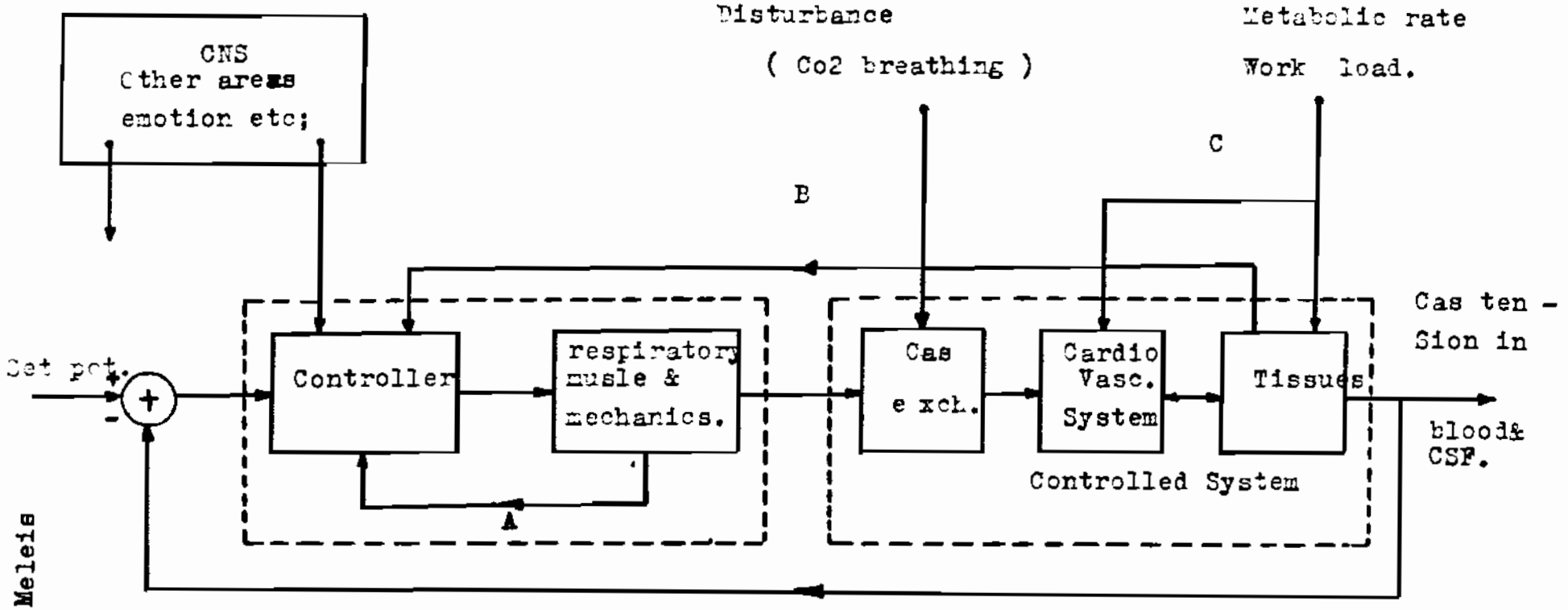

Fig. 2 : Functional Block Diagram of Respiratory Control System .

A = local control loop is involved in control of respiratory rhythm and depth.

B = Represents afferent neural pathways from muscles thatprobably are involved in vausing exercise hyperpnea.

C = Indicated how the respiratory system is coupled with circulation.

In a classical work on the regulation of respiration Douglas and Haldane [12] conducated a series of tests designed to investigate the cause of periodic breathing. This term refers not to the regular inhalation and expiration of air which normal man experiences, but to a periodicity in the total effect - ventilation as measured in liters per minute. Ventilation is normally relatively constant at about six to eight liters per minute. However, ther are subjects in which ventilation, at rest, is periodic. Ventilation builds up from zero to perhaps 16 liters per minute and back to zero in cyclic fashion whith a period of 30-90 seconds. For 10-30 seconds of this period apnea exists, i.e, there is no breathing. Douglas and Haldane showed that transient periodic breathing could be induced in a normal individual by a period of two minutes of hyperventilation (deep breathing). This resulted typically in an apneic period of about two minutes, followed by several cycles of periodic breathing. In this investigation, Douglas and Haldane reported a number of variations on the basic experiment, including shortening the period of forced breathing, breathing pure oxygen during the last two or three breaths of hyperventilation, and breathing an oxygen-poor mixture for the last two or three breaths of hyperventilation. They also showed that periodic respiration could be induced by having the subject breathe through a tin of soda-lime (which removes CO_2 from the air passing through it), the distal and of which is connected to a long tube. Effectively, the subject rebreaths his own expired air after it has been deprived of CO_2. Variations on this experiment include changing the length of the tube and removing the CO_2 filter.

The effect of inhaling carbon dioxide on the respiratory patterns of patients exhibiting periodic breathing has been investigated by Lange [13]. An interesting animal experiment showing the effect of cerebrospinal fluid composition on respiration was reported by Mitchell [14], who were able to change

suddenly the carbon dioxide concentration in the d cerebrospinal fluid of the cat and observe the consequent effects on respiration.

One of interesting investigations for studying the dynamics of exercise was reported by Mandour and El-Awady [15] . It was generally accepted that the control of respiration during exercise is dependent on chemical factors. A respiratory adaption curve due to change in value of exercises was deduced, this value was measured by the amount of laotic acid in the body; (Fig. 3).

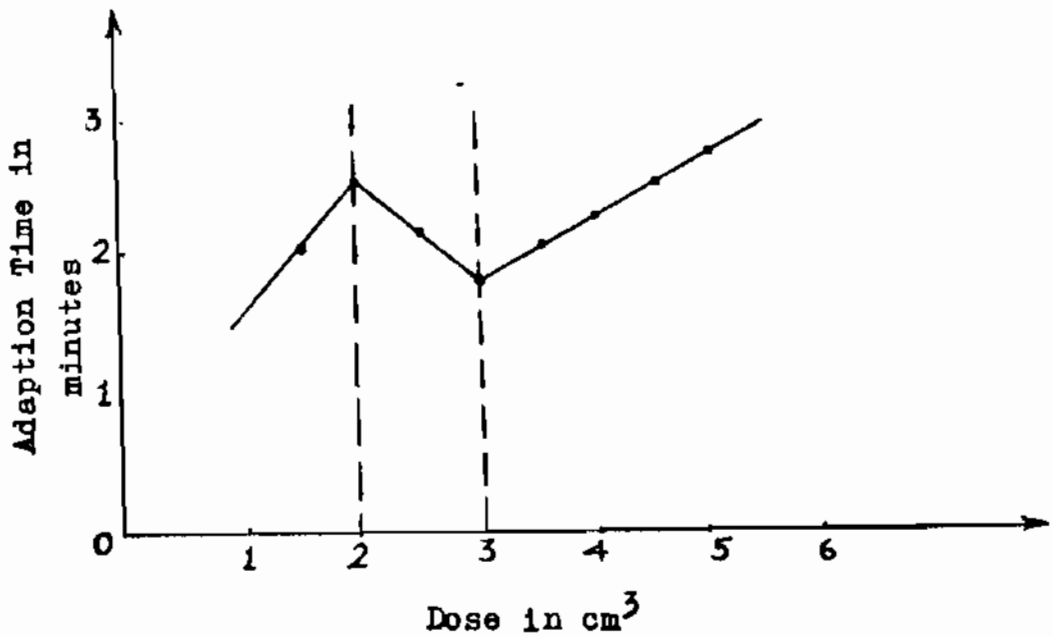

Fig. (3): Respiratory Adaption Time due to Dynamics of Exercise.

Part (IV):

MATHEMATICAL MODELING OF THE RESPIRATORY CONTROL SYSTEM.

Grodins and his associates, in the classical work published in 1954, [16] , were the first to apply the techniques of mathematical modeling to the respiratory control system. A block diagram illustrating their concept is shown in(Fig. 4). In this

nodel, as in most that have followed, individual events during the respiratory cycle or cardiac cycle are not represented.

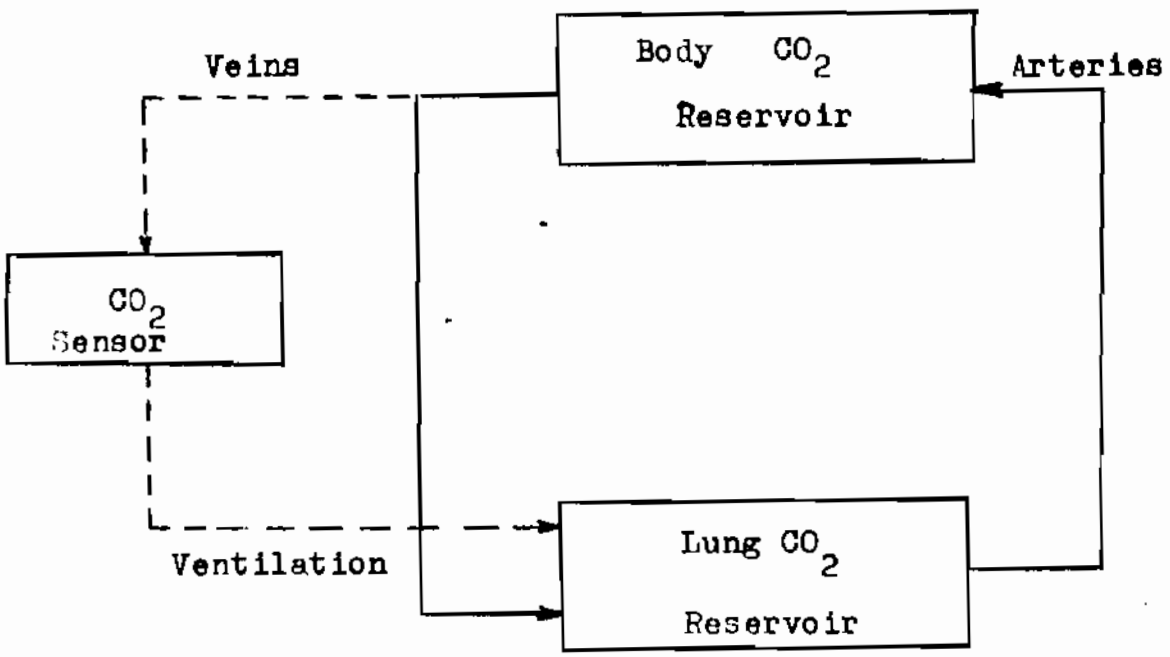

Fig. (4): Block Diagram of Grodins Model of the Respiratory Control System. 1954.

Tha lungs are viewed as a rigid box through which air irculates at the ventilation rate and exchanges gases with lood flowing at a fixad rate. In Grodins' model, the ventilaion rate is assumed to be linearly dependent on the partial ressure of carbon dioxide in the venous blood. The linear, teady-state relationship between alveolar ventilation and the O_2 partial pressure of arterial blood had been established arlier by Gray [17] . He had alsc shown the linear relationiip between the concentration of hydrogen ions and CO_2 partial ressure of normal blood. Therefore, the effects of PH and

CO_2 changes are combined in the model. In Grodins' model, the effect of O_2 partial pressure on the control of ventilation is neglected. Gray had shown this to be approximately valid for O_2 partial pressures of 75 percent normal and above. Two single time constant reservoirs for carbon dioxide are included in the model.: The lung reservoir and the body tissue reservoir.

In an effect to gain better understanding of periodic breathing, Horgan and Lange [18] presented a model in 1962 in which ventilation was assumed to be dependent on arterial blood, as shown in(Fig. 5). Transport delay and mixing were introduced between lung and arterial chemoreceptors to simulate the flow of blood through the lung and left heart. This delay time was closely related to the period of Cheyne-Stokes respiration as had been observed in patients by Lange and Hecht [19] . In a 1963 publication of Horgan and Lange, [20] . The chemoreceptor characteristic was restored to Gray's form and a second oxygen control loop was added (Fig. 6).

In 1964, Horgan and Lange [21] presented a model of the respiratory control system which included the effects of CO_2 in the cerebrospinal fluid and brain tissue. A more detailed account was published in 1965 [22] . This refinement developed as a result of attempts to simulate CO_2 inhalation with an earlier model [20] . Such simulation was successful only if one of the model time constants associated with mixing in the left heart was arbitrarily increased from 10 to 20 seconds. Unfortunately, induced periodic breathing could not be simulated with this change. Fortunately, the experimental work of Mitchell [14] . Made it possible to induce the effect of cerebrospinal fluid, which was associated with a time constant of 20 seconds, and thus develop a simulation which could mimic both the high frequency phenomena associated with Cheyne-Stokes respiration and the low-frequency phenomena associated with CO_2

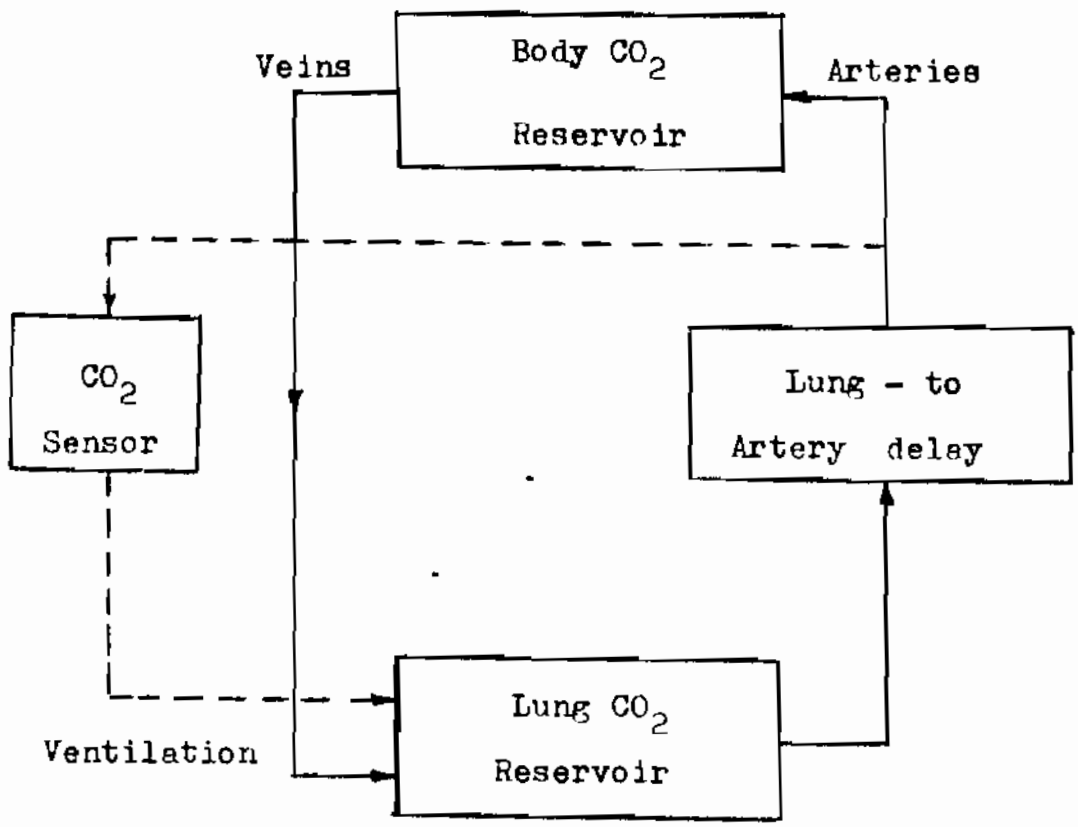

Fig. (5): Block Diagram of Horgan and Lange Respiratory System. 1962.

inhalation. (Fig. 7) shows the block diagram of this model.

In 1965, Milhorn and Guyton published an analogue computer analysis of Cheyne-Stoke breathing [23] . The model, an extension of Grodins' earlier model, includes the addition of circulation times and ventilatory dead space. Like Grodins, they assumed that the chemoreceptor was responsive to tissue CO_2 concentration rather than to the CO_2 in the arterial blood. Thus, while the model could successfully simulate the relatively slow phenomena observed in CO_2 inhalation, it could demonstrate Cheyne-Stokes respiration only when one or more parameters

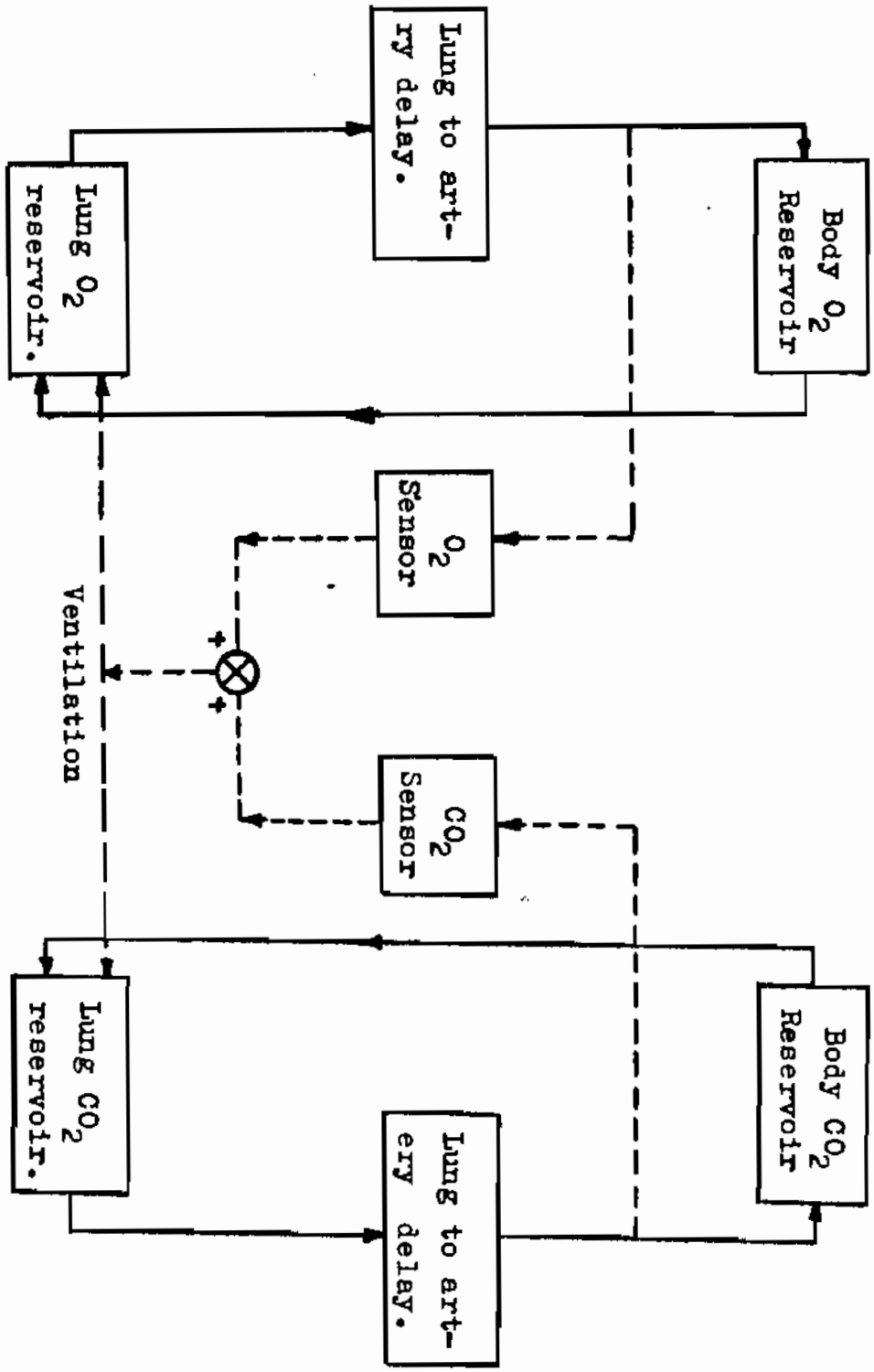

Fig. (6): Block Diagram of Horgan and Lange form of Respiratory System. 1963.

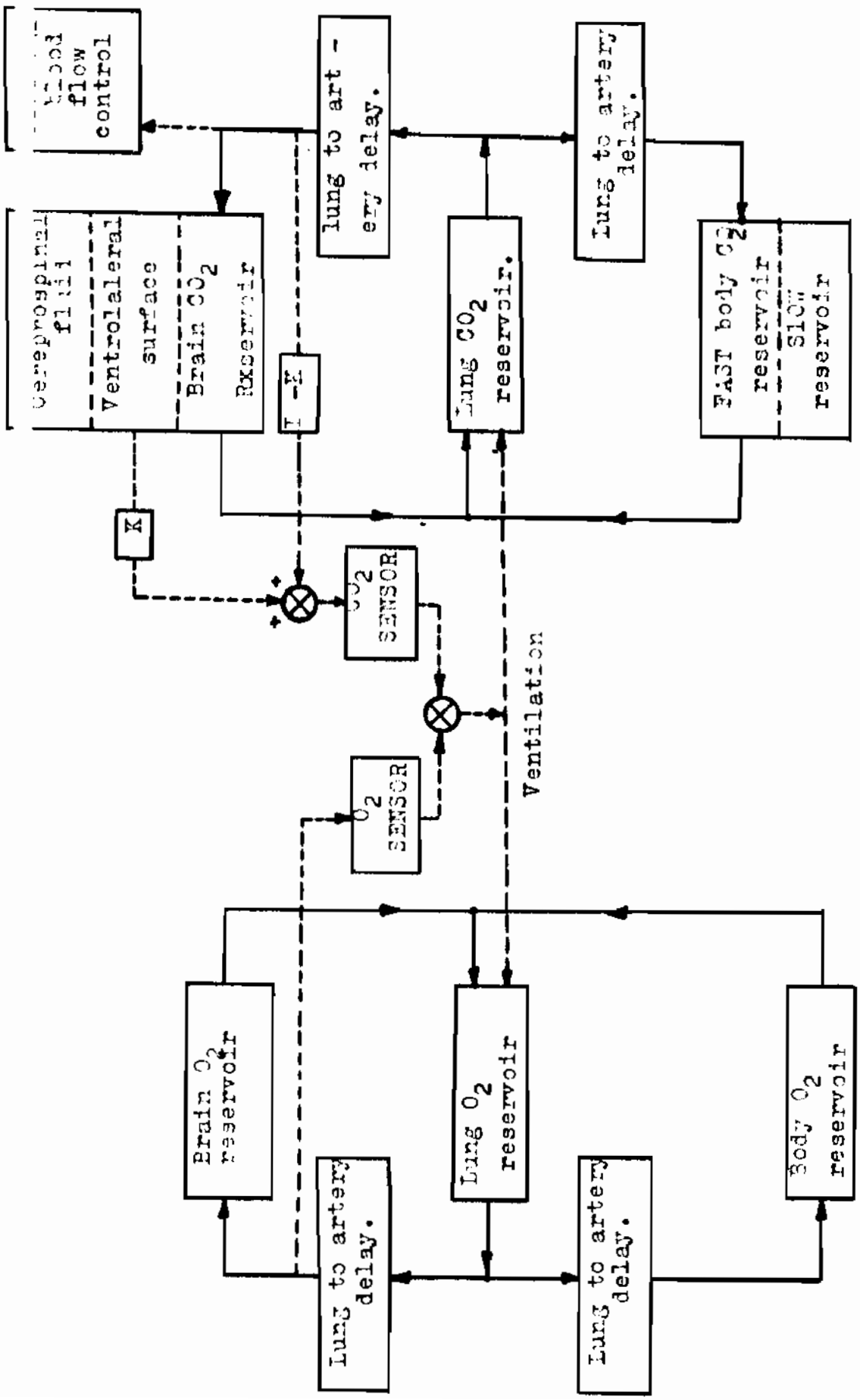

Fig. 7 : Block Diagram of Respiratory System by Defalan 1964.

were adjusted to unusually high or low values. For example, if controller gain is normal, circulation delay time in the model had to be increased to three and one-half minutes, corresponding to a period of seven minutes, to produce sustained periodicity.

A more detailed model was also published by Milborn in 1965 [24]. It ix essentially a three-reservoir model which includes a lung reservoir, a brain reservoir and a body reservoir, with circulation time delays between each (Fig. 8). The effects of both CO_2 and O_2 on cerebral blood flow, as well as on ventilation, are included. The CO_2 chemoreceptor was now assumed to be responsive to cerebral venous blood. This introduced an additional 60 seconds first order time lag, as compared with a chemoreceptor responsive to arterial blood, making Cheyne-Stokes simulation difficult.

In 1966, Longobarda [17]. Published the model of the human respiratory system shown in (Fig. 9). It is similar to the model published earlier by Milborn and Guyton [24], with two important differences: (1) The chemoreceptor is assumed to be responsive to arterial blood rather than cerebral venous blood. (2) The response to CO_2 and O_2 is taken to be multiplicative rather than additive as in all previously published models. Evidence for this multiplicative relationship has been presented by Nielsen and Smith [26] and others.

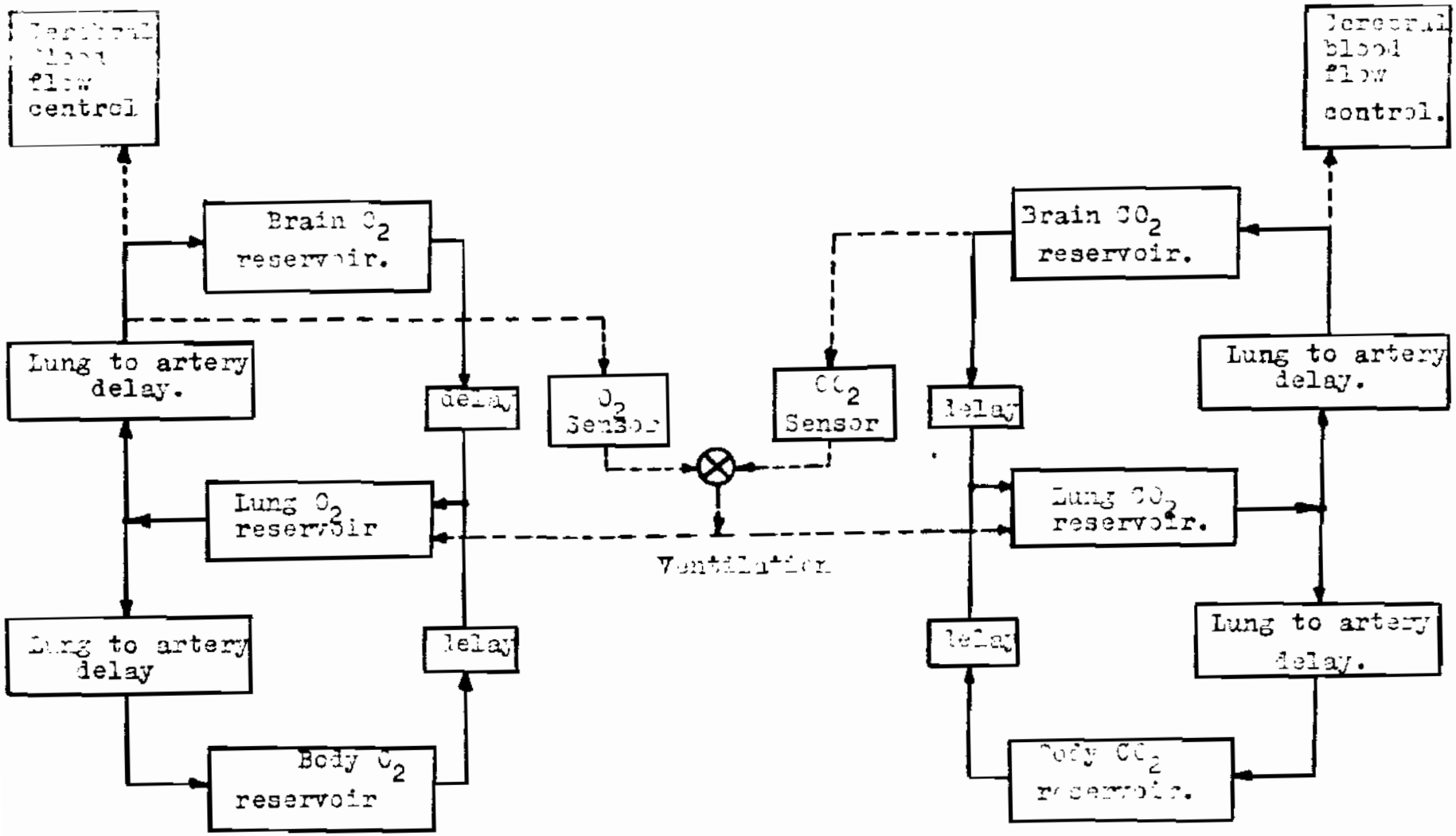

Fig. 3 : Block Diagram of the Respiratory Control

By Milhorn 1963.

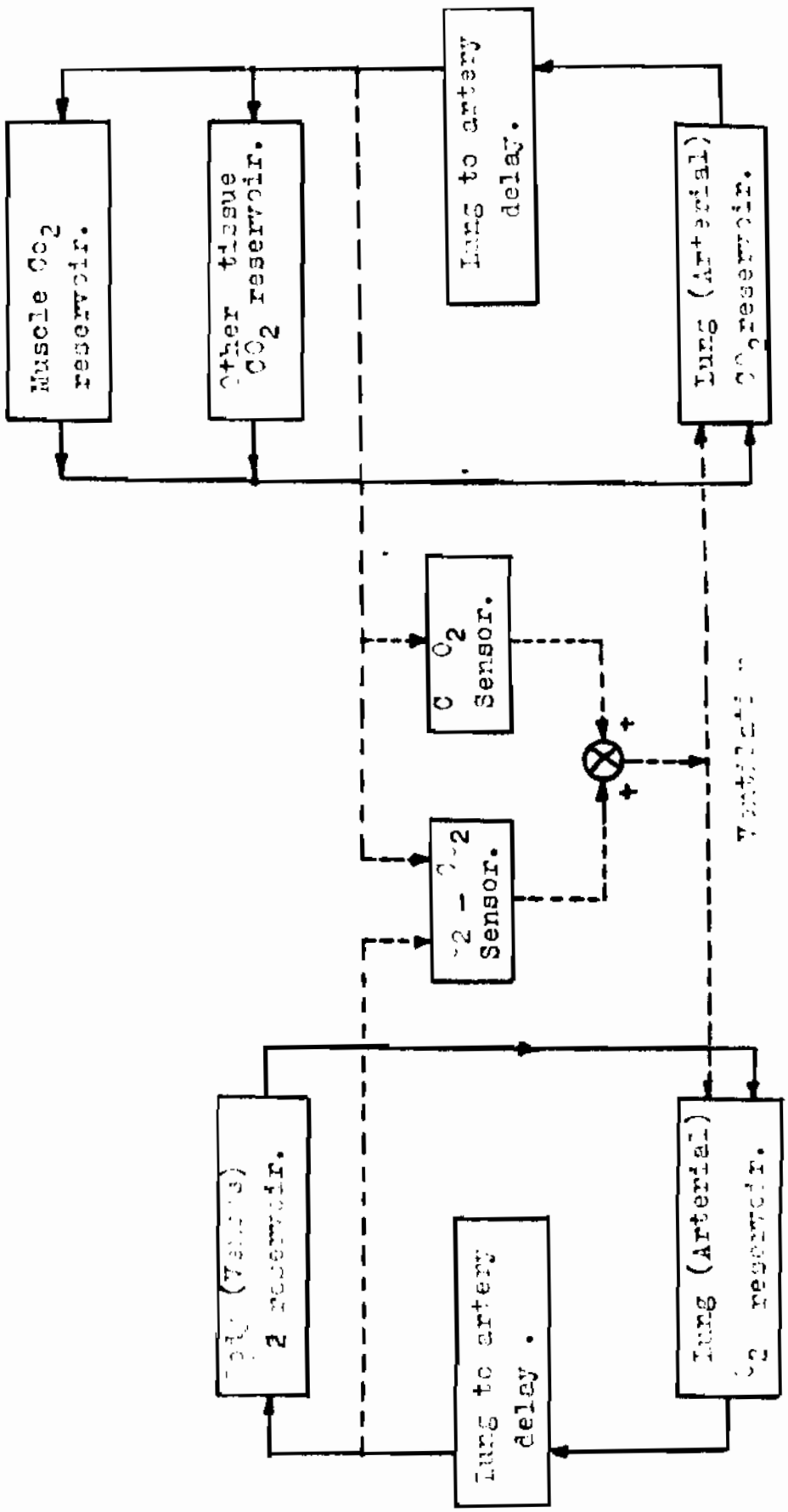

Fig. 9 : Block Diagram of th Respiratory System Model by Longobardo 1966.

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