A **SYSTEM** OF EQUATIONS FOR COMPUTATIONS ABOUT PULMONARY MECHANICS

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INTRODUCTION

A mathematical description of the mechanical system of a person's lungs can be analogous to the description **of** an electrical circuit with pulmonary resistance (electrical resistance), compliance (capacitance), and inertance (inductance). However, to be **useful** and realistic, computations about **respiratory** equipment or work of breathing in unusual environments should recognize the h i t s of attainable forces and volumes and should account for several mathematical complications: the limitations and complications can be of crucial importance in exercise or in persons with pulmonary disease. **One** complication is that resistance is far from a simple constant: the pressure to cause *air* flow depends **on** lung volume, gas density and the flow itself. Furthermore, there can be a mathematical **discontinuity --** when a **person** exhales rapidly, airways may become "choked"; when it occurs, **this** "dynamic airway compression" causes a step increase in pressure for flow.

METHOD

With a system **of** equations which are solved by a numerical method **on** a Macintosh IIcx microcomputer, I estimate **the** total pressure generated **by** the respiratory musculature, **as** a function of time, from **the** flow-resistance, elastic-recoil, and inertance components; calculate the instantaneous pressure-flow product (power); and integrate the power to estimate work of breathing and oxygen requirement for a breath **(1).**

RESULTS

Figure 1 shows **sample** computations **for** a normal person who is exercising vigorously in a normal environment The top panel shows volume during a breath. The second panel shows total pressure, composed of pressures to cause air flow and to overcome elastic recoil. Note that total pressure is not in phase with either volume or rate of change of volume (flow), and that during the expiratory phase, choking of otherwise **open** airways causes a sudden increase (downward) of flow pressure and **total** pressure. The next panel shows flow pressure divided by flow **(** = resistance **)**: **it** varies by a factor of ***5*** during the breath. The lowest panel shows instantaneous power and work for the breath. **The** oxygen cost of the breath is expected ***to*** be proportional to the height of the work curve reached by the end of the breath; it includes a ramp-like **rise** during the choked-airway phase ***of*** expiration.

DISCUSSION

Literature about pulmonary mechanics **tends** to focus **on** one or another isolated aspect; this computer model allows one to develop an overview of how the parts fit together. Application of the system of equations to a person without breathing apparatus in a hyperbaric environment has predicted that the very high pressure necessary to cause *air* flow overshadows the small pressure needed for overcoming inertia of the dense gas (1), and that in hyperbaric environments, an exercising person's ventilation and breathing pattern **are** limited by the muscular forces which can be exerted; mechanical work accomplished is inversely related to ambient pressure. Non-linearity of compliance is important for large breaths, and inertance is negligible except when **the** subject breathes very dense gas.

Although Fig. 1 illustrates **the** consequences of choked airways, exercising people may sometimes **sense** the approach to a choked condition and avoid it by decreasing **the** airflow: this would save **energy** but would require adjustments in other parts **of** the breath if decrease of overall ventilation is to be avoided **(2).**

Those concerned with ergonomics **of** utilizing respiratory apparatus would be well advised to calculate the total work done by a person (work done **on** the person's body structures plus work occasioned by **the** apparatus) rather than just the work **of** breathing through the apparatus divorced from the person. The phase of maximum pressure to move gas through the apparatus will depend on elastic, resistive and inertial properties of the apparatus. The phase relations of **the** apparatus could interact favorably or unfavorably with the phase relations that are intrinsic to the human body.

REFERENCES

1. Van Liew, H.D., Components of the pressure required to breathe dense gases. Undersea Biomed. Res., 14:263-276, 1987.

2. Van Liew, H.D., Compensations for flow limitation while breathing dense gas. In Underwater and Hyperbaric Physiology IX, edited by A.A. Bove, A.J. Bachrach, and L.J. Greenbaum, Jr., pp 449-456, Bethesda, Undersea and Hyperbaric Medical Soc, Inc, 1987.

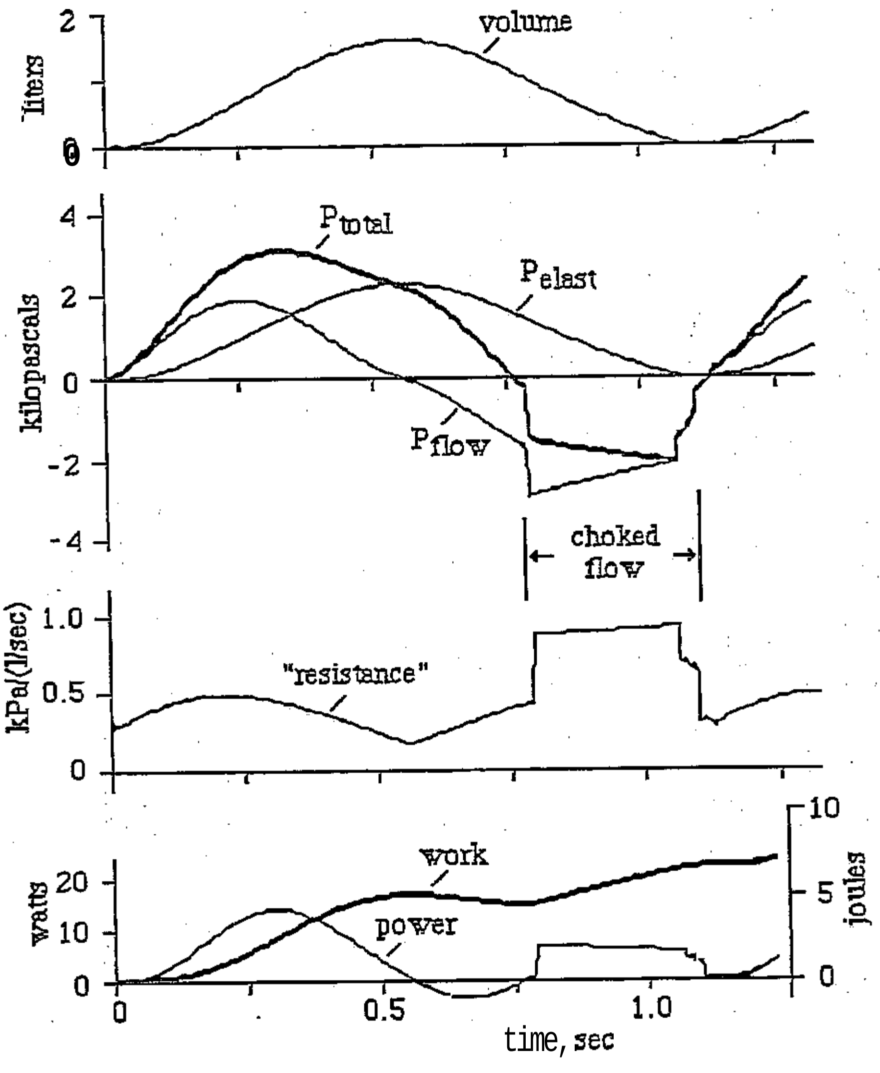

Figure 1. Breath variables vs time during strenuous exercise. For convenience, inflating pressures are shown as positive, as would be the case if the breaths were imposed on a person by a positive-pressure ventilator pump.