Cleveland Clinic

History of Mechanical Ventilation Technology

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Disclaimer

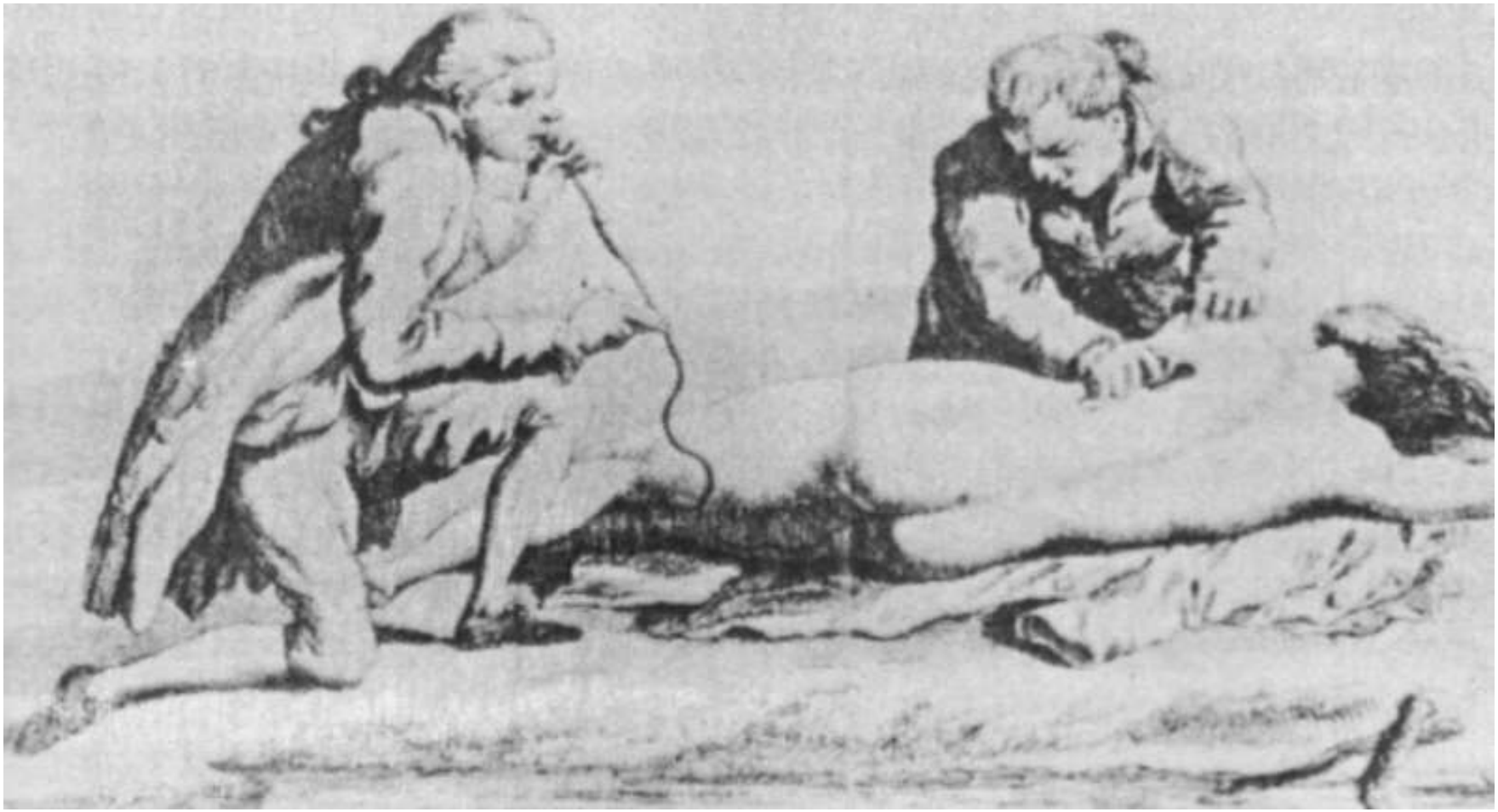
- **All views expressed are my own opinion and not necessarily those of the Cleveland Clinic.**

Disclosure

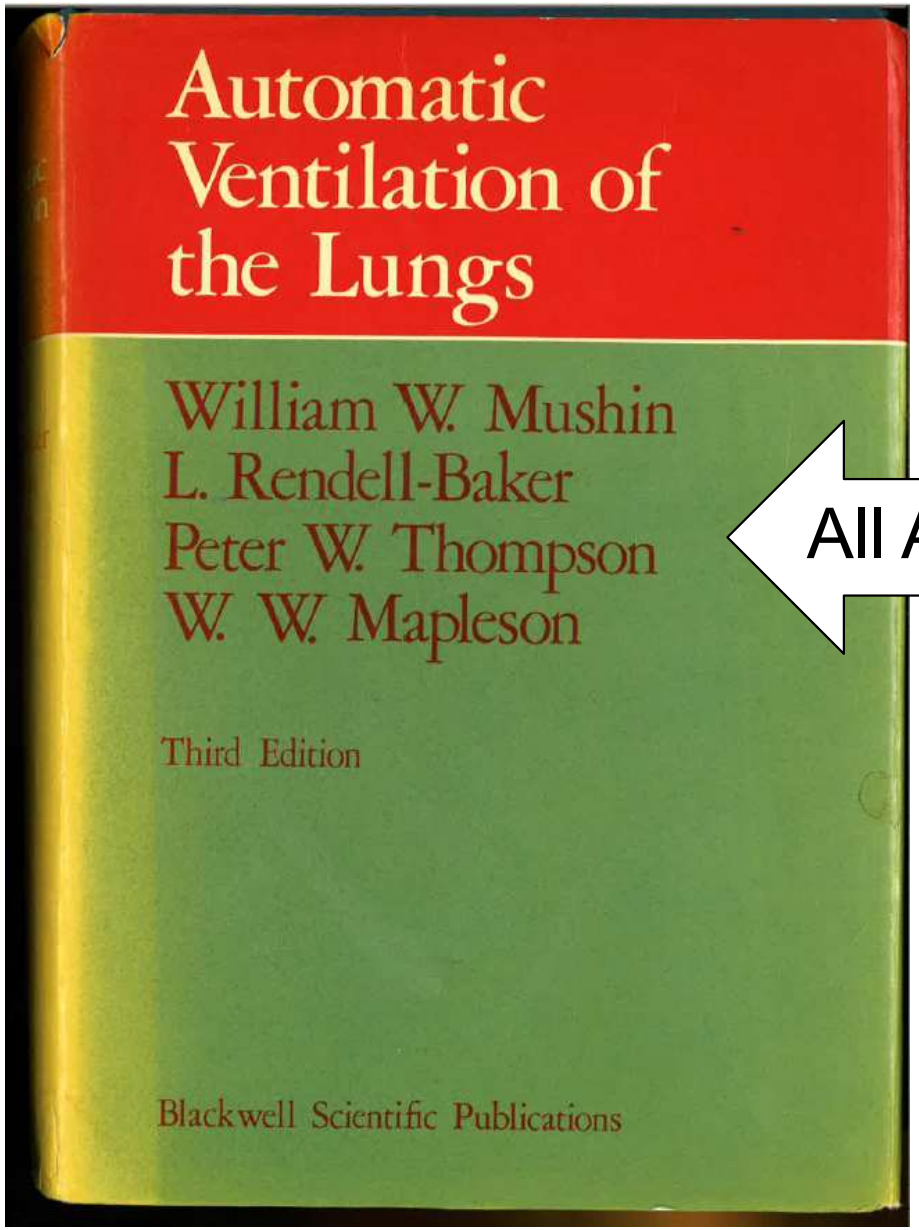
- **I have affiliations with, special interests, or have conducted business with the following companies that in context with this presentation might possibly constitute a real or perceived conflict of interest: :**
  - IngMar Medical
  - DeVilbiss

History of Resuscitation

Origin of the term “blowing smoke”???



Original Bible of Mechanical Ventilation

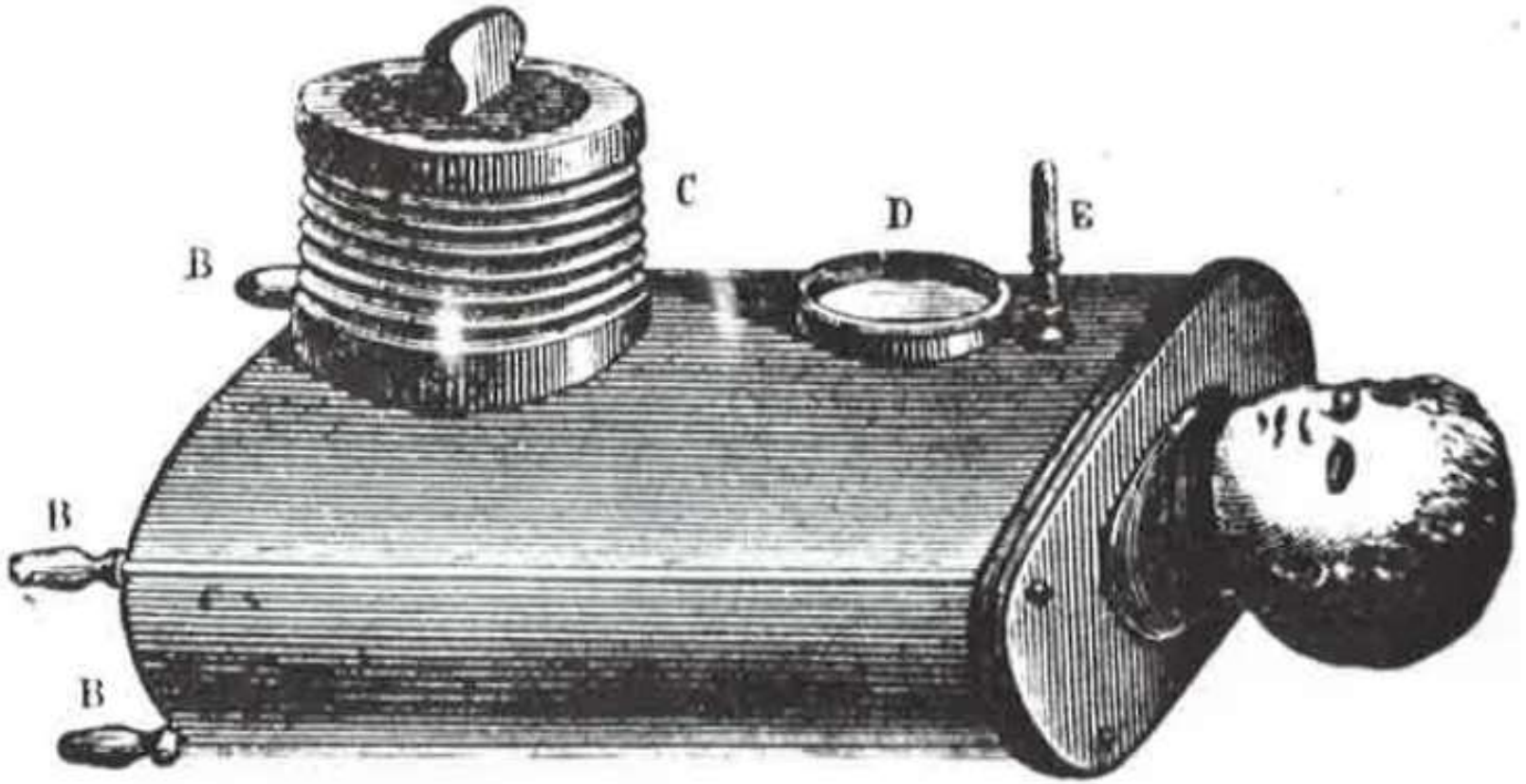


London 1959

All Anesthesiologists

Detailed descriptions of 74 ventilators!

Woillez's Spirophore (1876)



Fell-O'Dwyer Apparatus (1888)

Cleveland Respirator

photo courtesy of Rich Branson

Early Operating Room Ventilator

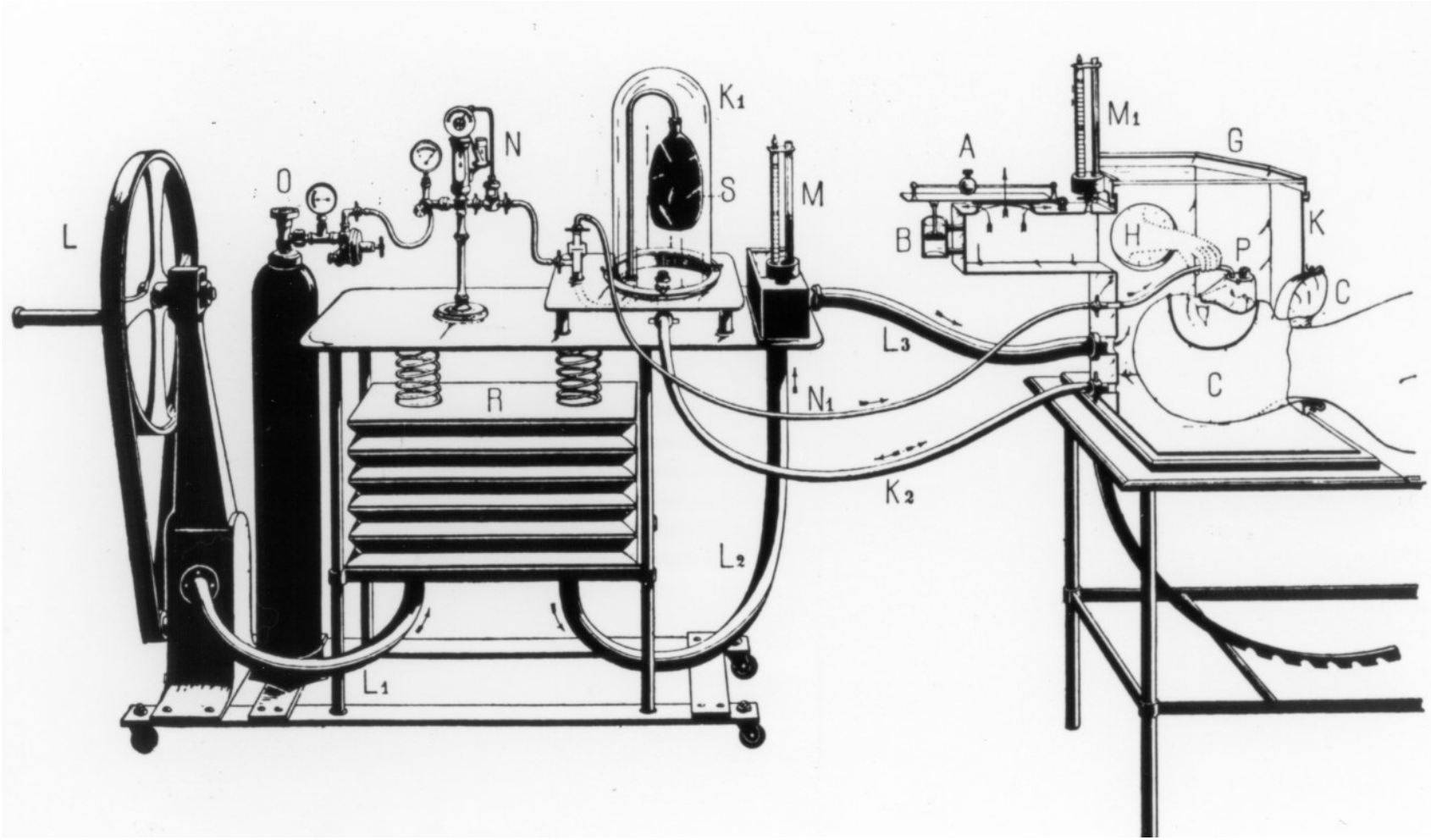
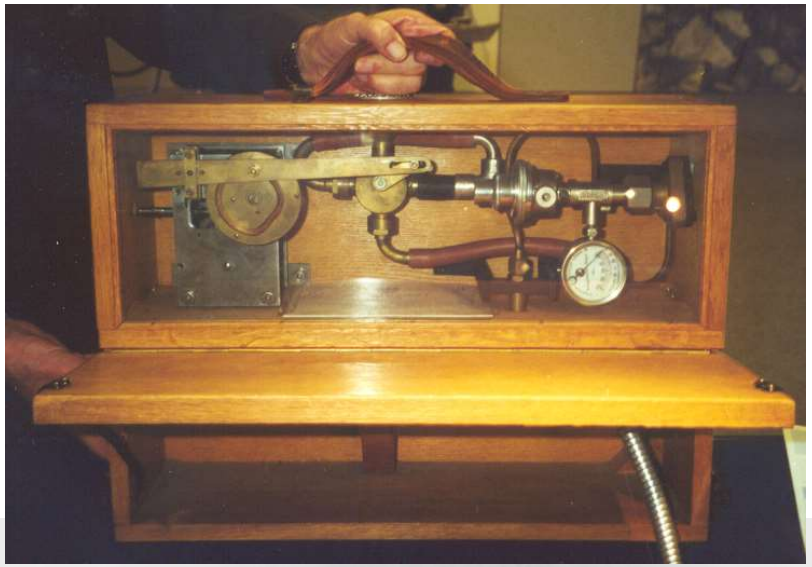


photo courtesy of Rich Branson

Dräger Pulmotor (Germany 1907)

Heinreich Dräger



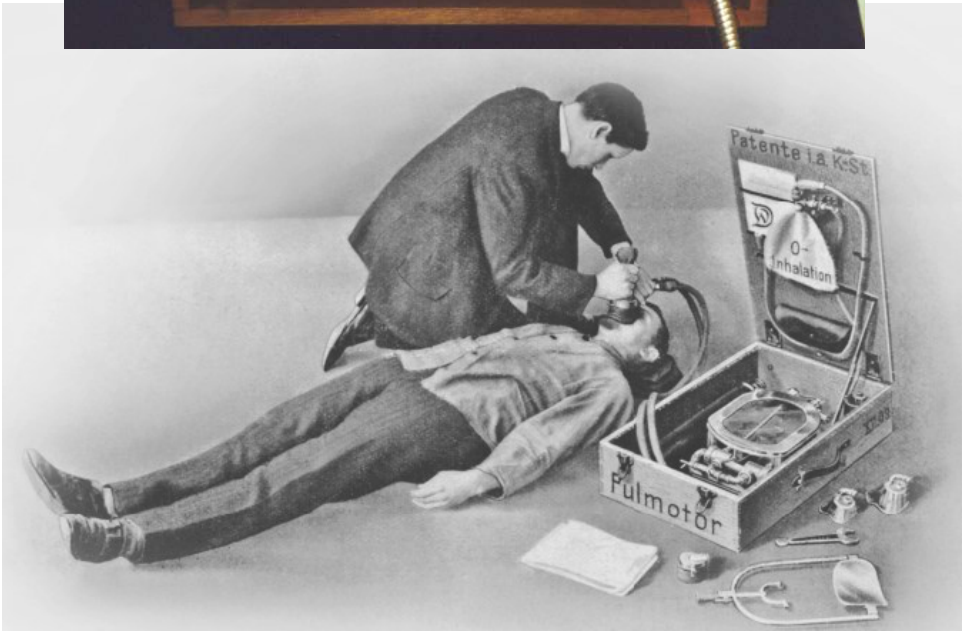
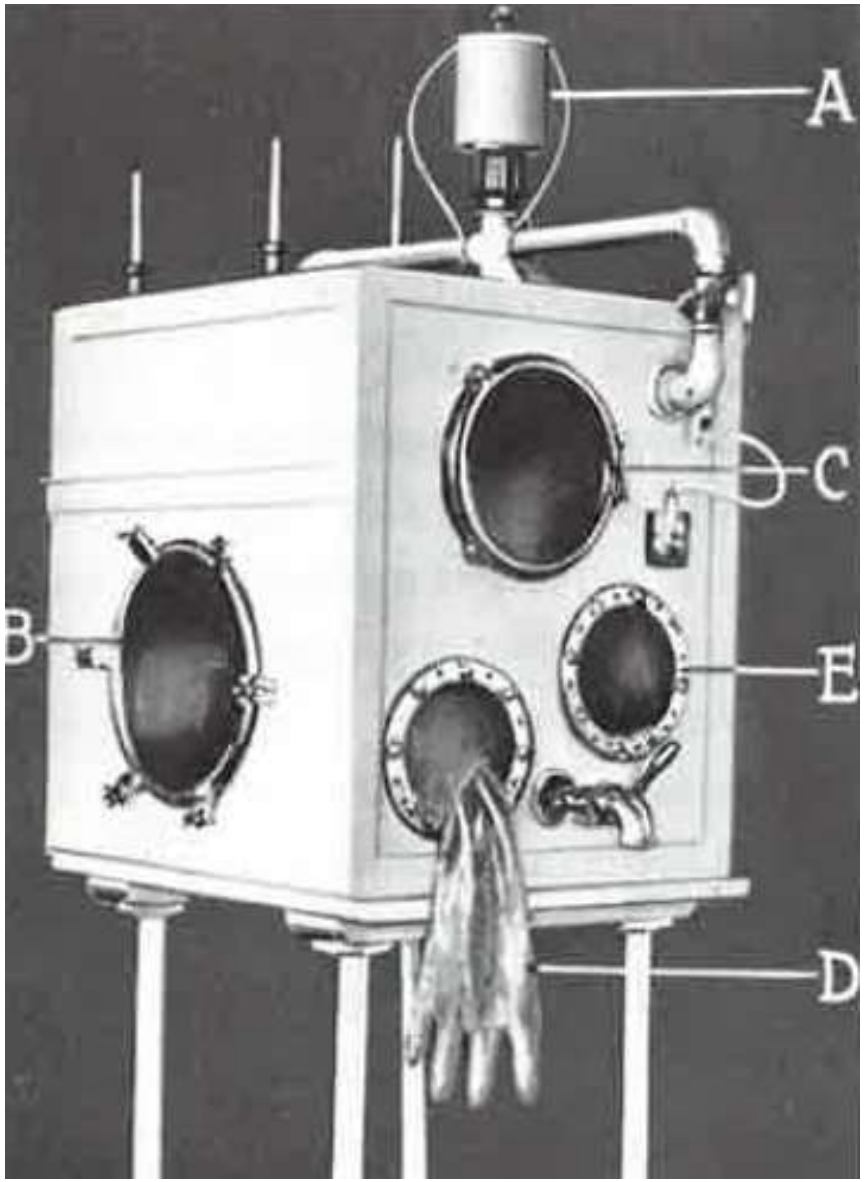
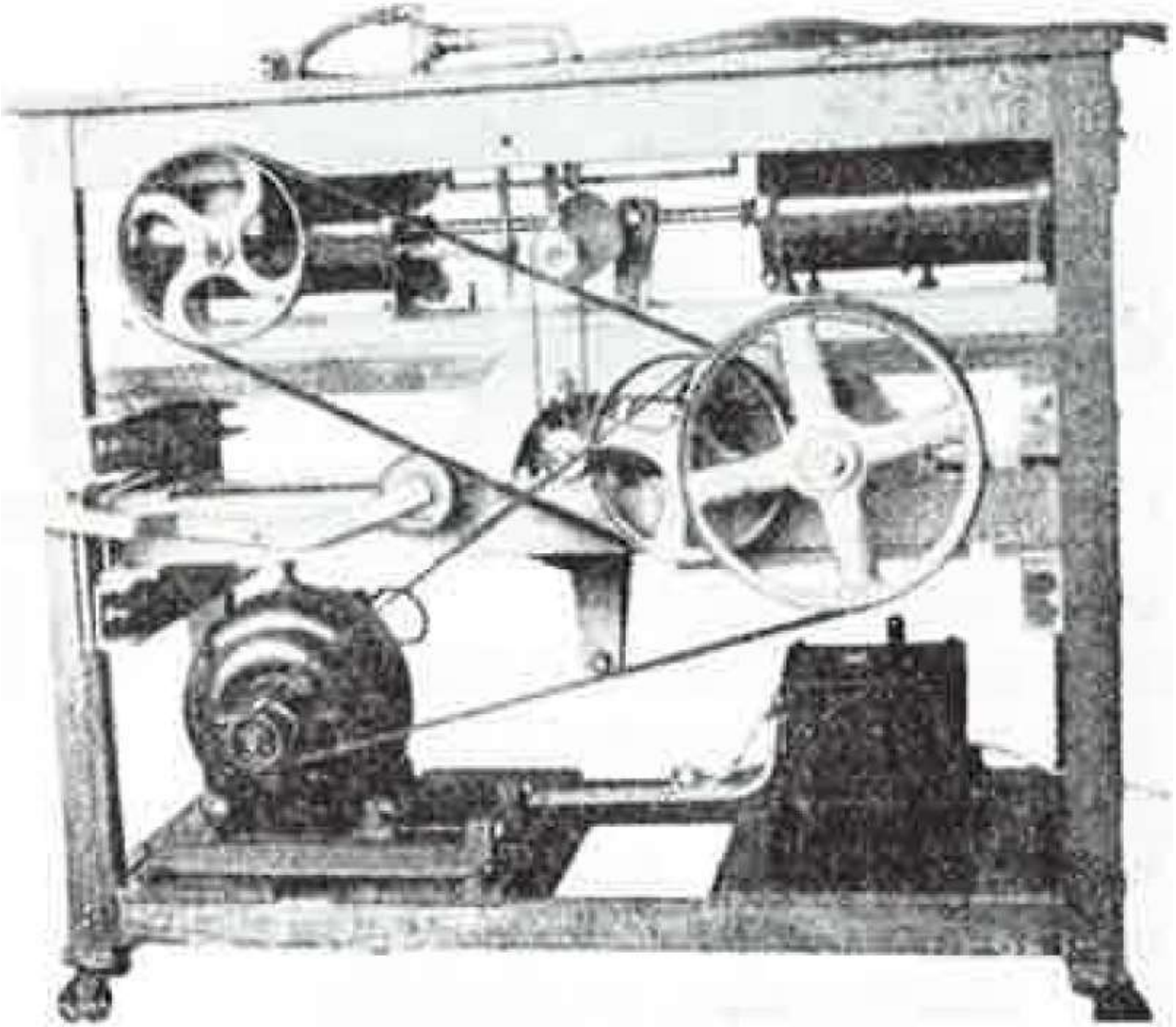


photo courtesy of Rich Branson

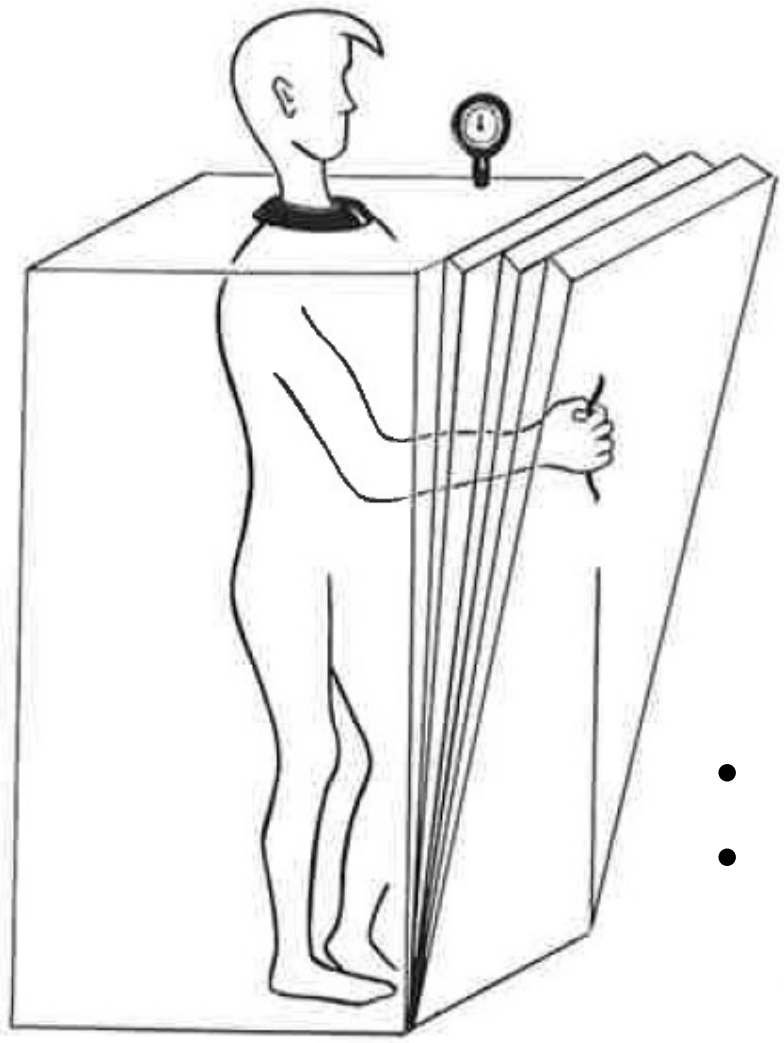
Janeway-Green
Rhythmic Inflation Apparatus (1909)



Läwan - Sievers
Anesthesia Apparatus (1910)

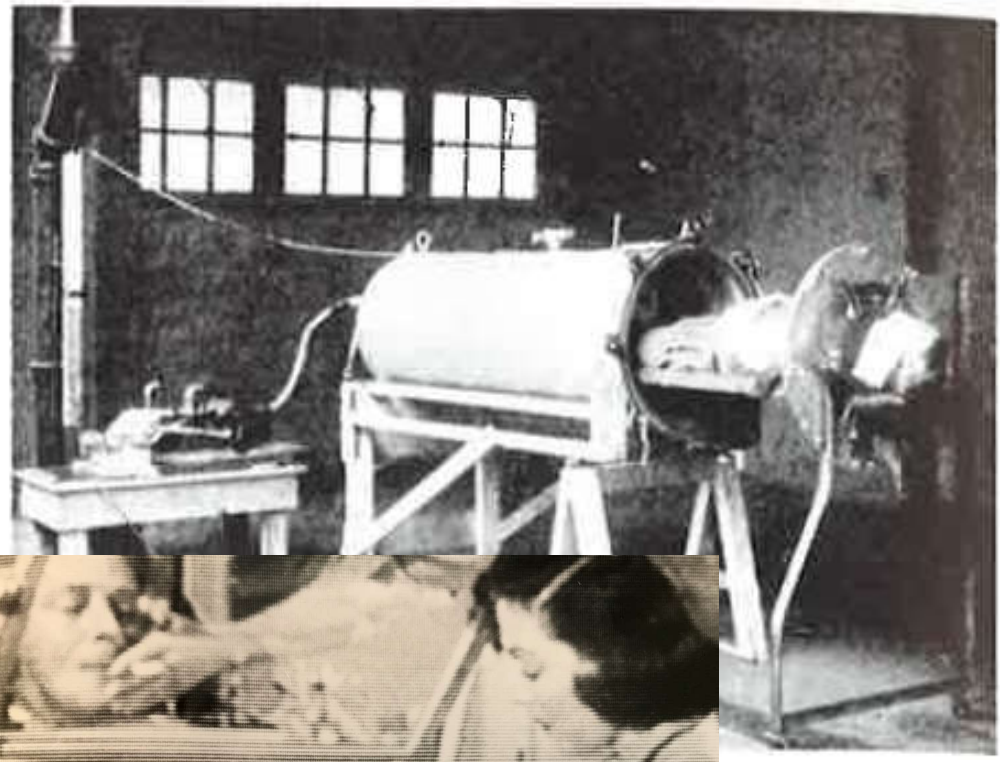


Wilhelm Schwake Germany (1926)



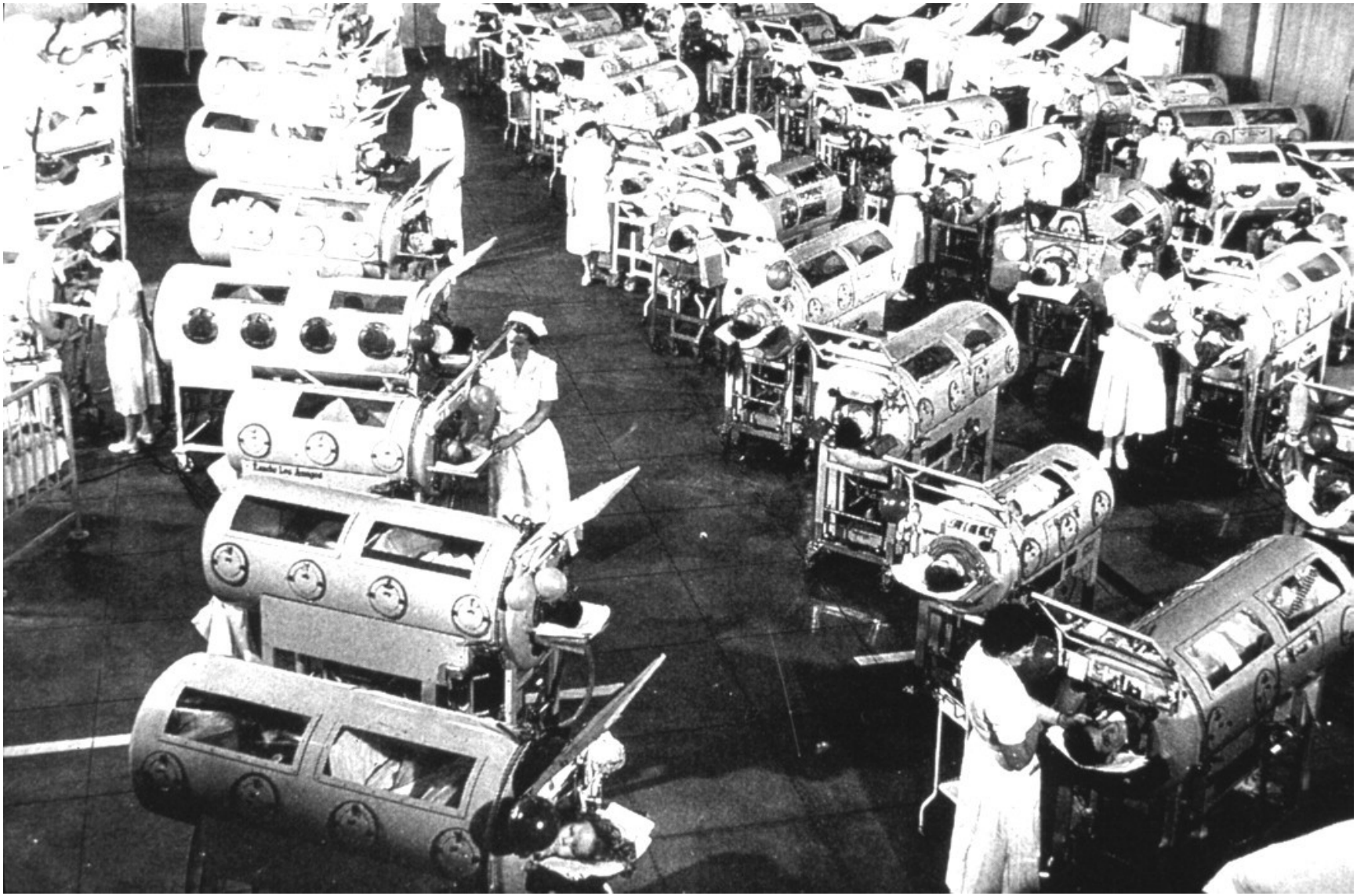
- **Designed to improve synchrony**
- **“Negative pressure on the skin pulls out gaseous by-products”**

Drinker-Shaw
New Mechanical Respirator (USA 1929)

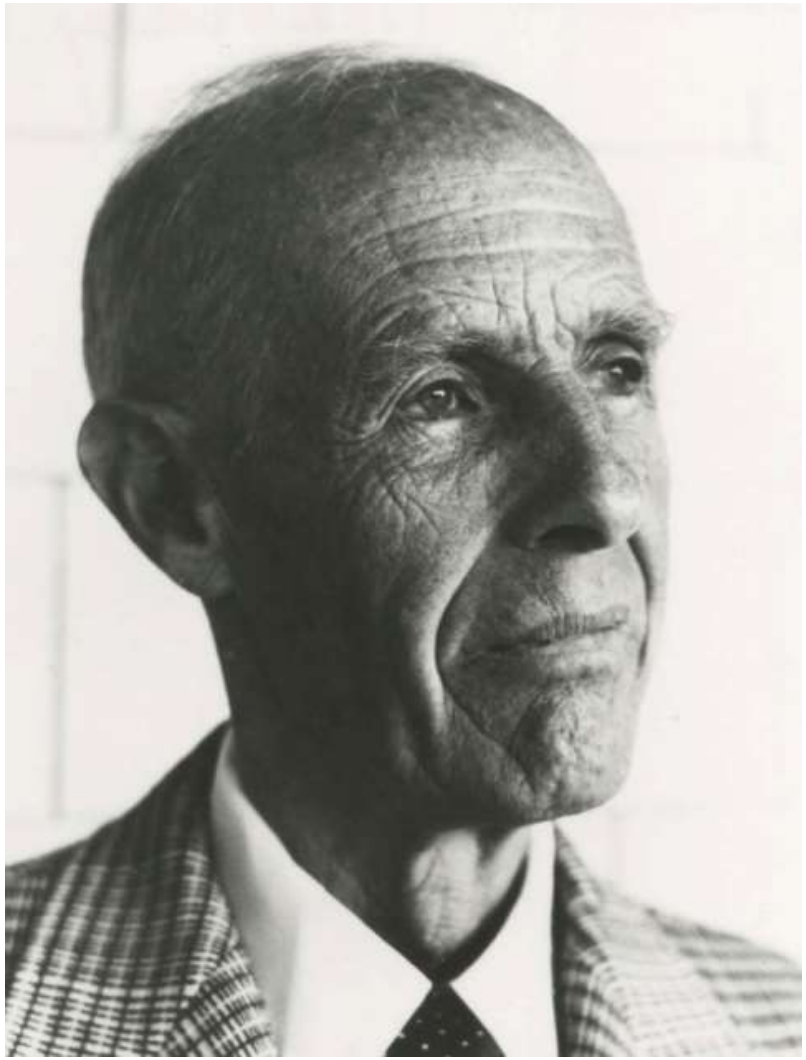


First mass produced Iron Lung
Dräger (1950)

Polio Epidemics



John Haven "Jack" Emerson
(USA 2/5/1906 – 2/4/1997)



Pioneer of tank and piston ventilators

A Good Idea Never Dies

George Emerson

His mom

Mörch III Piston Ventilator (1954)

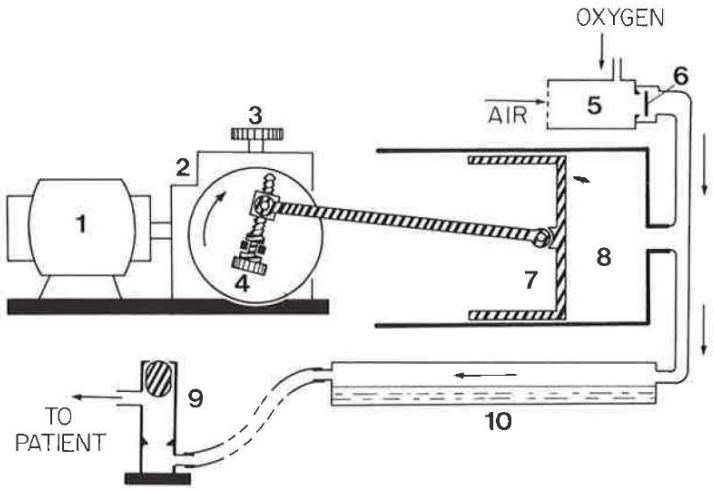
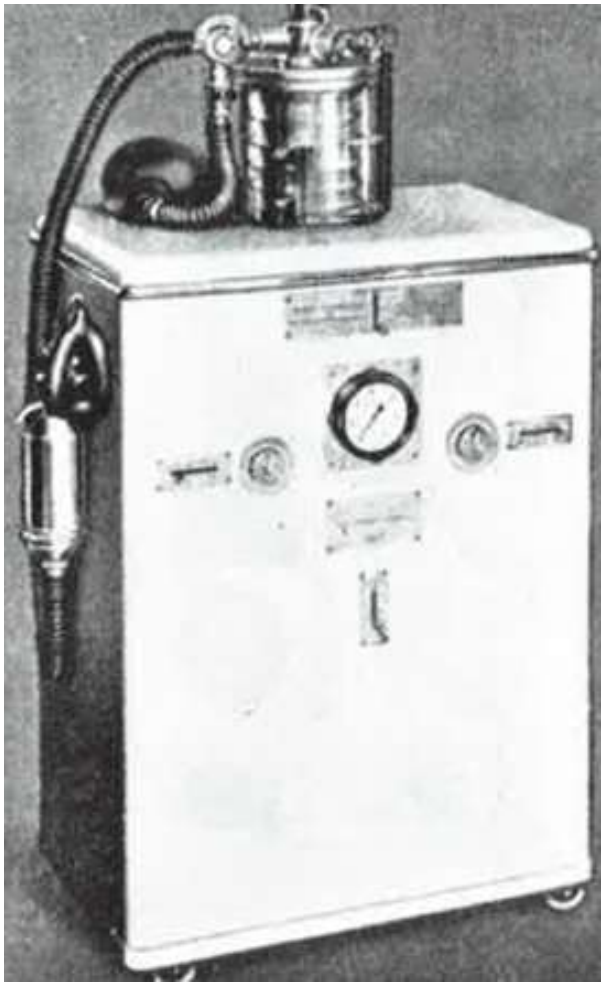


photo courtesy of Rich Branson

Blease Pulmoflator, London (1955)



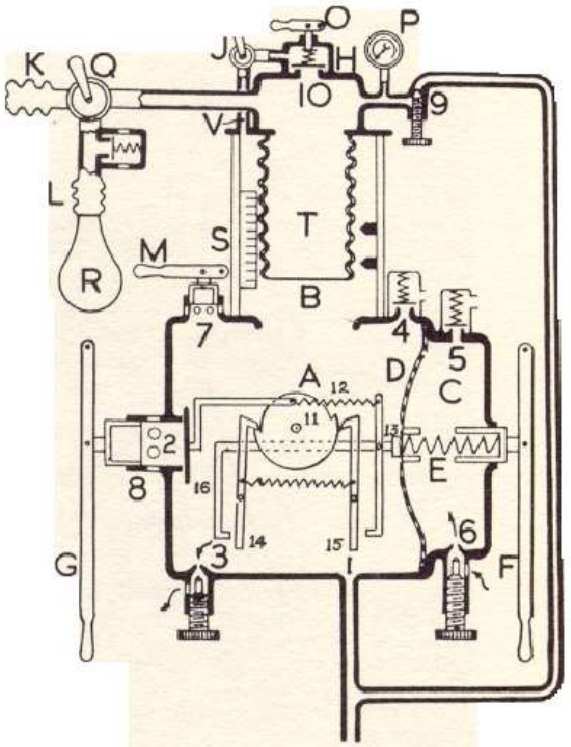
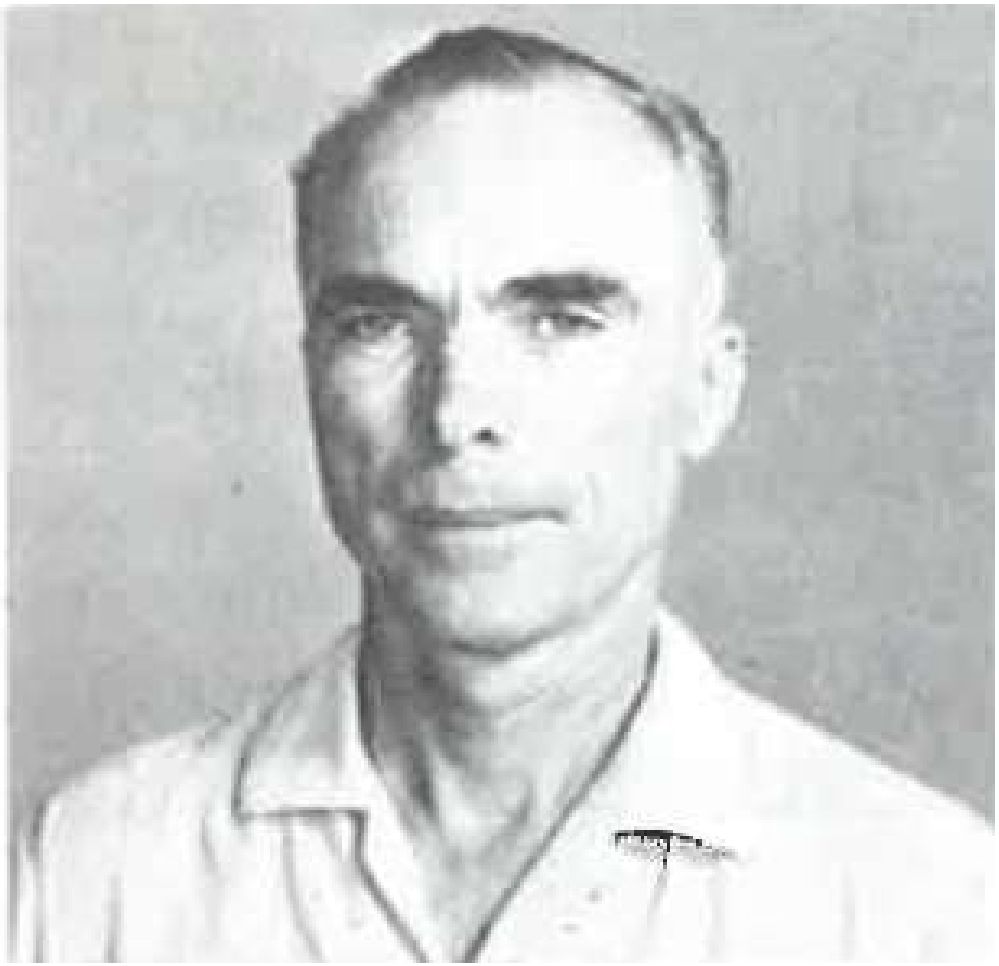


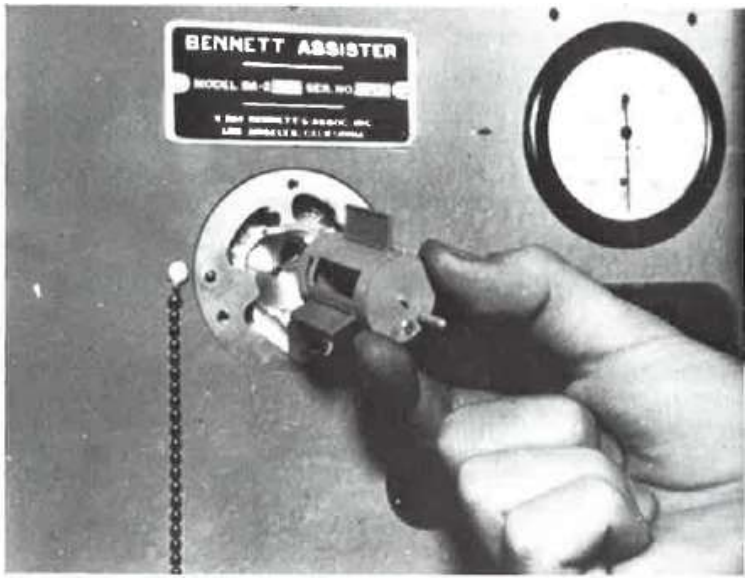
Diagram of Blease Pulmoflator

photo courtesy of Rich Branson

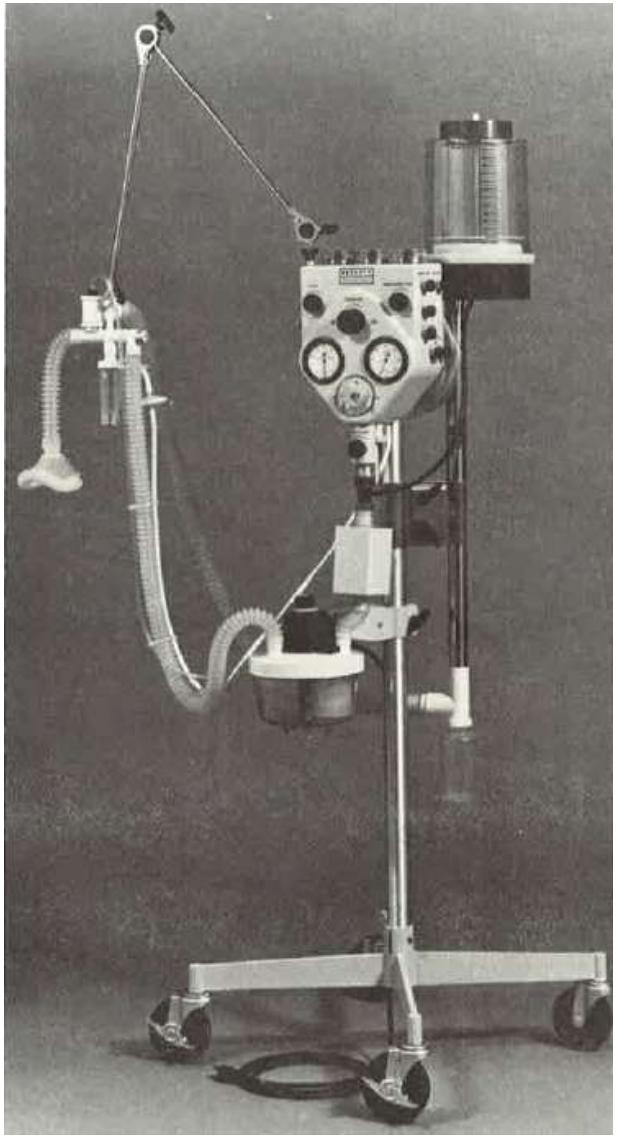
Ray Bennett, USAF (1970)

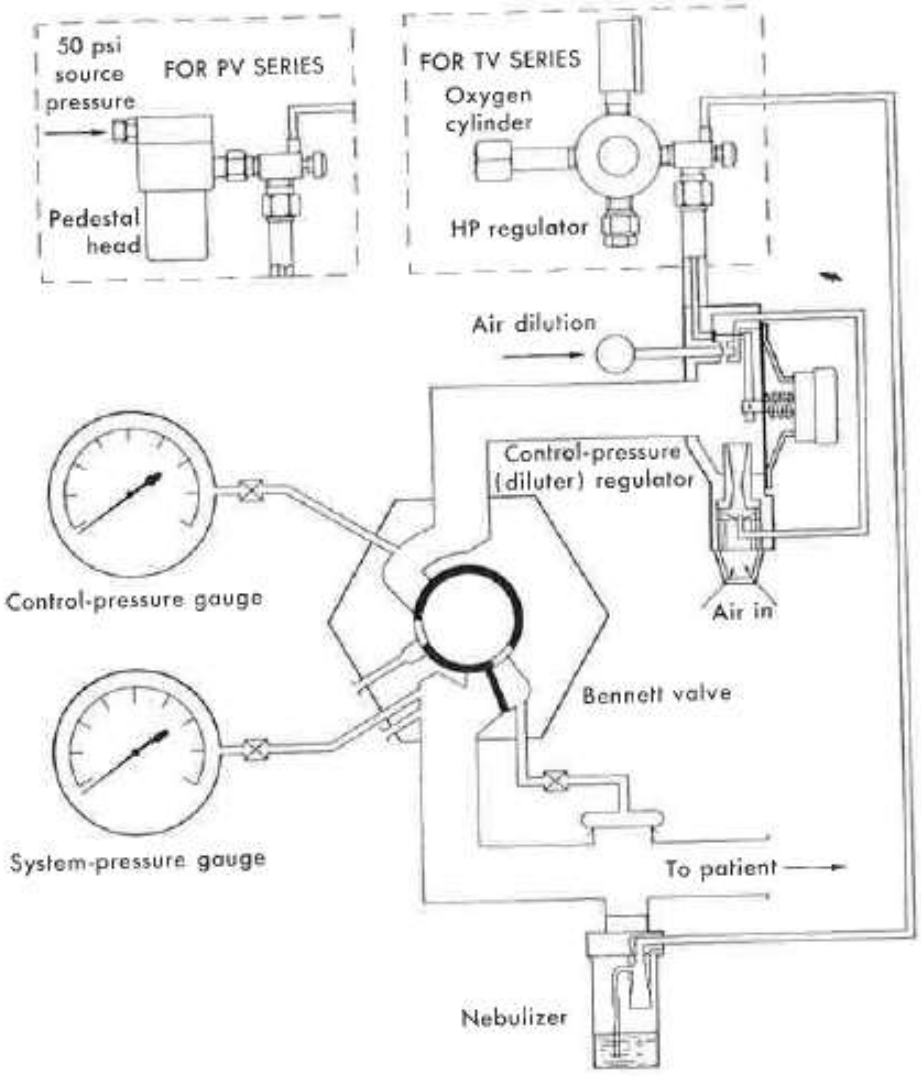


Flow control valve (1947)

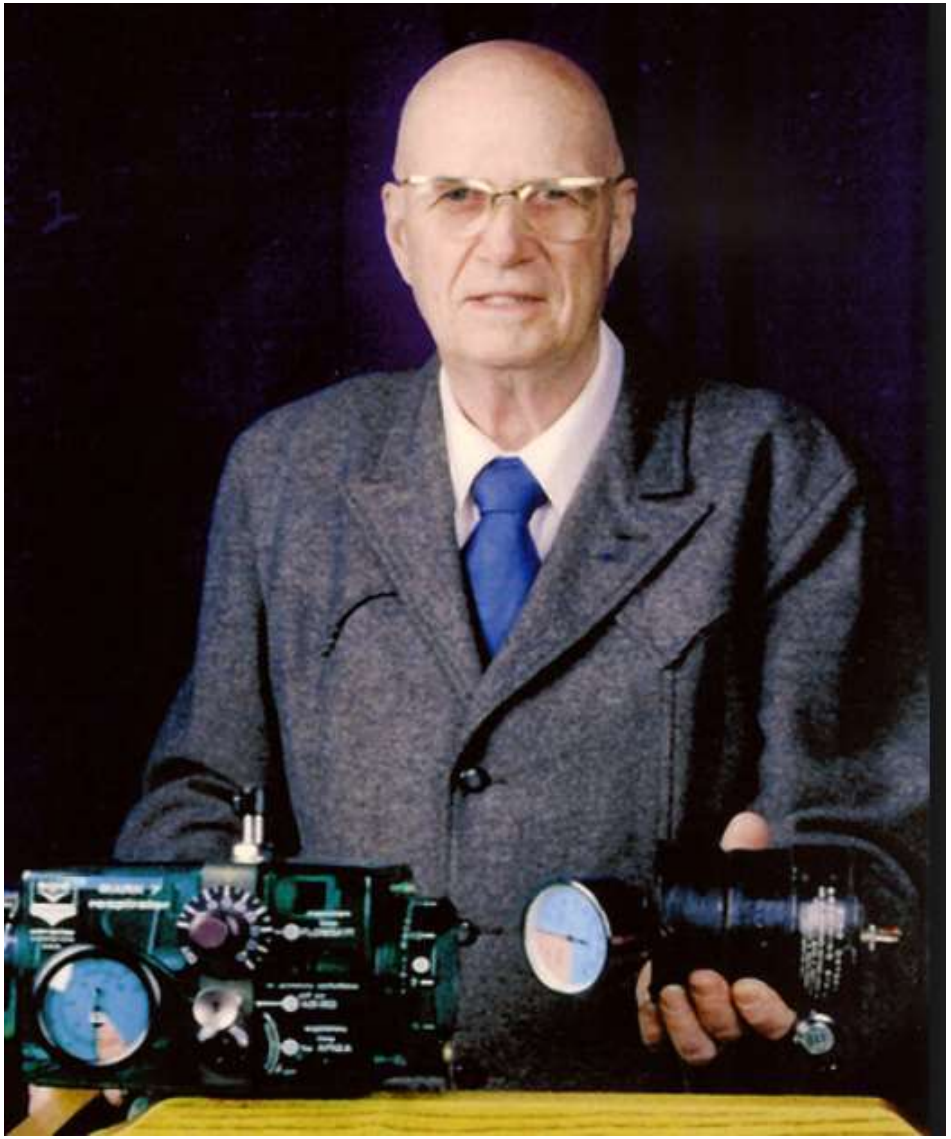


PR Series Ventilators (1948-1990s)





Dr. Forest Bird (1958)



Magnets and clutch plates

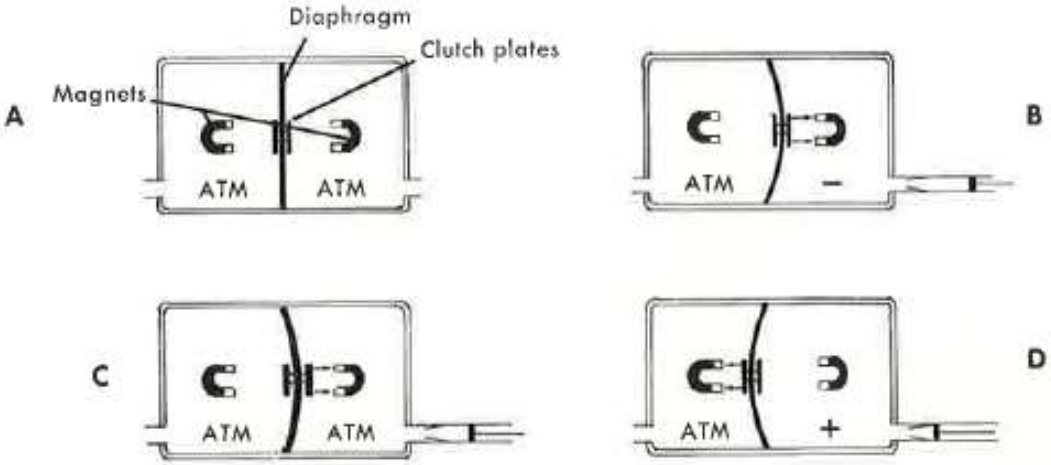


photo courtesy of Rich Branson

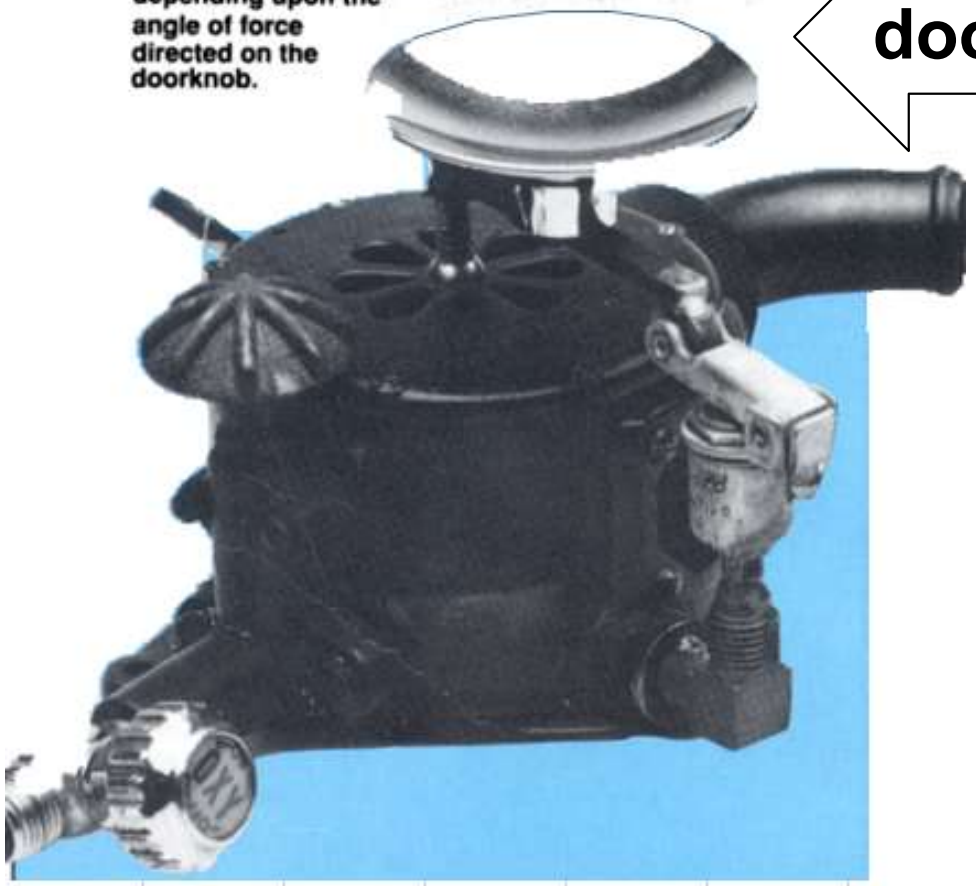
Bird Prototype Mark 7 (1951)

coffee can

photo courtesy of Rich Branson

Bird Prototype IPPB (1949)

(1949) Initial prototype of the hand-operated IPPB device. Note the silver doorknob on top for actuation of the unit. There are two sets of springs, one in the center over the diaphragm and one on the right-hand side. Depressing the doorknob straight down activated the positive pressure (by depressing the diaphragm) and flow for nebulization of medications (by depressing the spring on the right-hand side). This allowed the patient to have nebulization, positive pressure, or both — depending upon the angle of force directed on the doorknob.

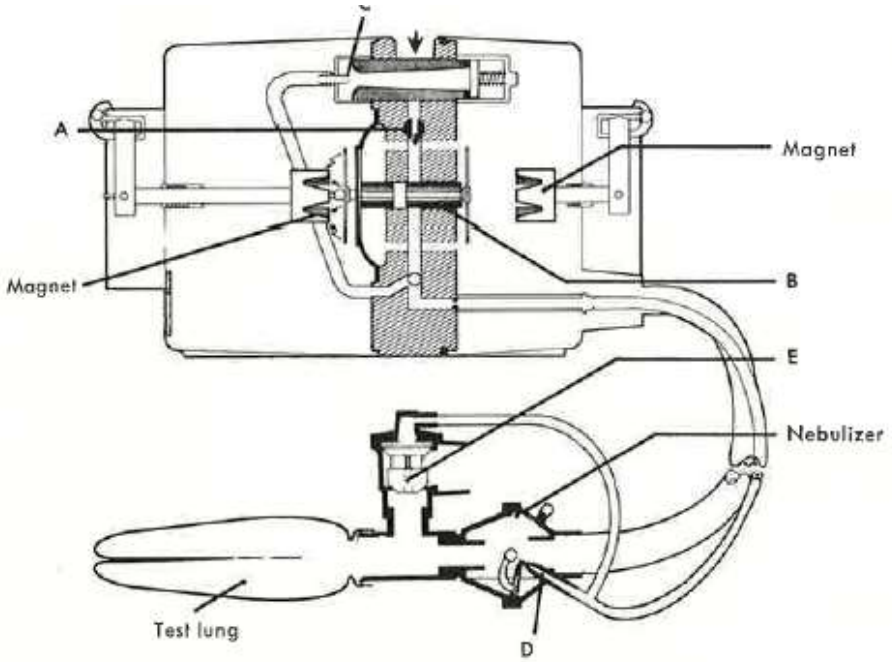


door knob

- positive pressure
- nebulization
- both

photo courtesy of Rich Branson

Bird “Respirators” (1959 to present)

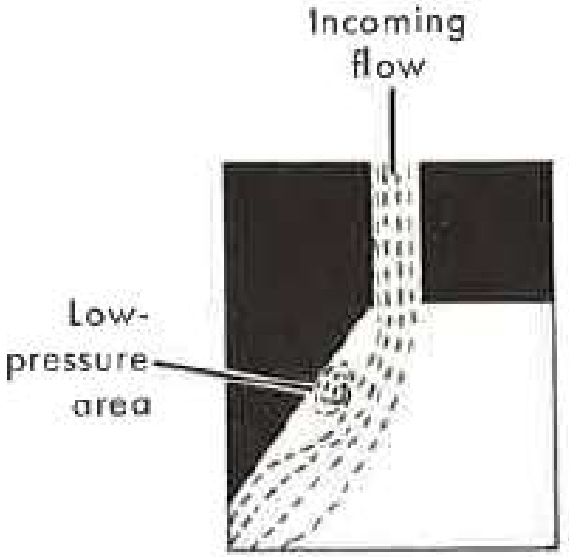


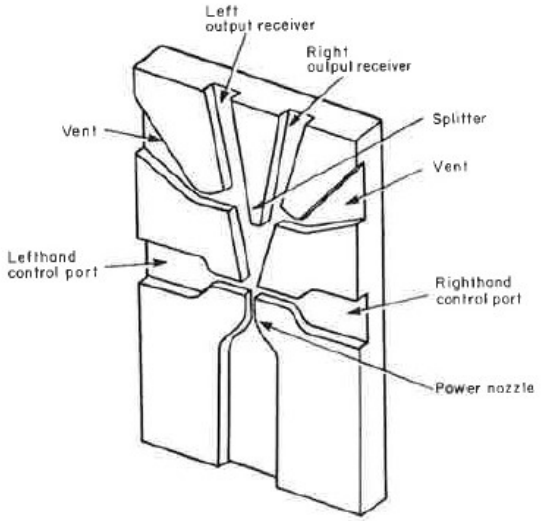
Henri Coanda (1933)
Father of fluidic control devices

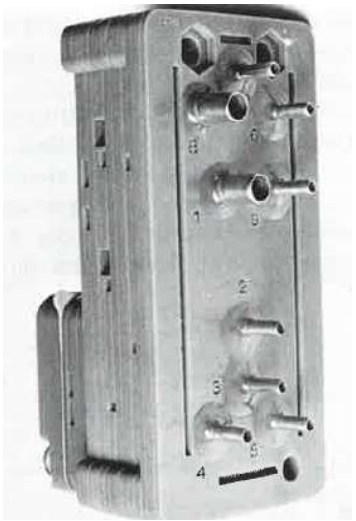
- Designer of early jet planes
- Discovered “wall attachment effect” – later named “Coanda Effect”

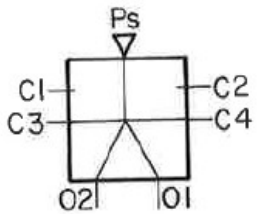
In his first and last jet test flight, the plane emerged from a sheet of flame and smoke. Coanda said “Apparently I had given it too much fuel. When I looked over the side I saw flames shooting out, and that should not be. I ducked inside to adjust matters. A moment later things felt very differently. I looked outside again to find myself many feet in the air. Straight ahead of me was the Paris wall. I didn’t know what to do. I pulled on the control wheels, the machine went up on one wing and I was thrown out. The plane crashed at the foot of the wall”

Fluidic Logic Control Circuits

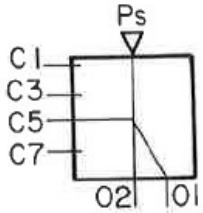




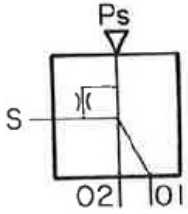




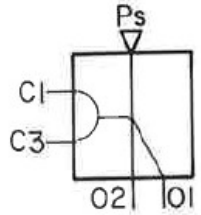
(A) FLIP-FLOP



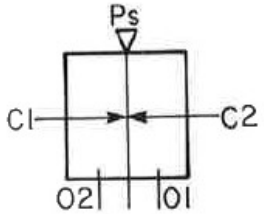
(B) OR/NOR GATE



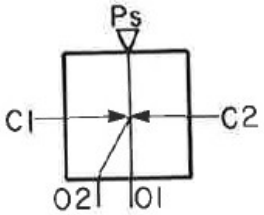
(C) BACK PRESSURE SWITCH



(D) AND/NAND GATE

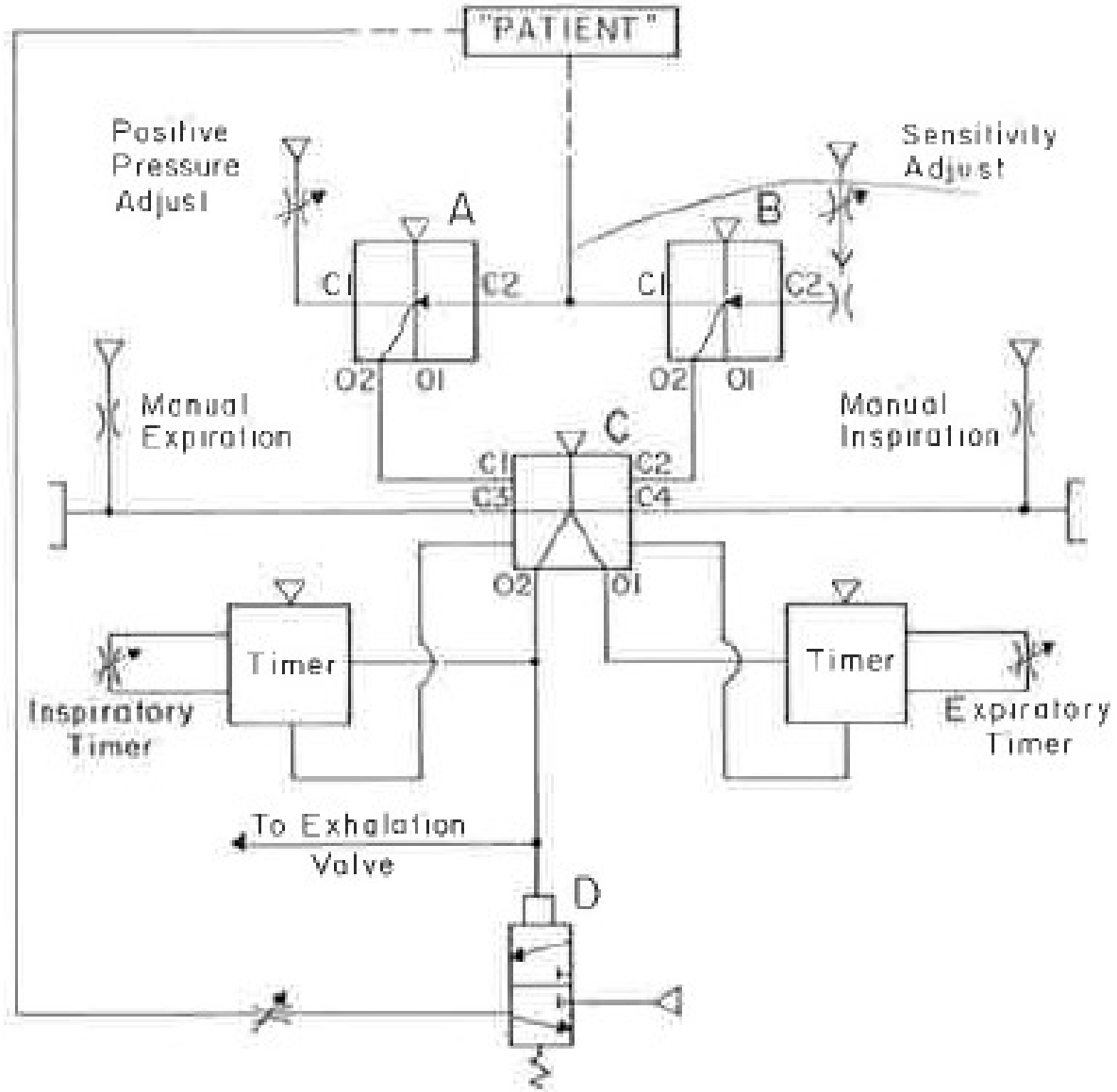


(E) PROPORTIONAL AMPLIFIER



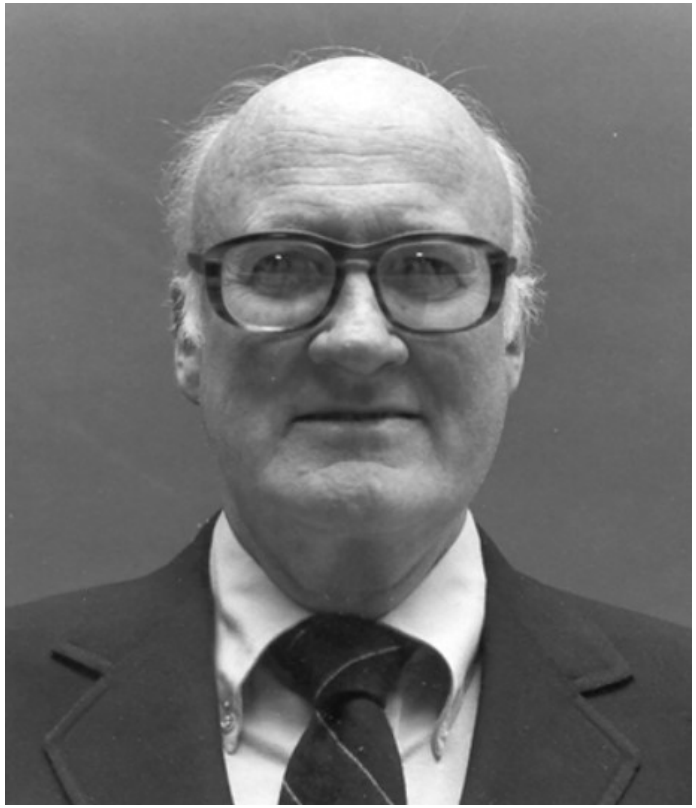
(F) SCHMITT TRIGGER

Corning Fluidikit Ventilator Circuit (1980s)



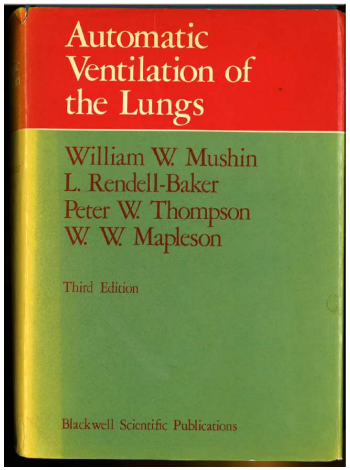
Dr. Jere Mead (1920–2009)

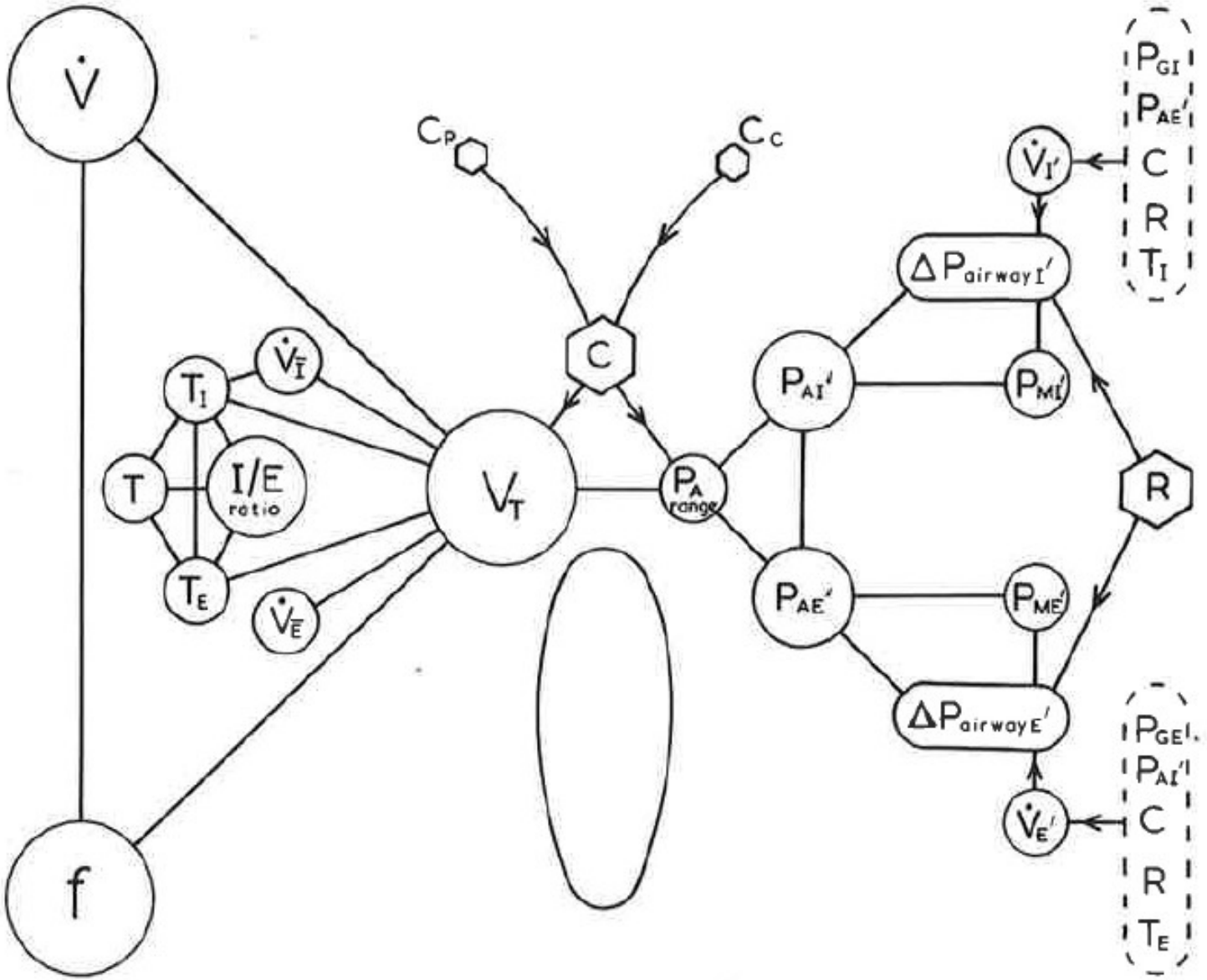
He established a whole new field of research.
Respiratory Mechanics was his invention.
Was the first to use the term "compliance" in medicine an idea he borrowed from electronics (capacitance)



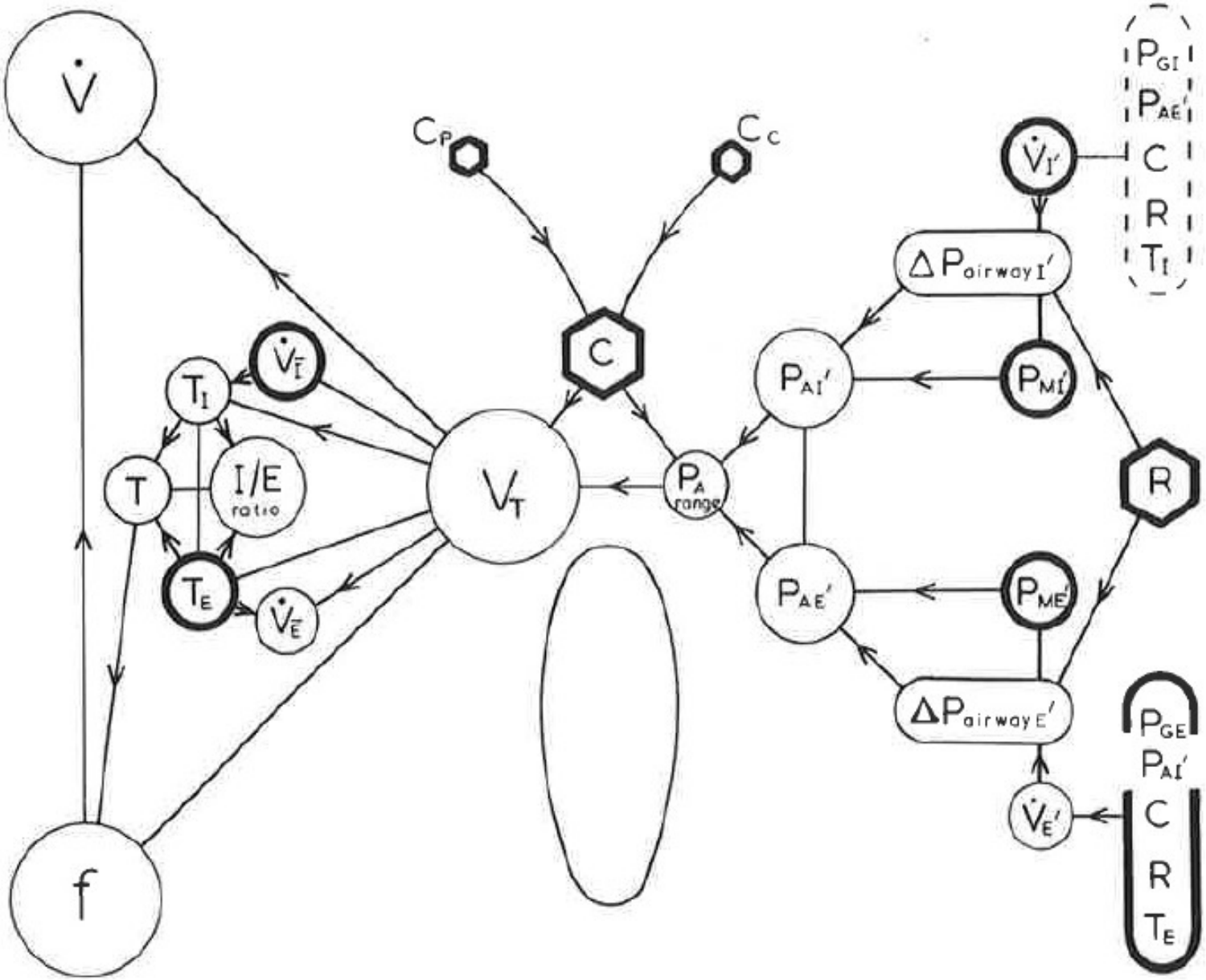
Journal of Applied Physiology;107(6):1679

Mushin "Butterfly Diagram"

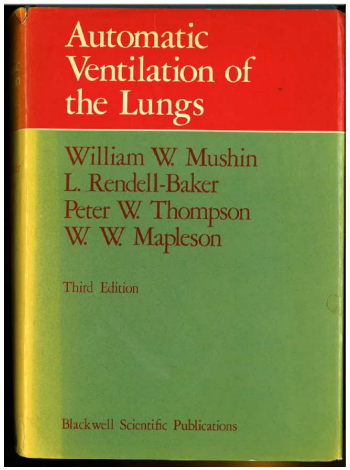


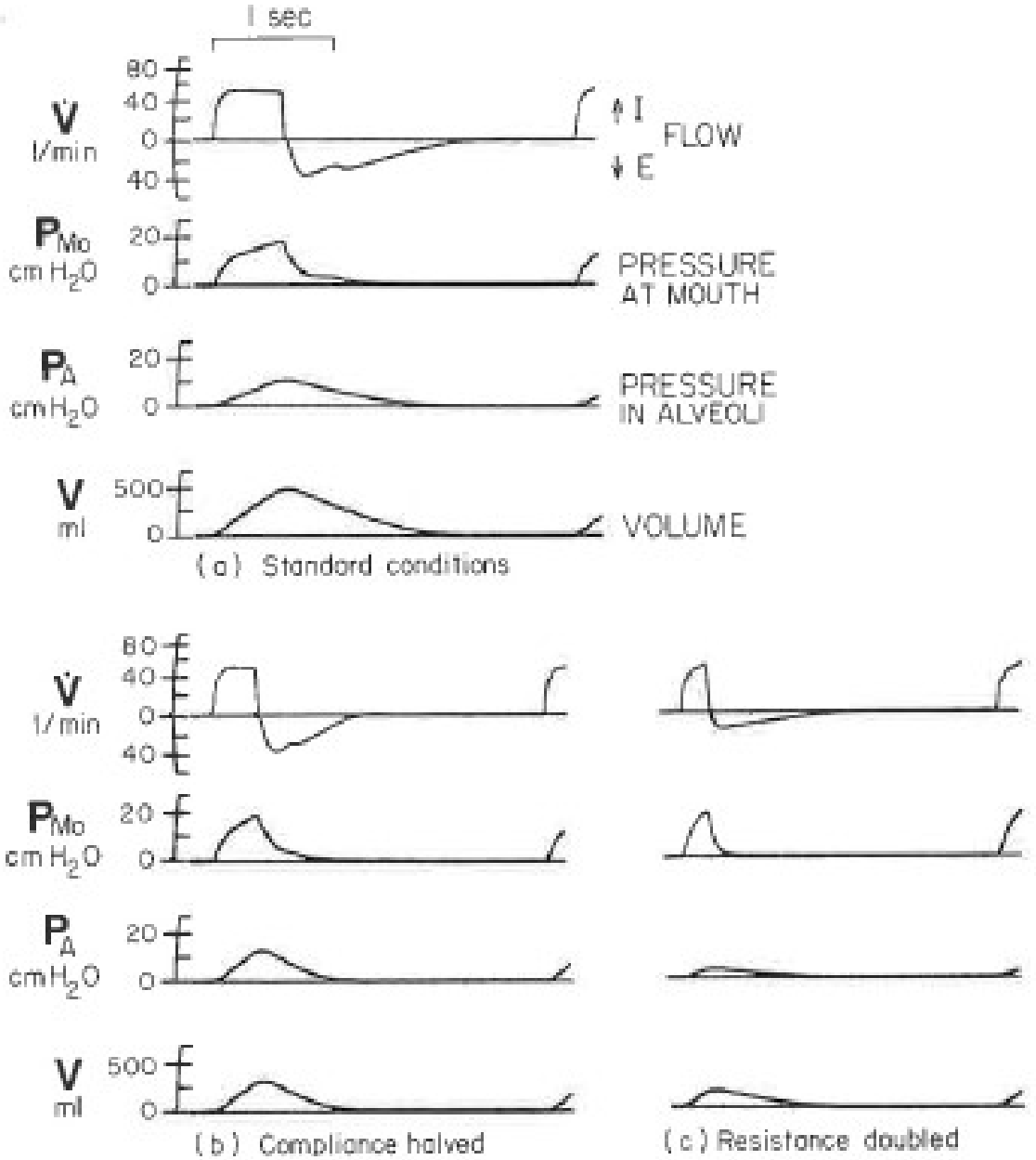


Constant Flow – Pressure Cycled



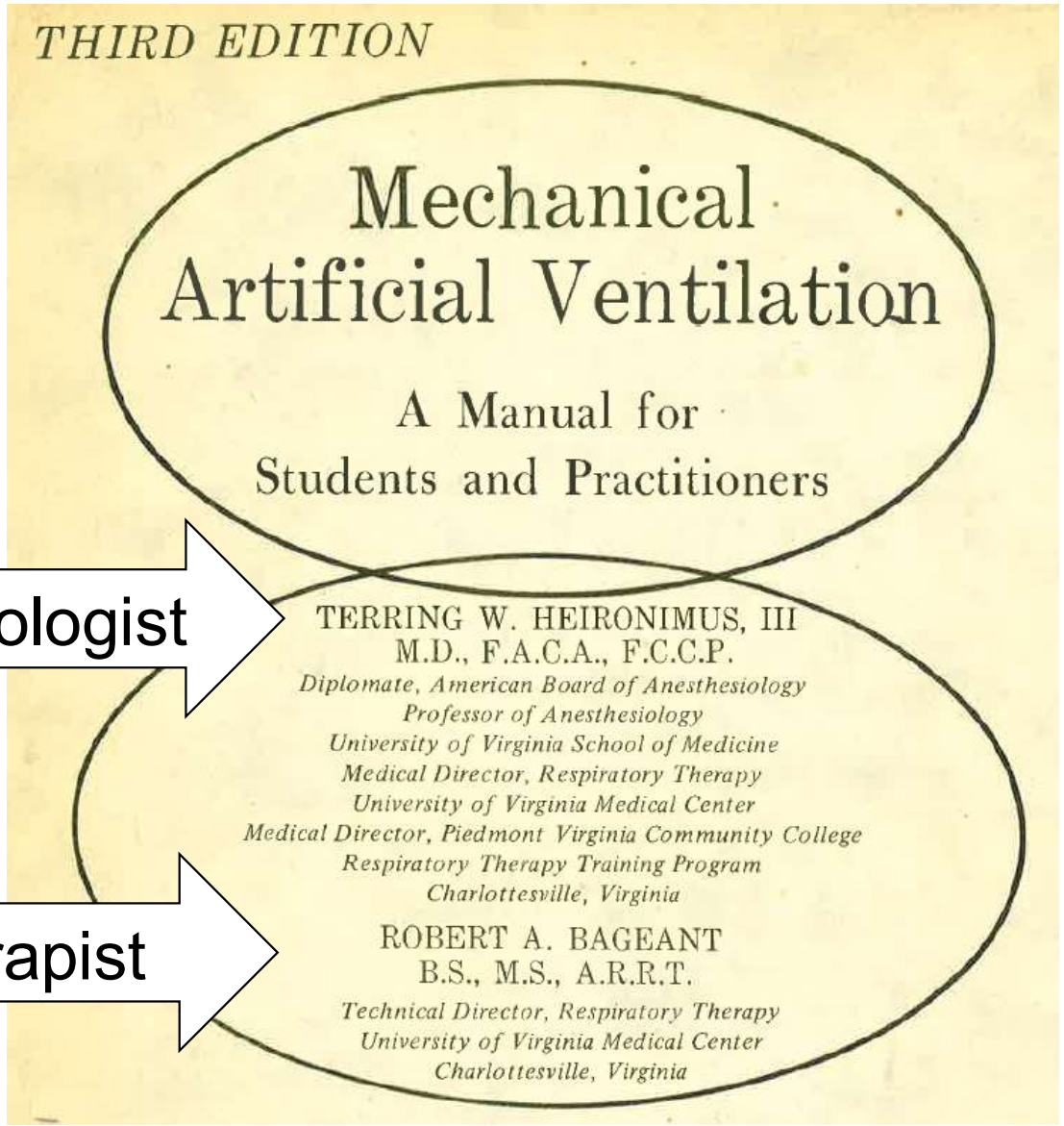
Simulator-Based Waveforms





1977 Textbook on Mechanical Ventilation

Described 10 ventilators



Anesthesiologist

Resp Therapist

CHAPTER 2 WHAT THE DESIGN, FUNCTION AND CARE OF RESPIRATORY THERAPY EQUIPMENT

"As he picks up his beautiful new tool, however it is well for the modern biologist to remind himself how subtly and completely a fascination for gadgets can betray sound sense."

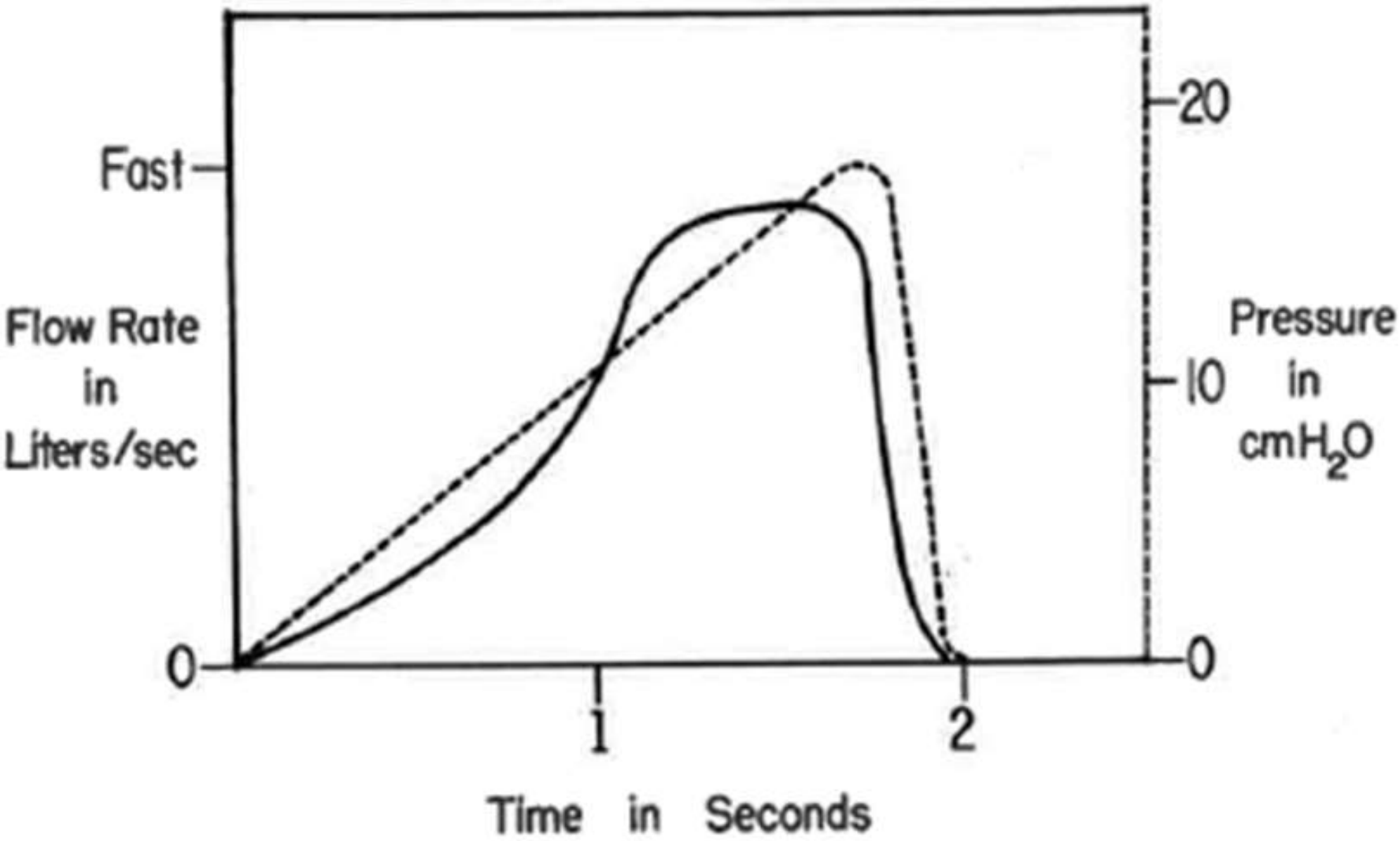
WILLIAM T. SALTER (1901-1952)

THE VENTILATOR

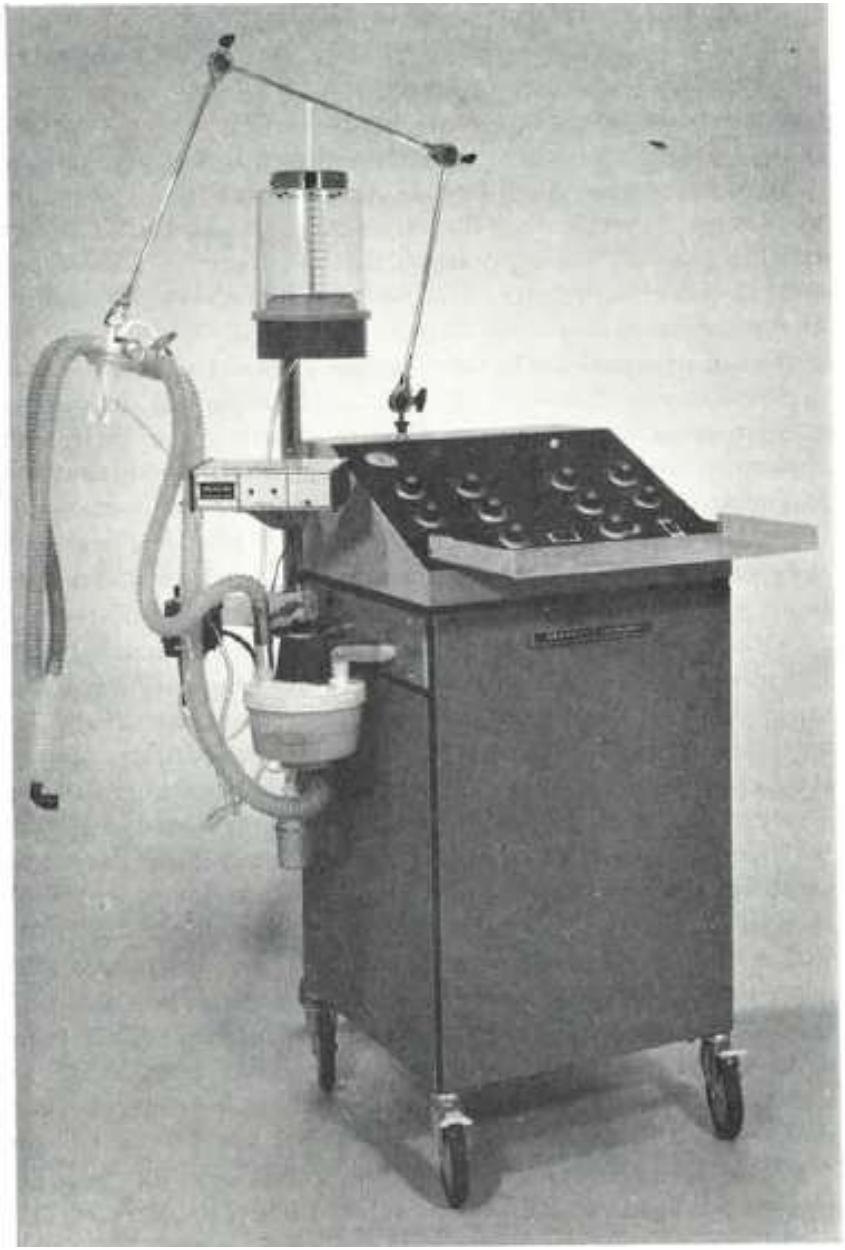
A. Classification

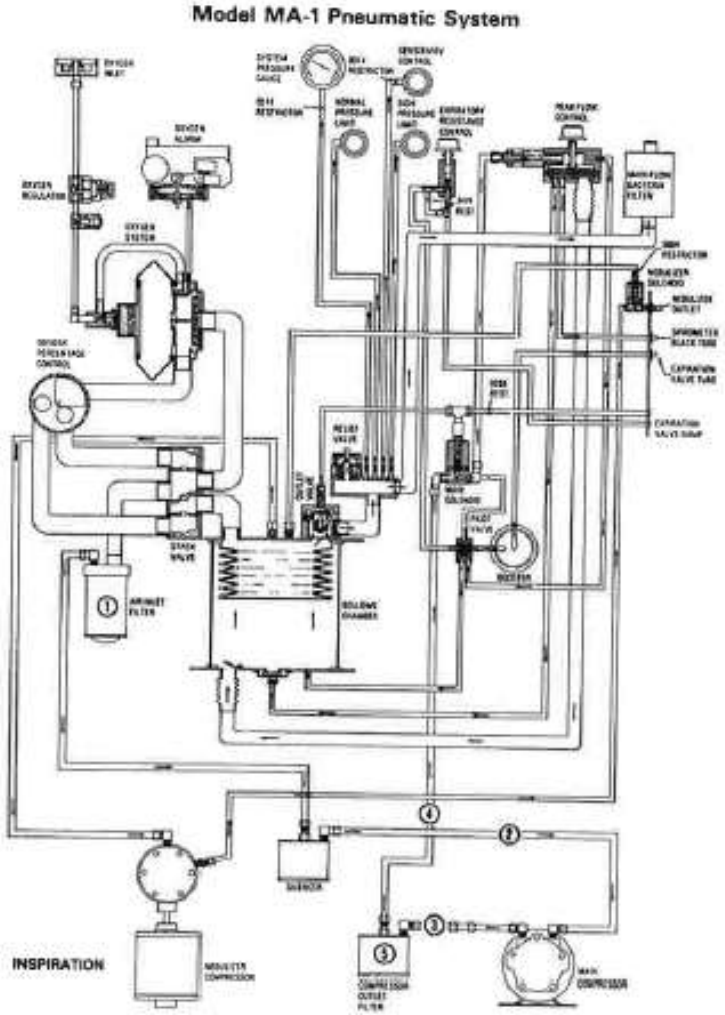
THE MOST COMMONLY employed ventilators today are those that exert a positive pressure at the upper airway to effect the

Pressure Control Waveforms



Bennett MA-1 (USA)

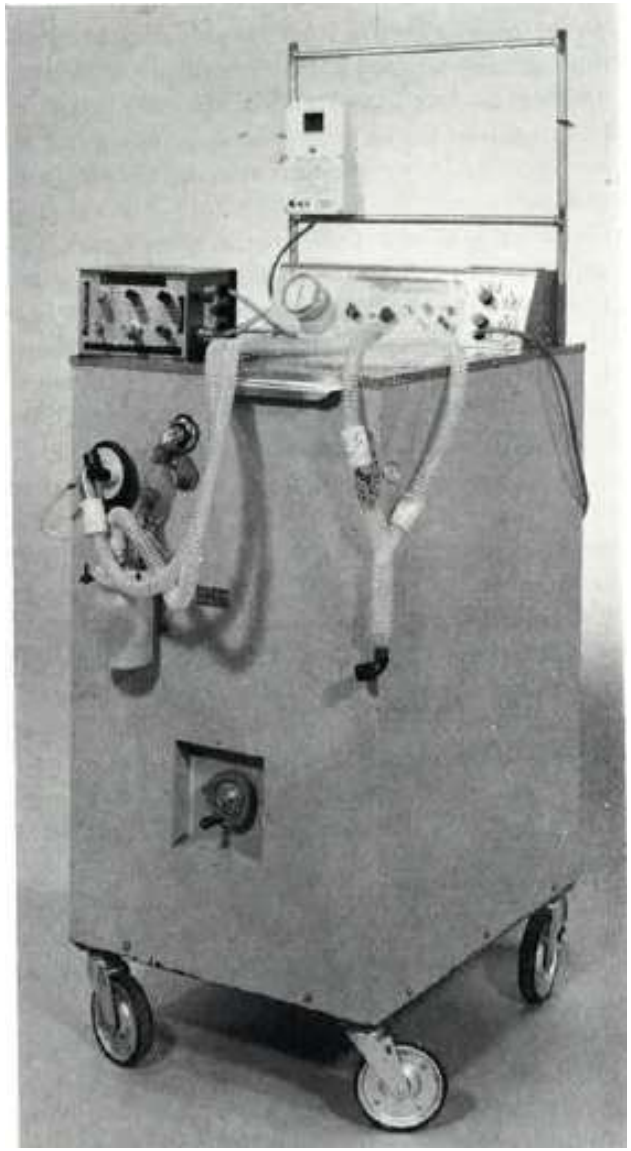


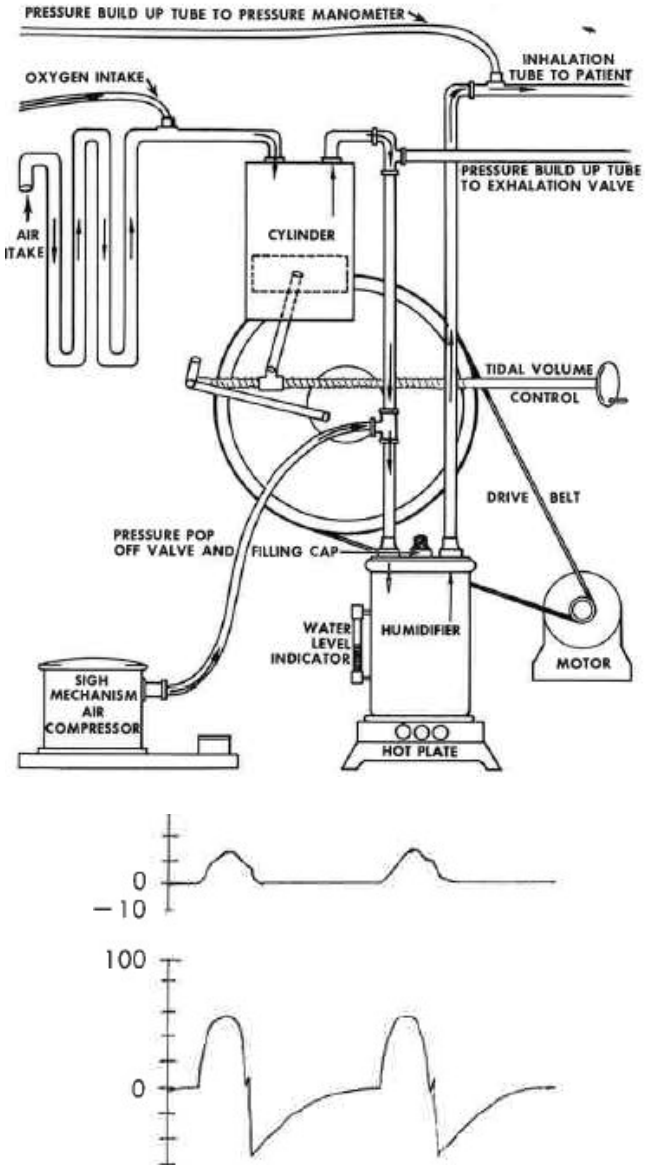


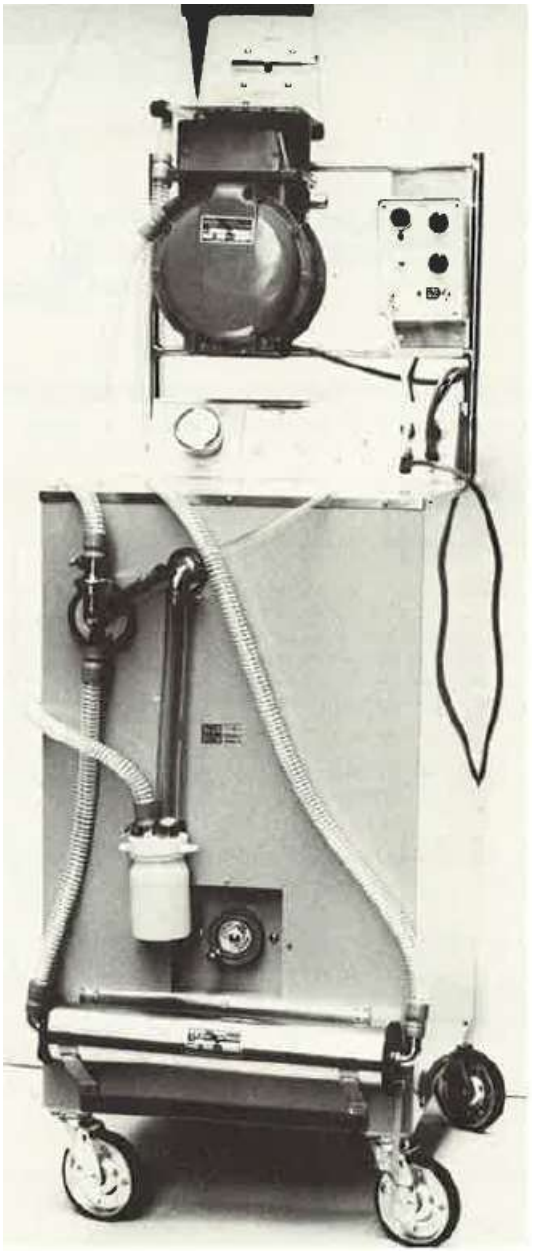
1	3664	INLET FILTER
2	3821	TUBE
3	3820	TUBE
4	3823	TUBE
5	*1535	OUTLET FILTER

* 6627 in early units.

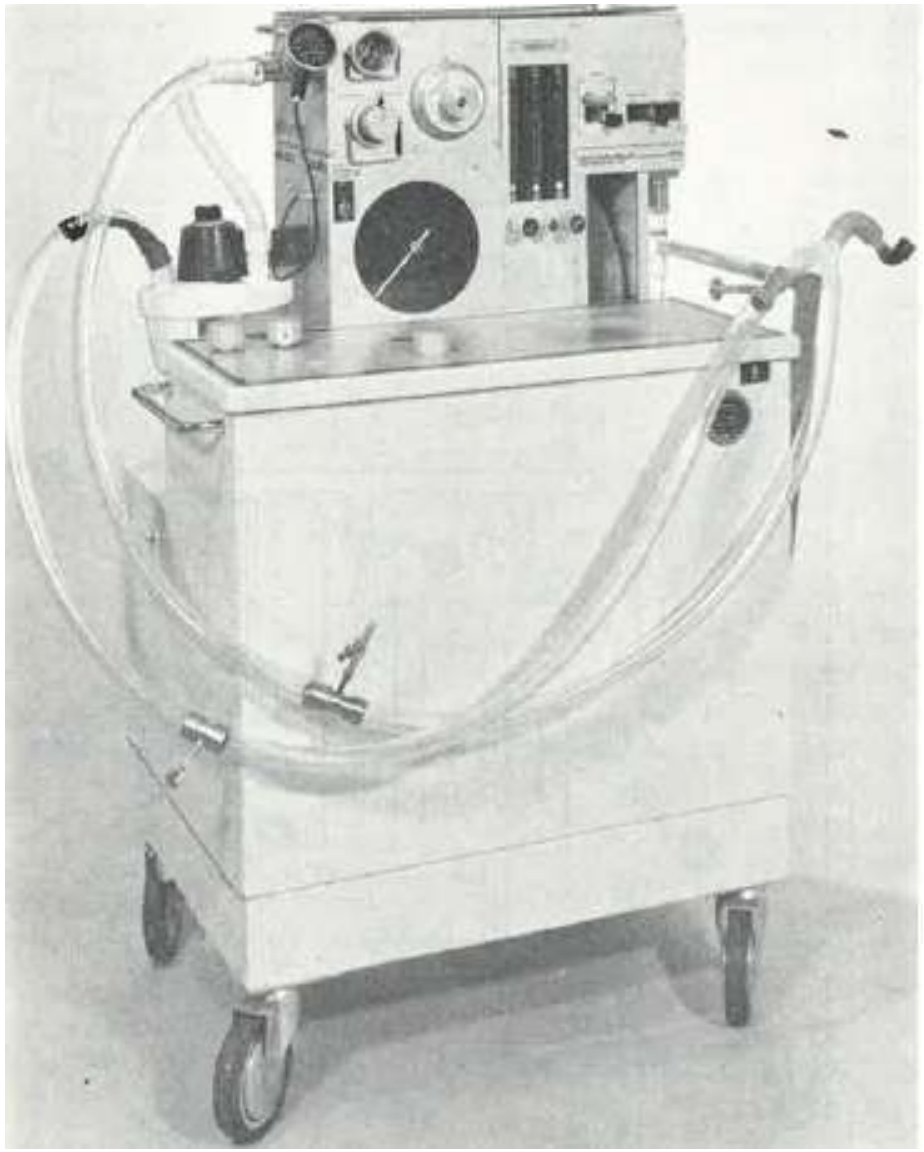
Emerson Post-Op and 3-PV (USA)

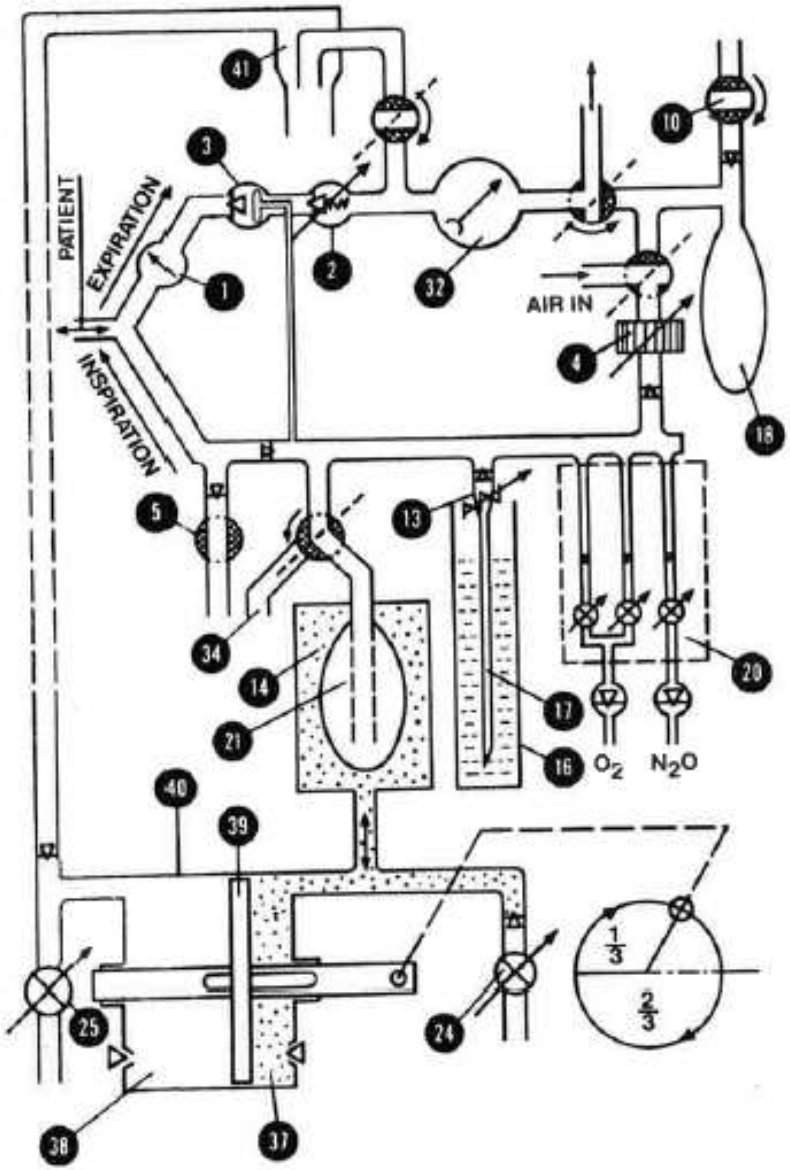




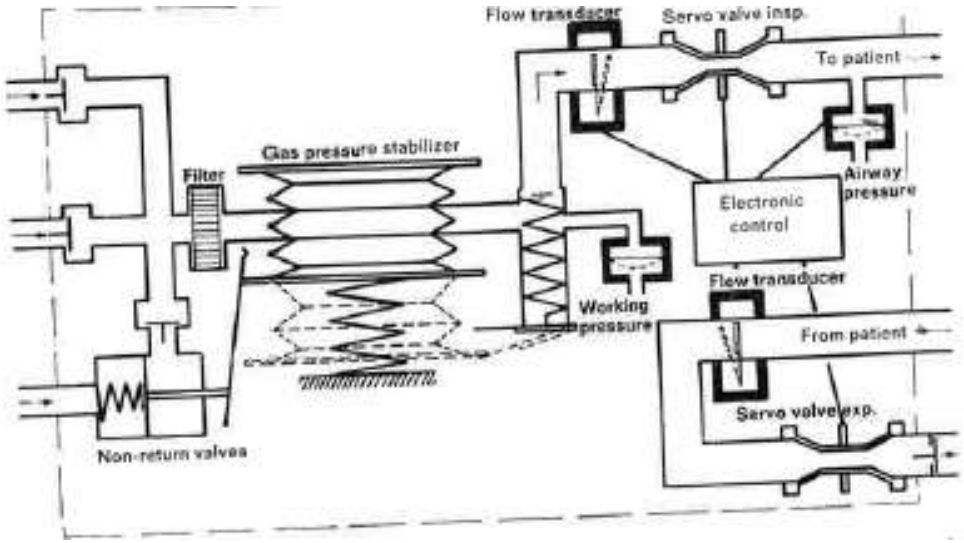


Engström (Denmark)

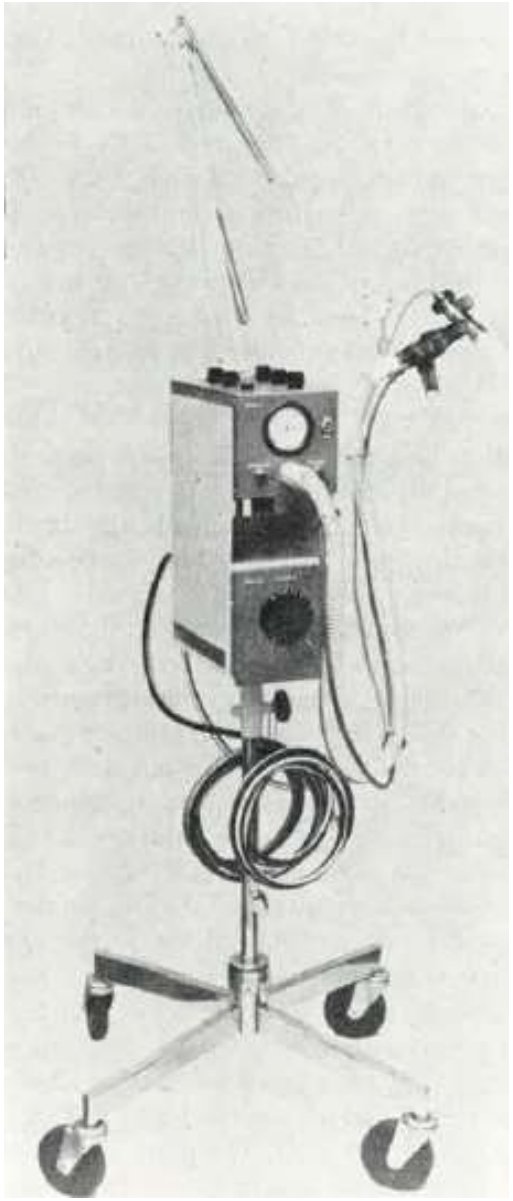


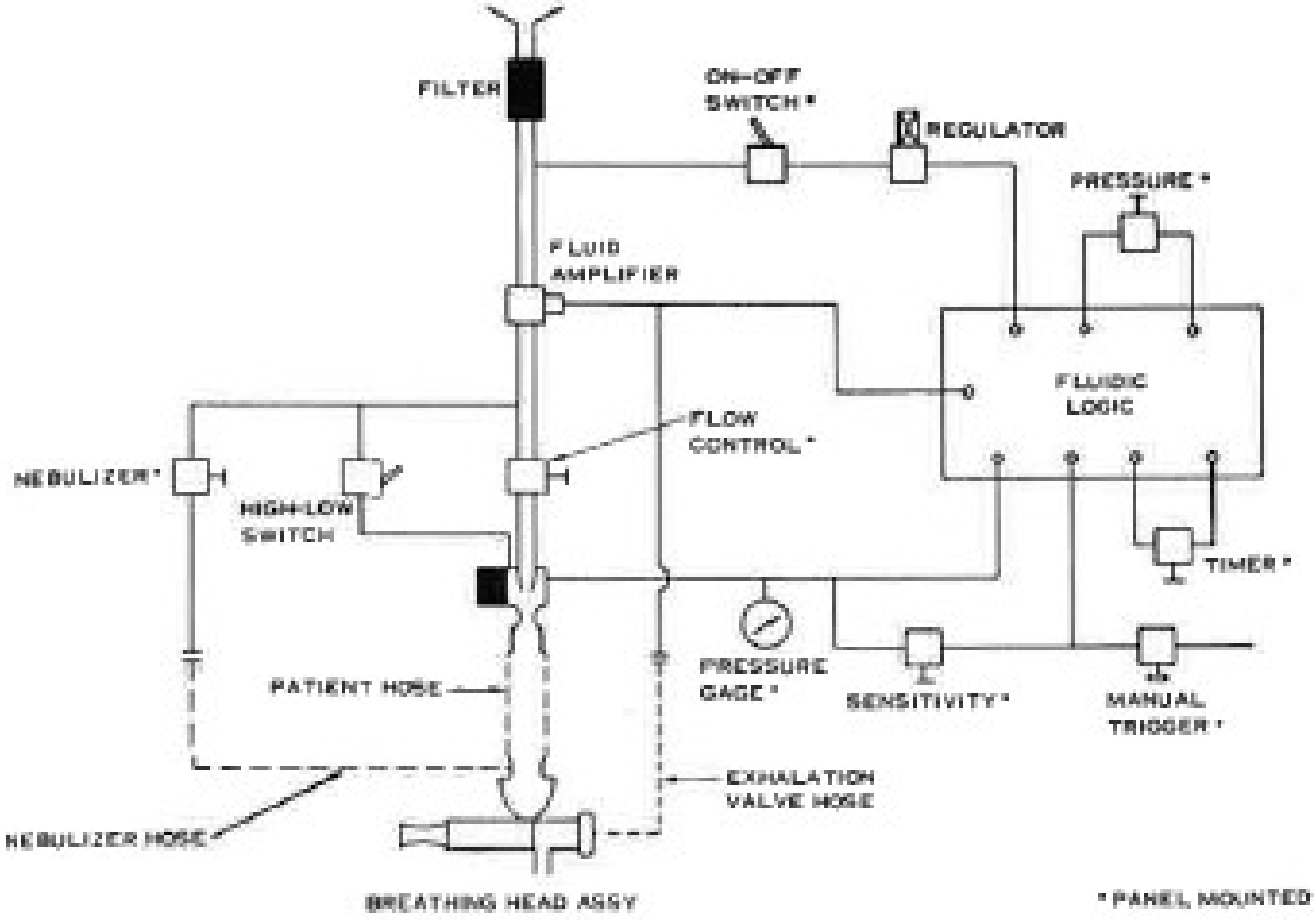


Servo 900 series Sweden (1970s)

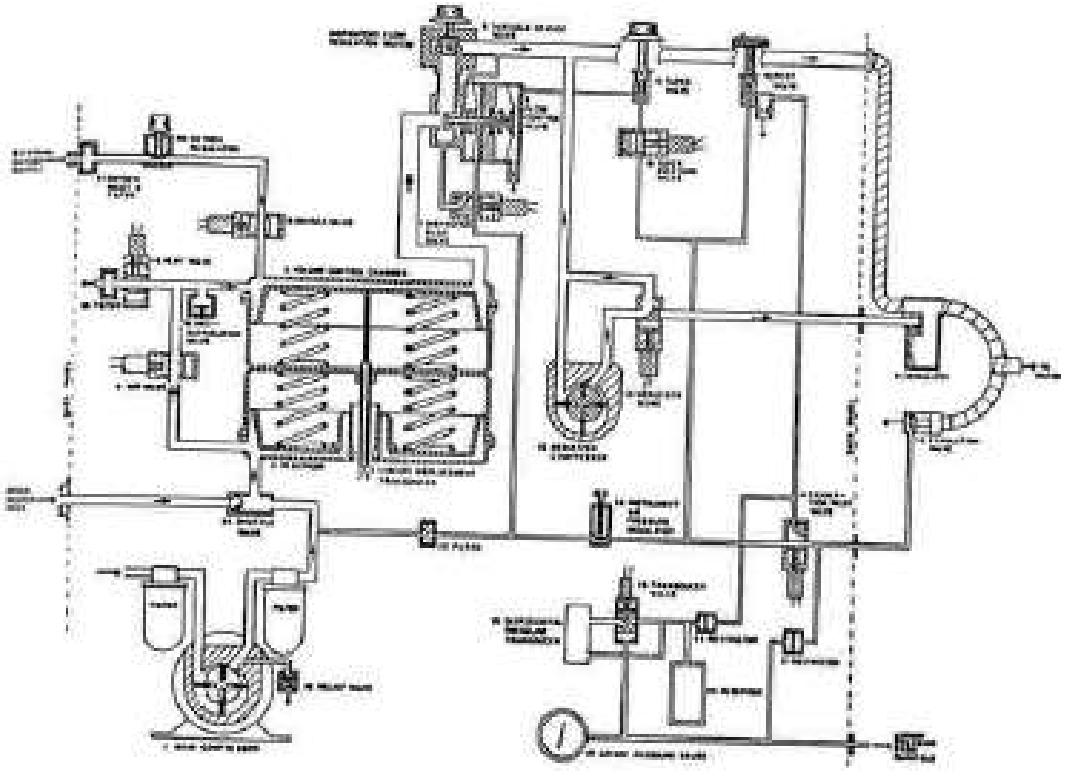


Vanguard Pad-1 Fluidic

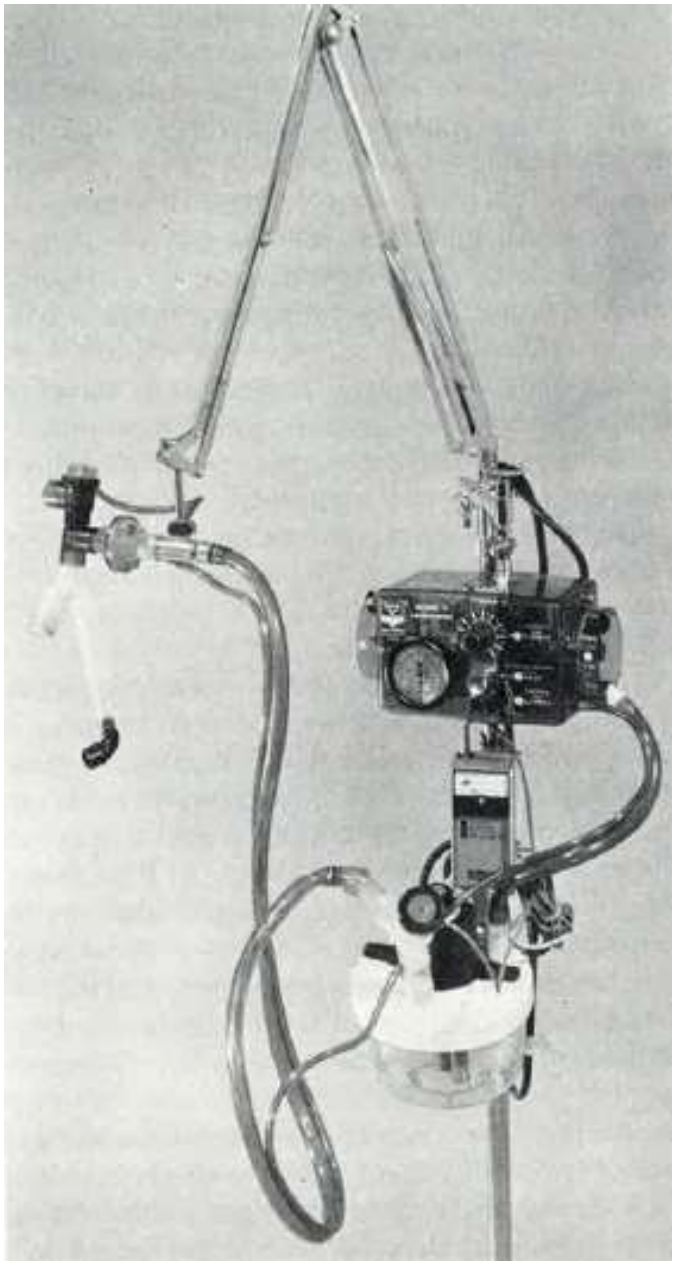


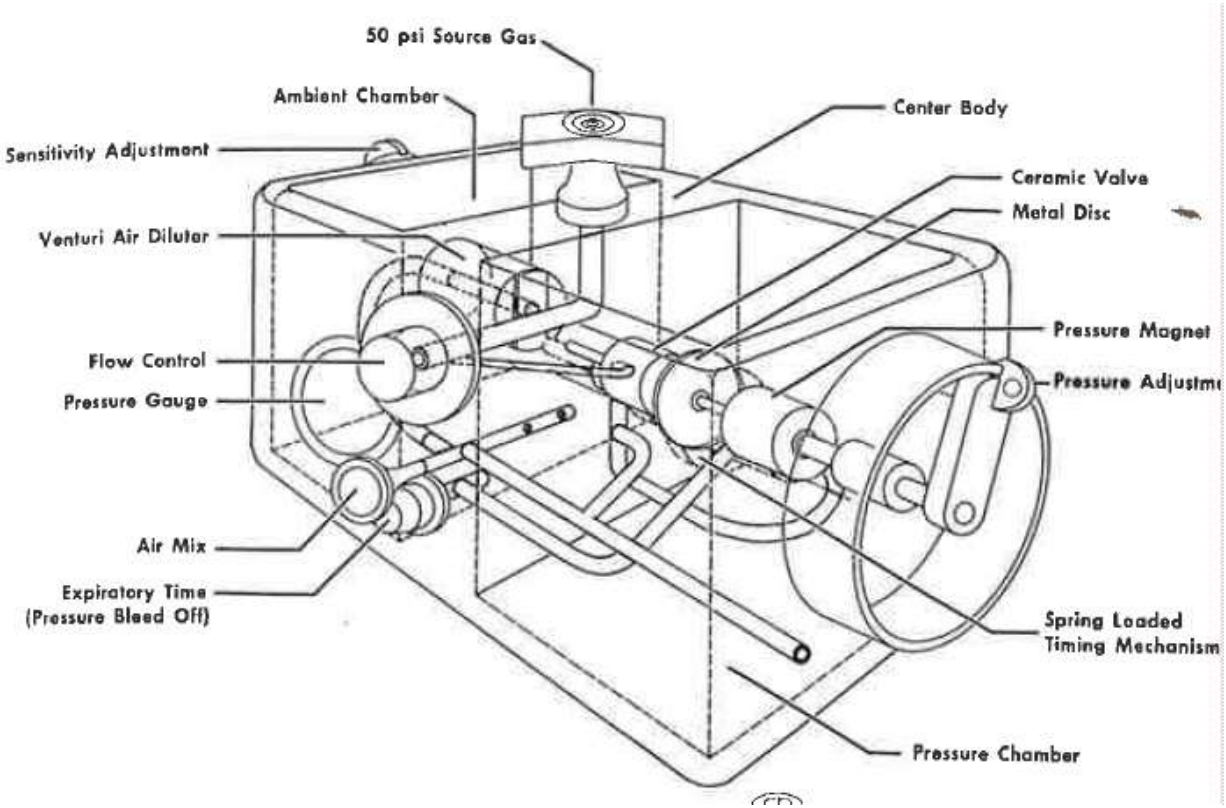


Searle

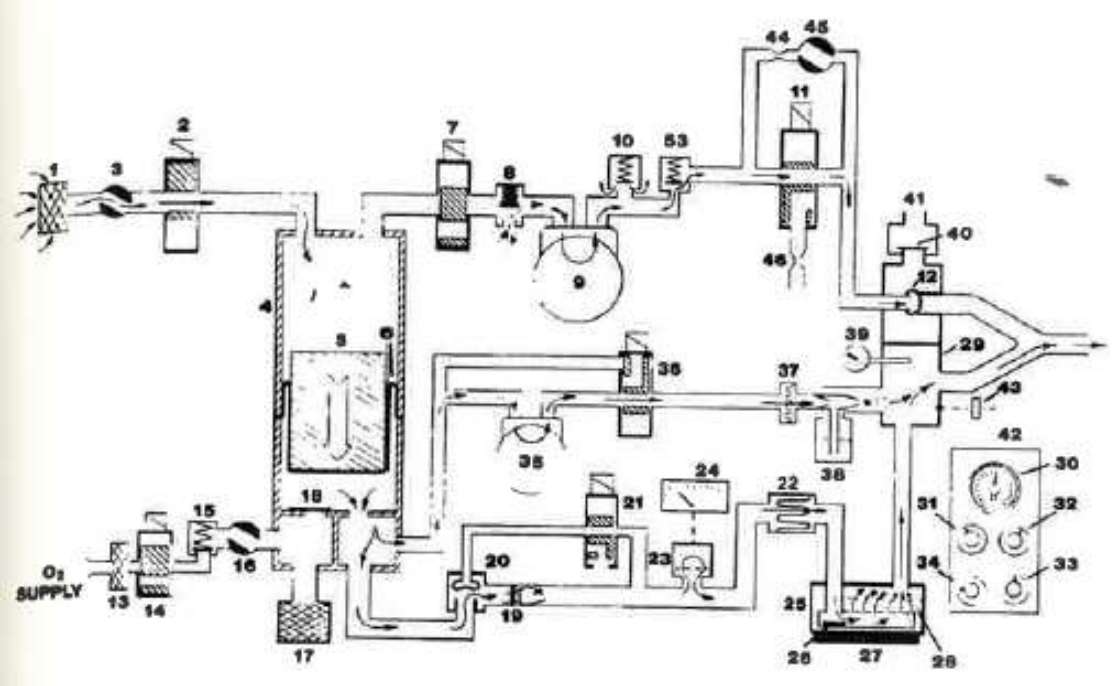


Bird Mark V11

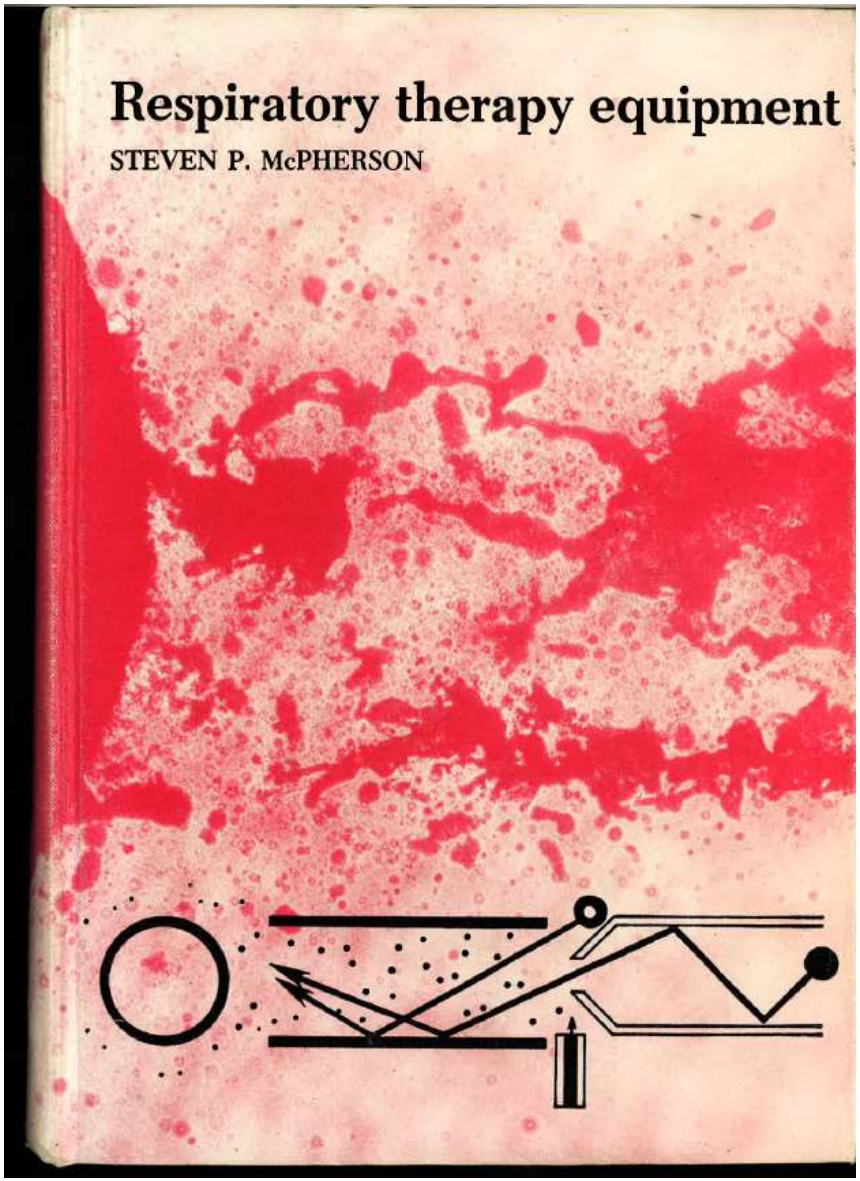




Gill 1



The First RT Equipment Book (1977)

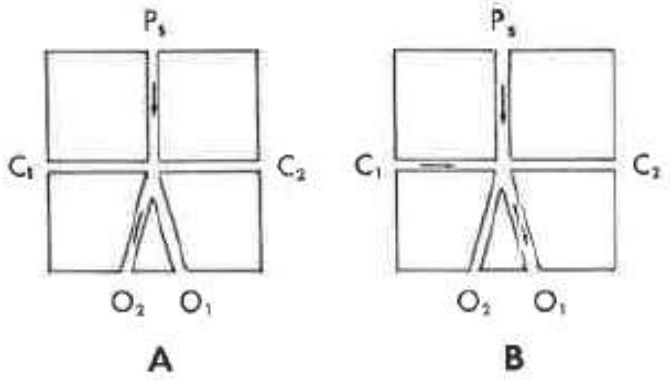


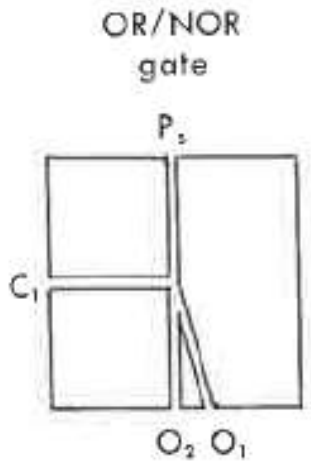
Respiratory therapist author

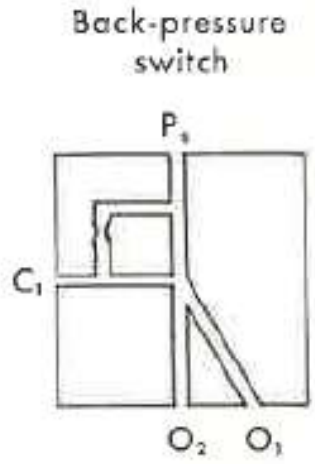
Detailed descriptions of 31 ventilators

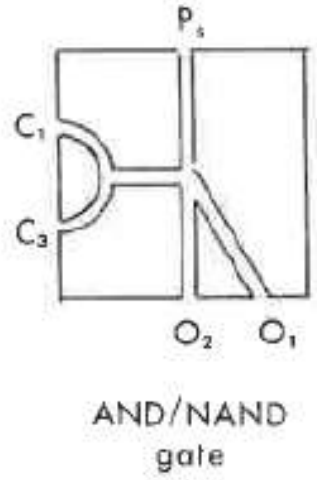
Only mentions 3 modes!

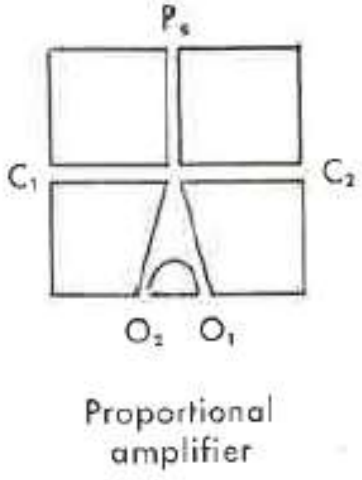
Fluidic Logic Control Circuits (again)

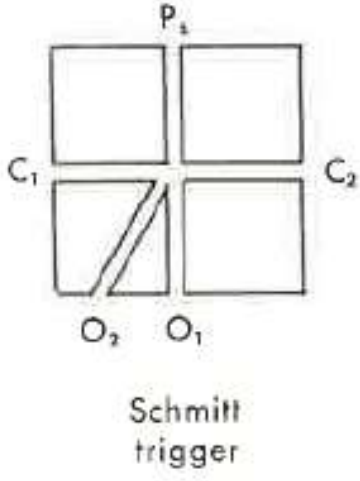






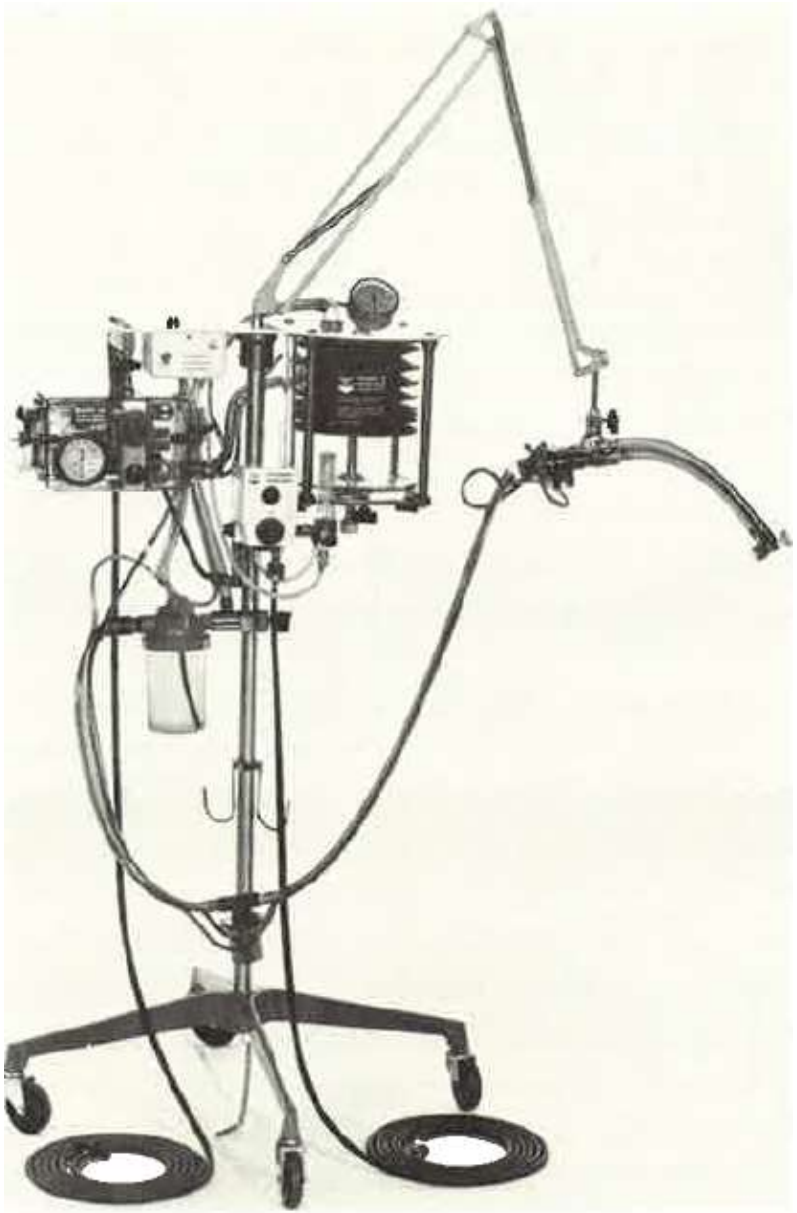






Emerson Cuirass

Bird Mark 14-6

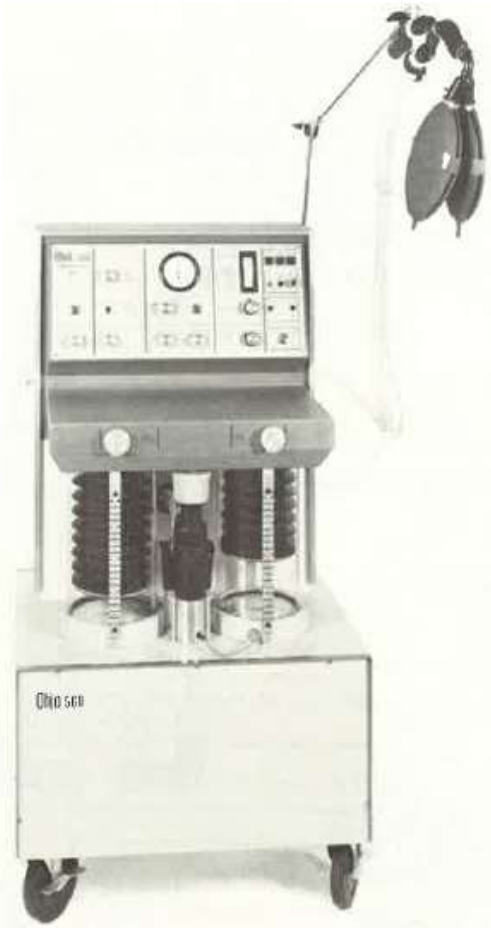


1980s philosophy:

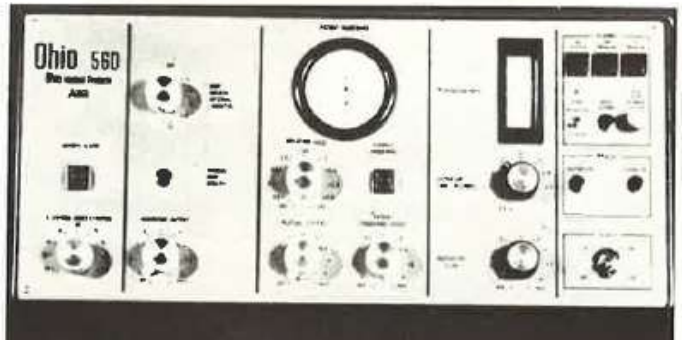
Normalize blood gases no matter what the inspiratory pressure

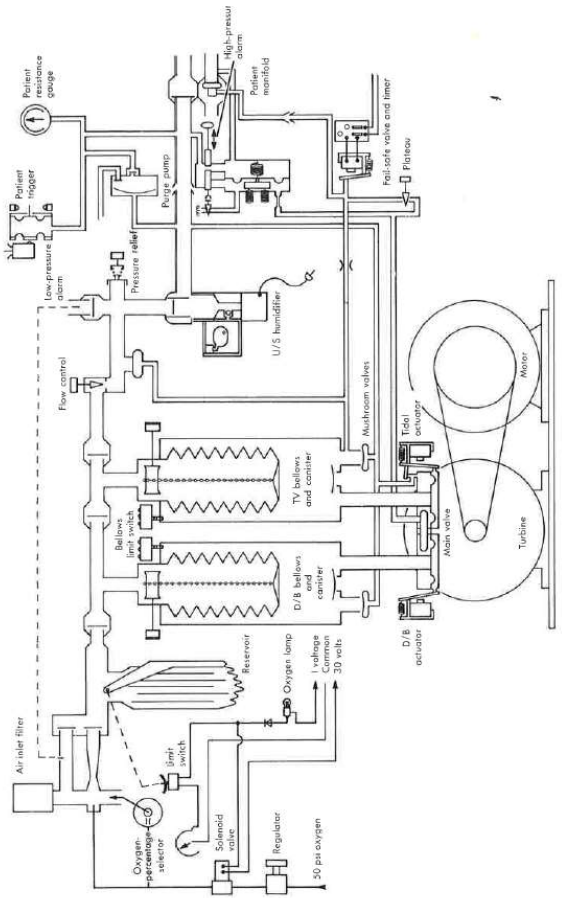
Ohio 550

A



B





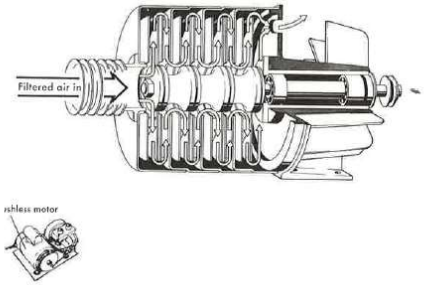
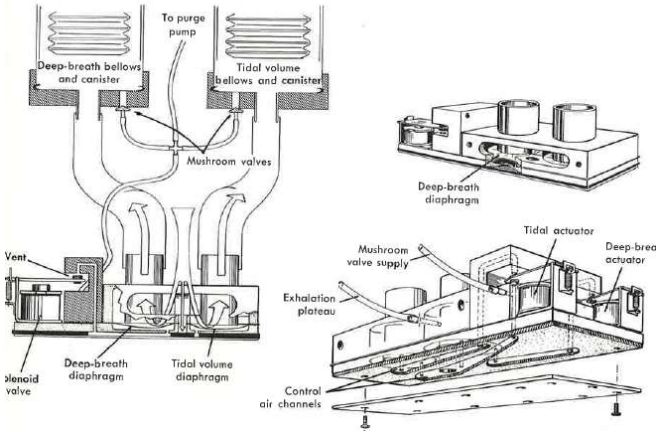
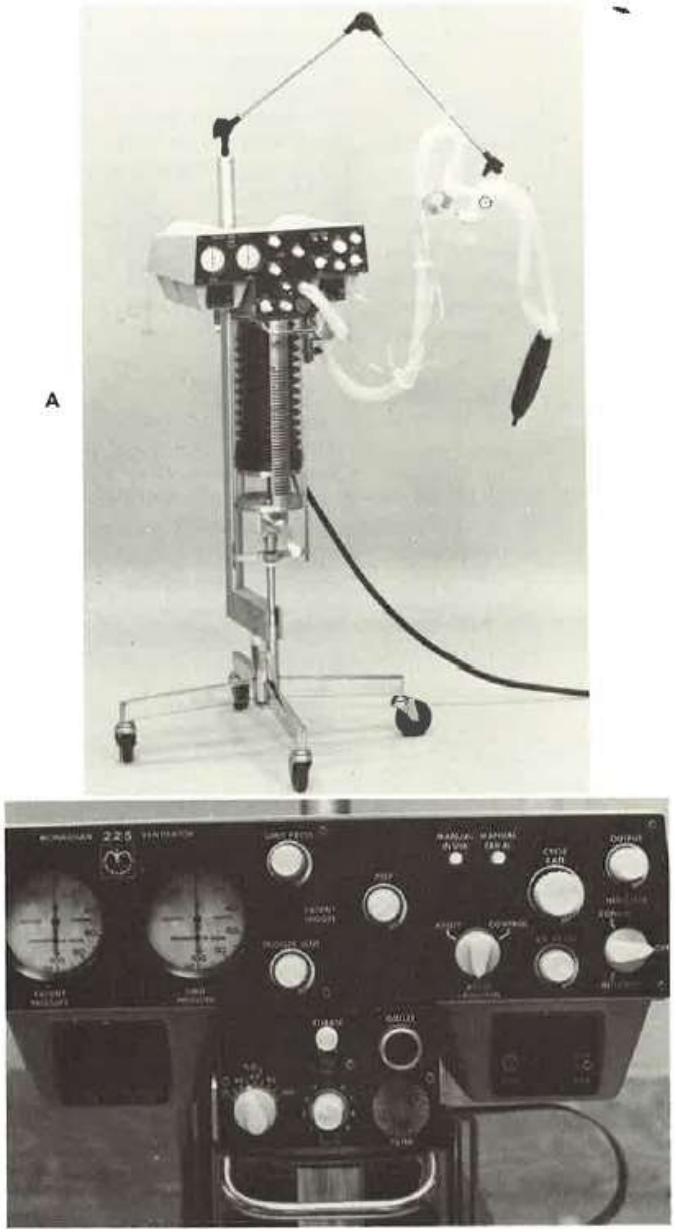
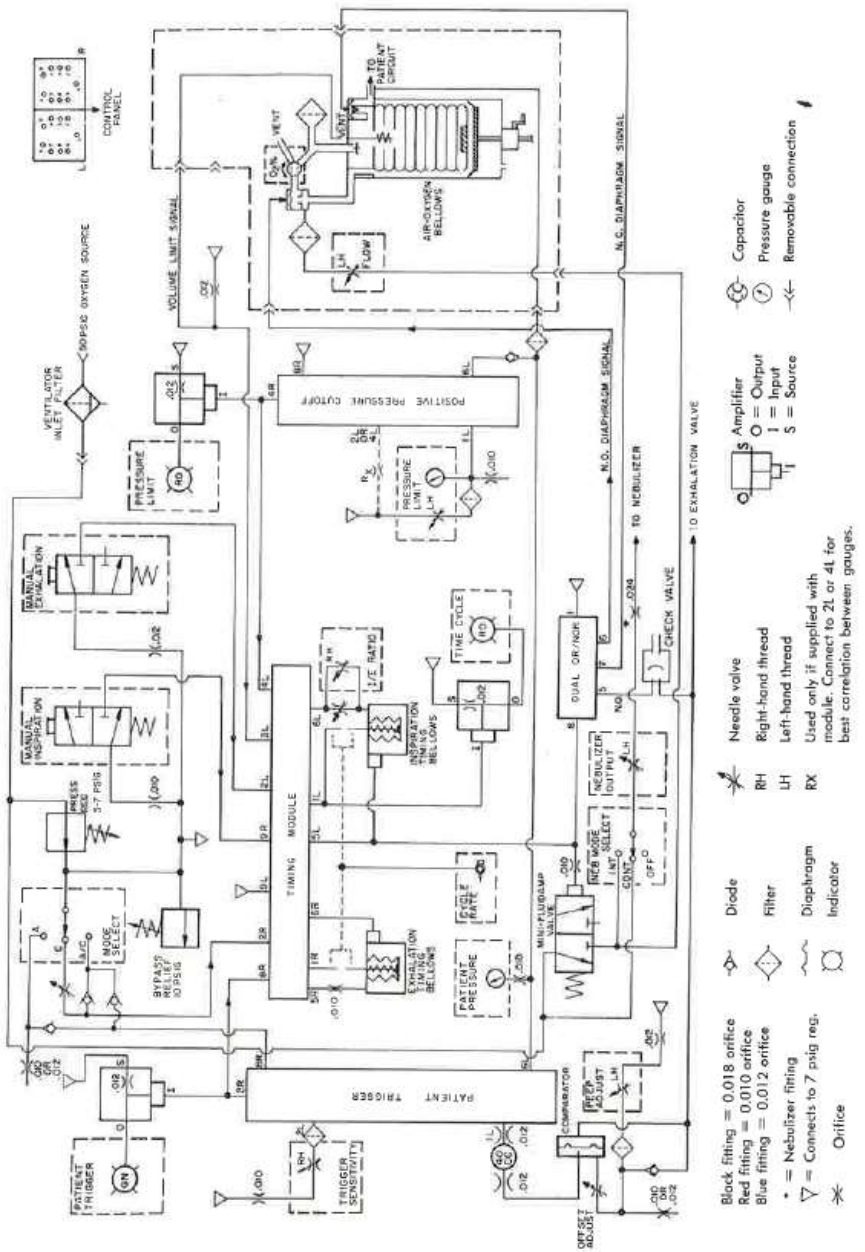


Fig. 12-23. Functional diagram of Ohio 560's rotary compressor. (Courtesy Ohio Medical Products, Inc., Madison, Wis.)



Monaghan 225





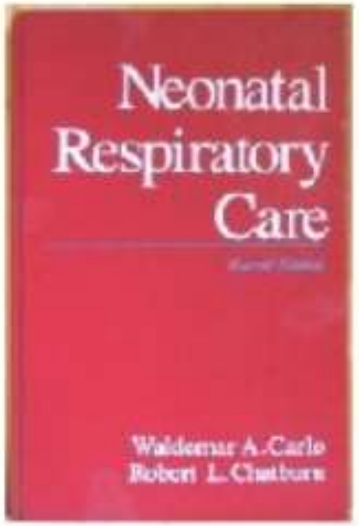
Bourns BEAR Series (1980s 1990s)

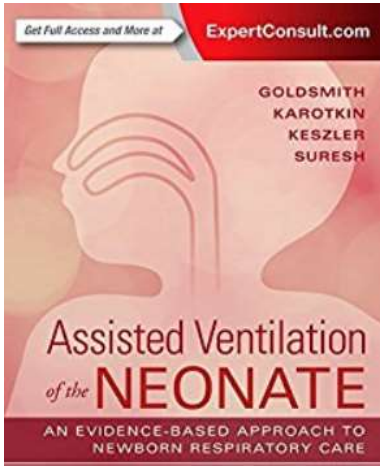
Bear 1

Bear 5

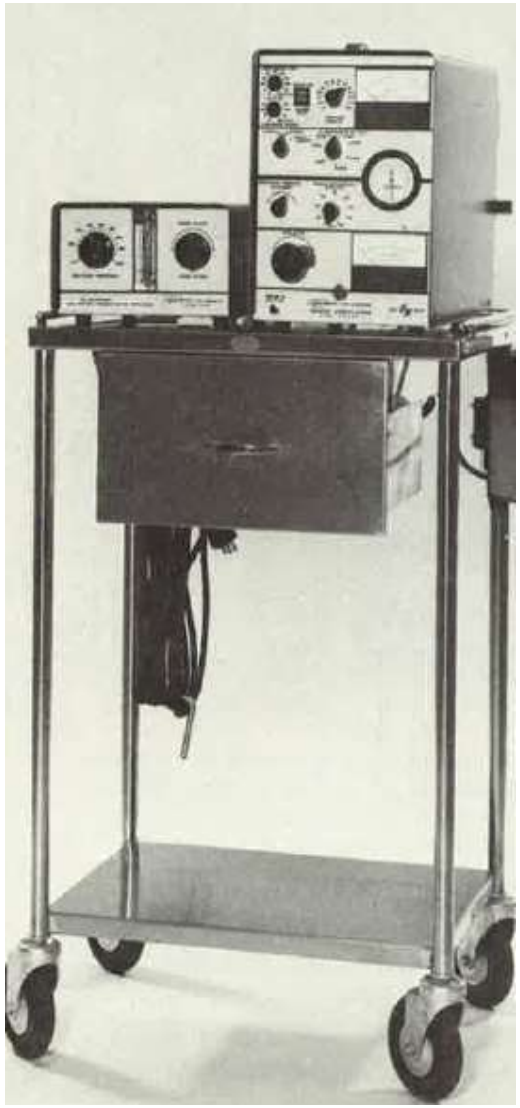
Bear 1000

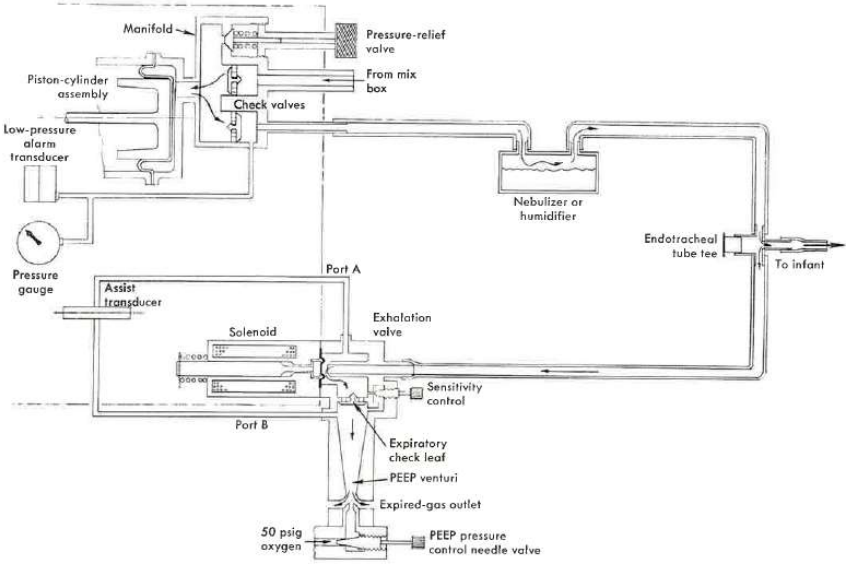
The First Infant Ventilators

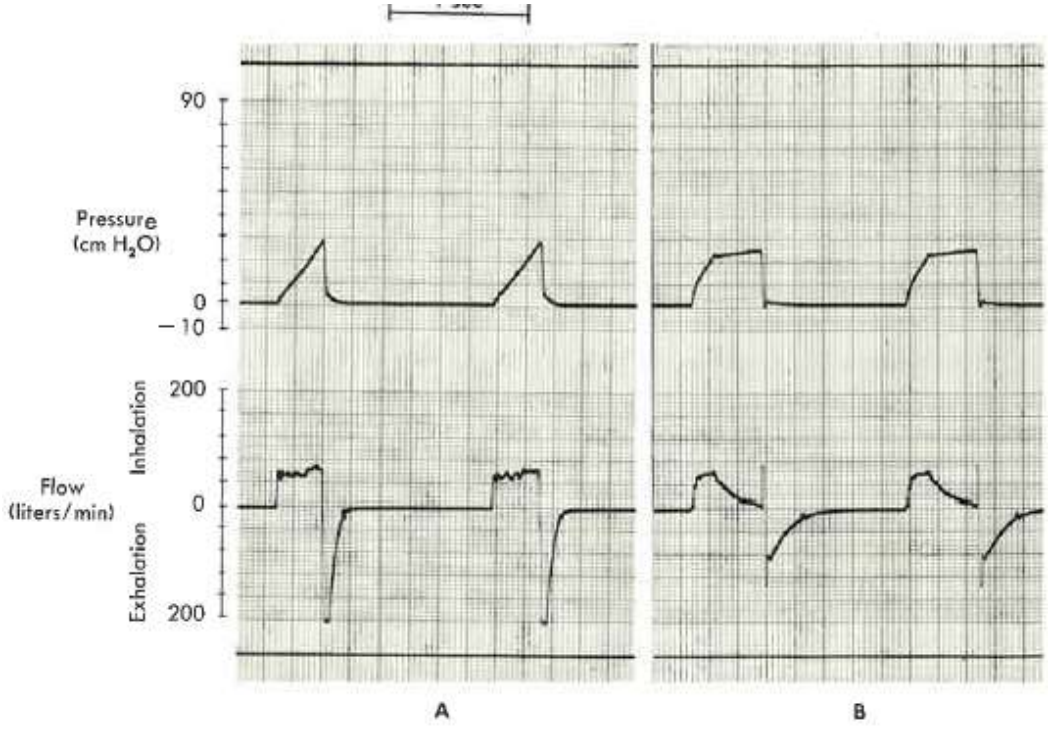




Bourns LS104-150 US (1960s)

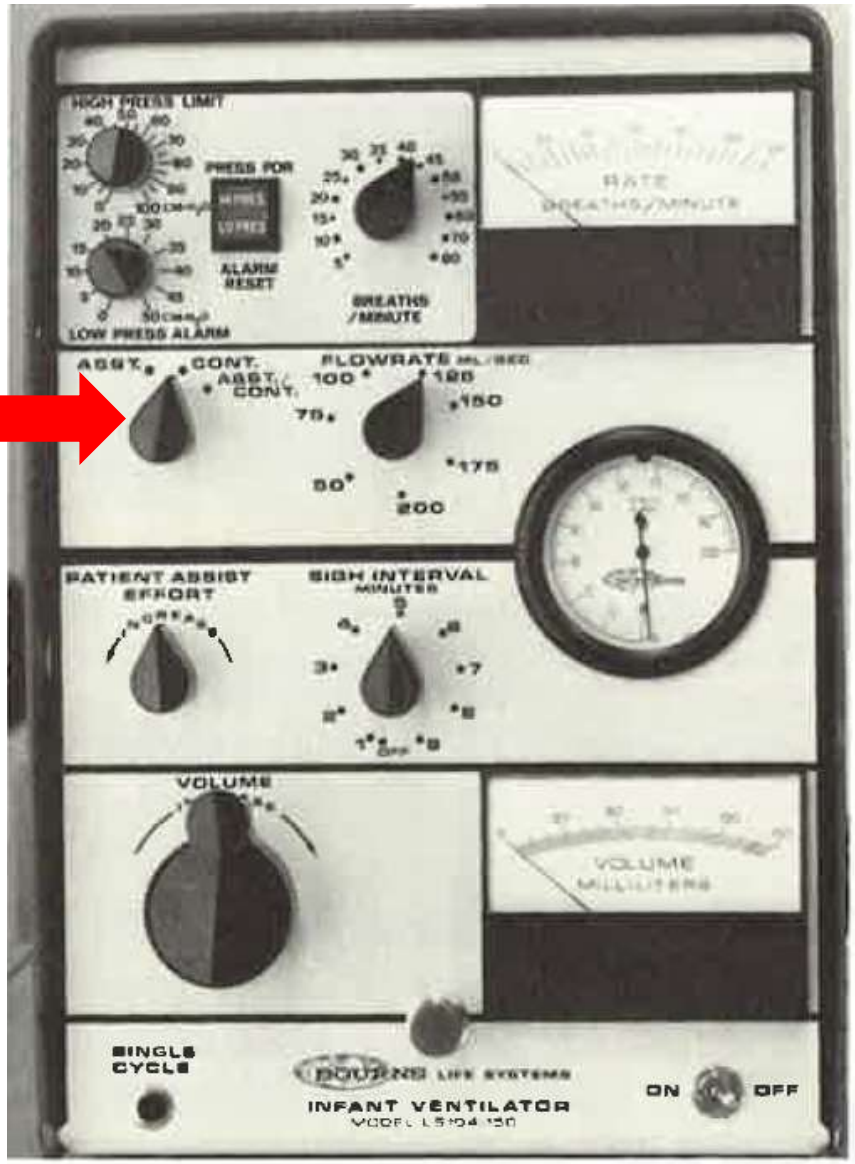


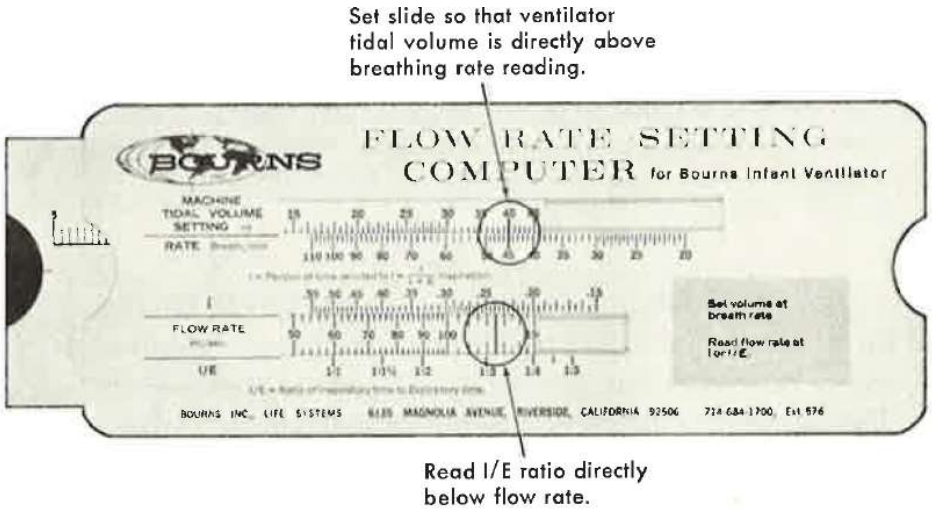




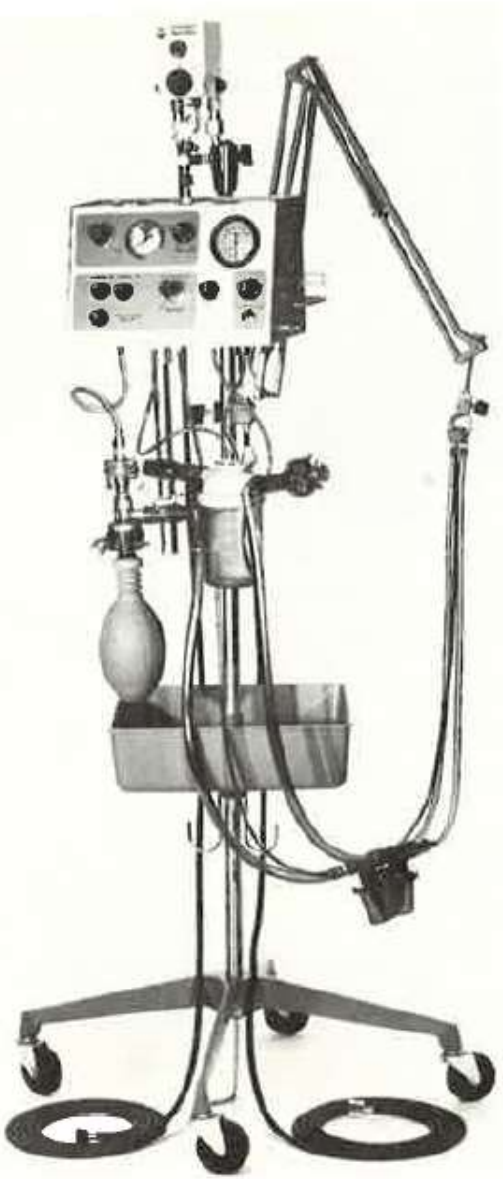
First ventilator with mode selection?

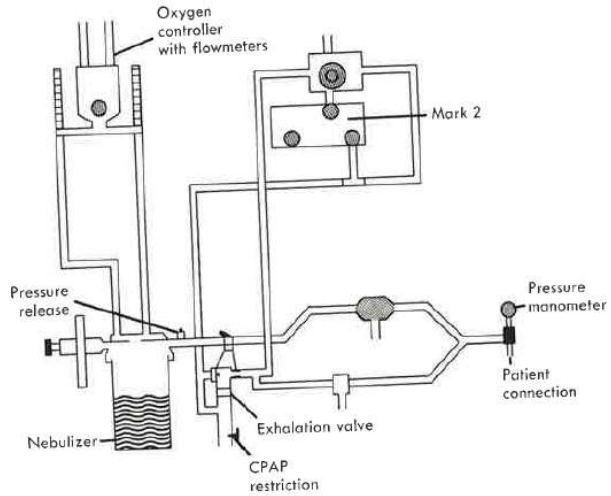
Assist
Control
Assist/Control



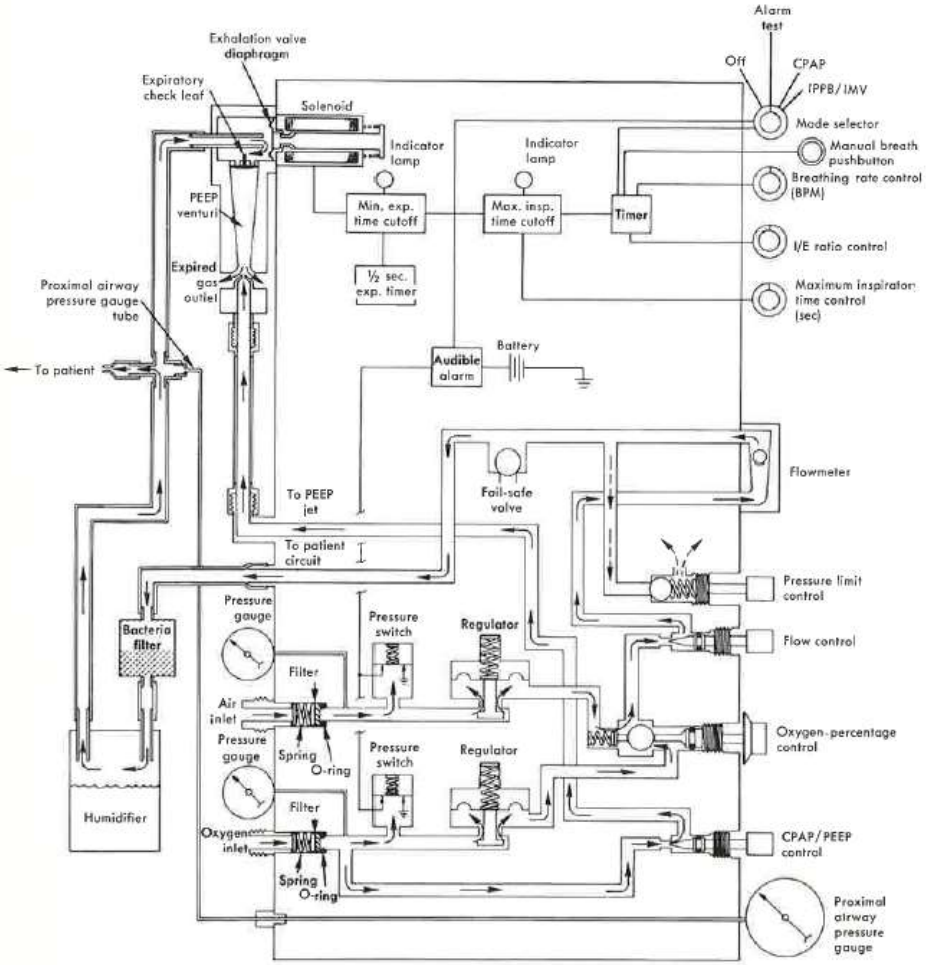


Babybird Ventilator US (late 1970s)





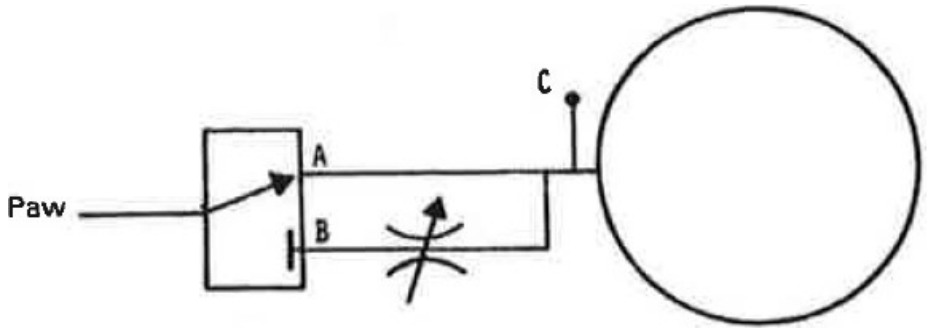
Bourns BP200 (late 1970s)

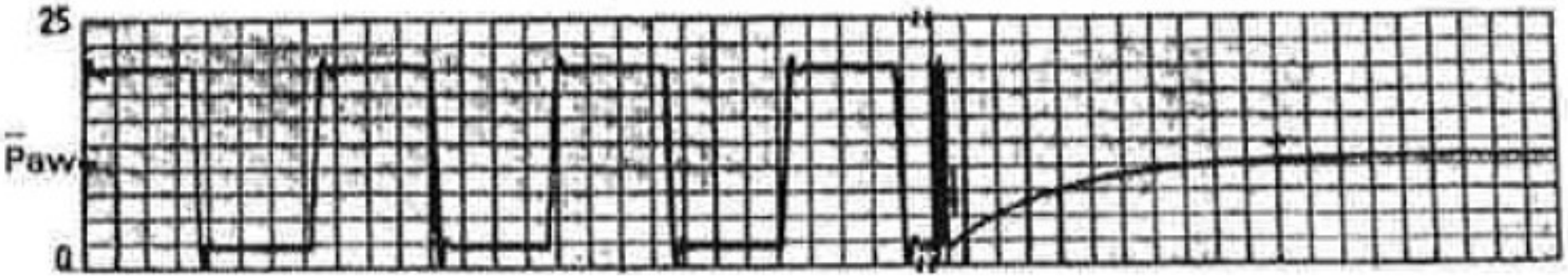


The First Mean Airway Pressure Device

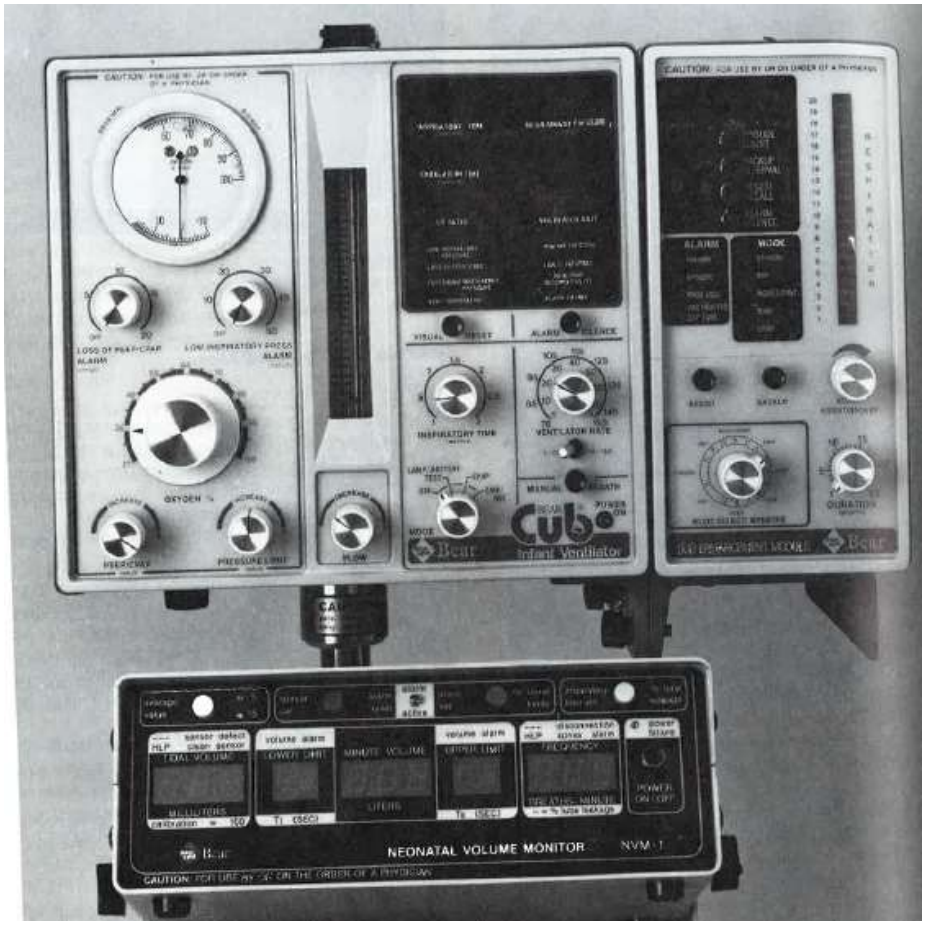
Modification of a Ventilator Pressure Monitoring Circuit To Permit Display of Mean Airway Pressure

Robert L Chatburn RRT, Marvin Lough RRT,
and Frank P Primiano Jr PhD





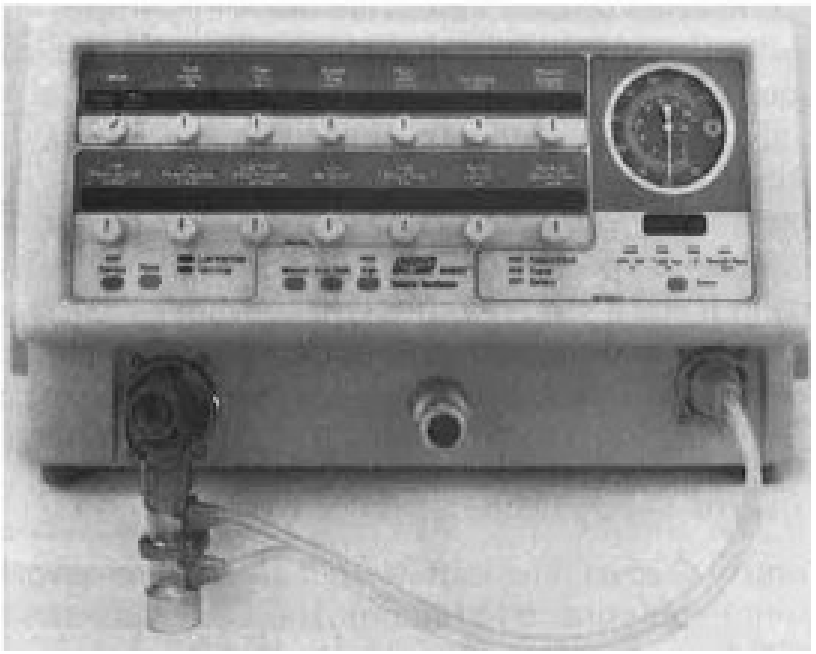
Bear Cubs (1990s)



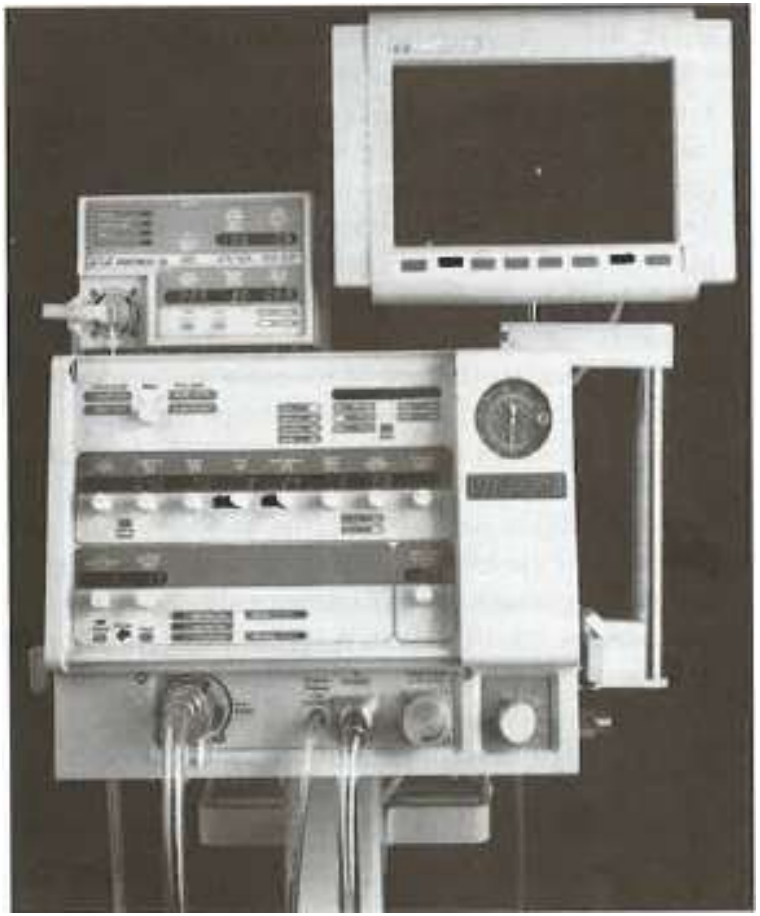
Bear Cub

Bear Cub 750

Bird Corporation Ventilators (1990s)

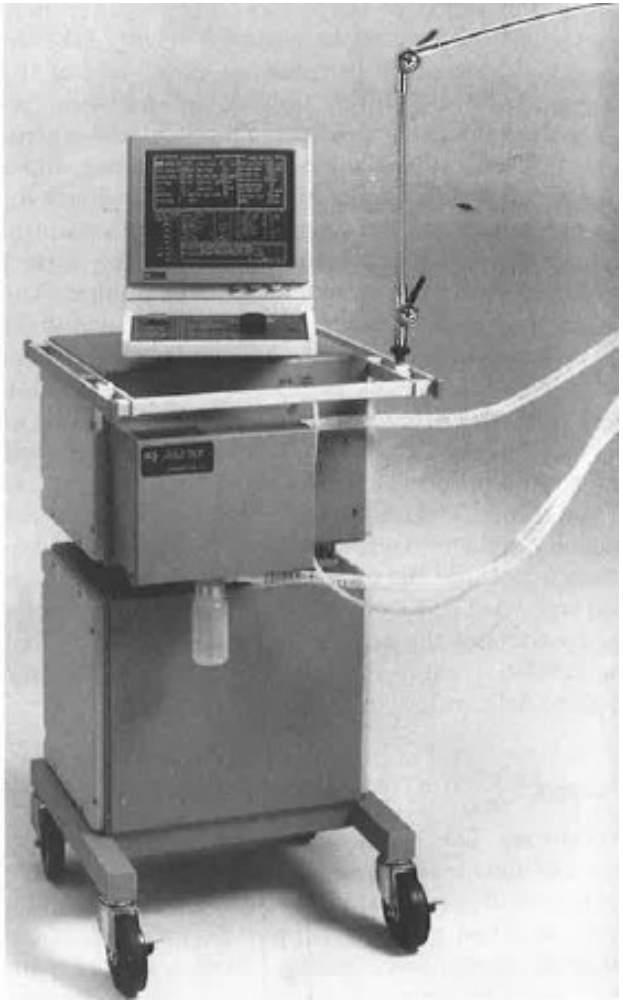


Bird 840 ST



Bird V.I.P infant ventilator

Infrasonics Ventilators (1990s)

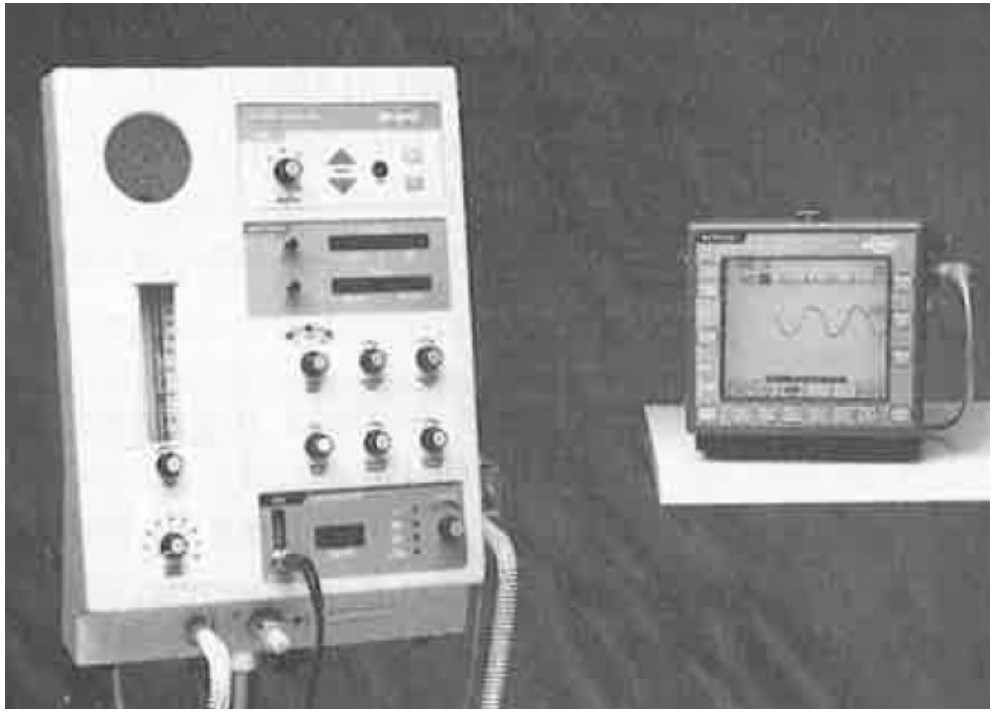


Adult Star

Infant Star

Sechrist ventilators (1990s)

IV-100B



SAVI

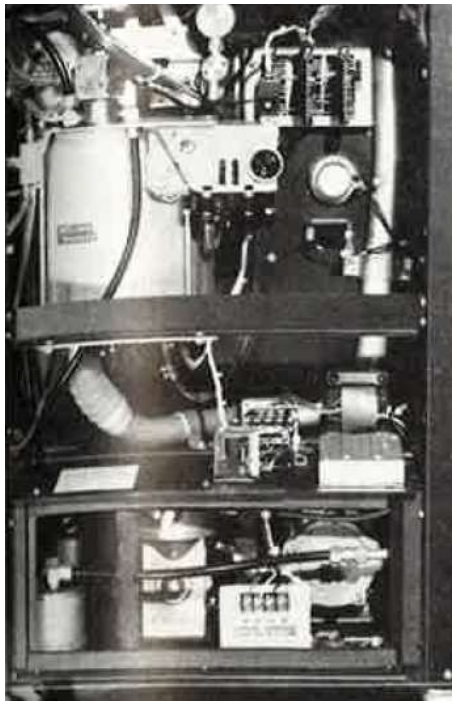
Healthdyne (1990s)

105 Infant Ventilator

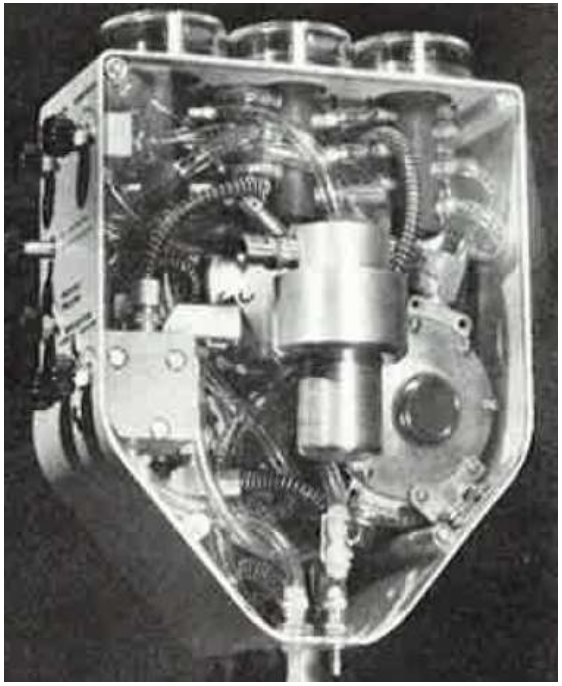
Respiratory Care Journal – 1976

Plexiglas Modification of Respiratory Therapy Equipment for Teaching Purposes

Baby Bird



MA-1



PR-2

Respiratory Care Journal – 1973

The origin of IMV – first used in pediatrics

Continuous-Flow Ventilation as an Alternative to Assisted or Controlled Ventilation in Infants

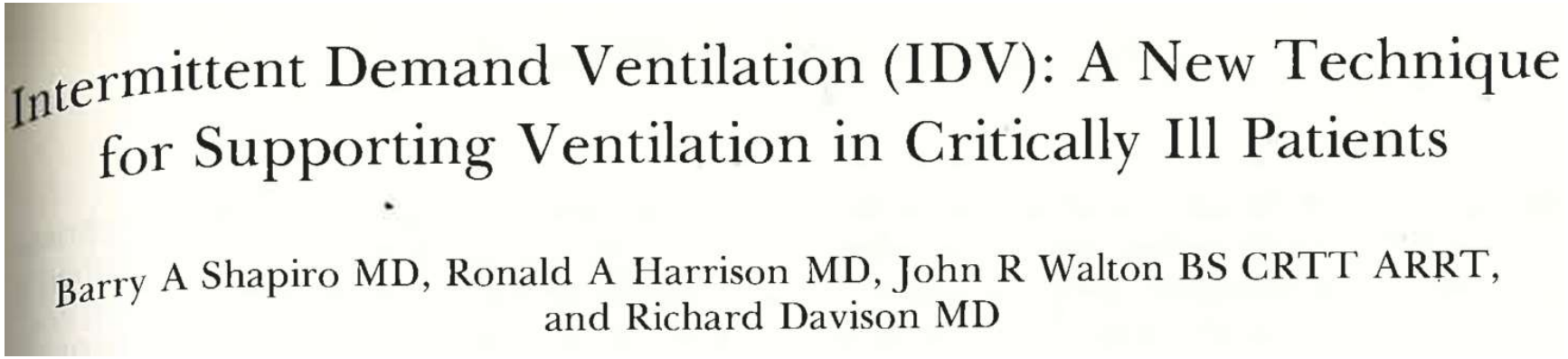
ROBERT KIRBY, LT. COL., USAF (MC)*
ELMO ROBISON, MAJOR, USAF (MC)†
JIMMY SCHULZ, A.A.I.T.†
ROBERT A. deLEMOS, LT. COL., USAF (MC)†

★ ROBERT R. KIRBY, Lt. Colonel, USAF, MC graduated from the School of Medicine of the University of California in San Francisco and served as a Resident in Anesthesiology at Wilford Hall USAF Medical Center, San Antonio, Texas. He is currently Chief of the Anesthesiology Service at the USAF Medical Center, Keesler AFB, Mississippi.

Intermittent Mandatory Ventilation: A New Approach to Weaning Patients from Mechanical Ventilators*

John B. Downs, M.D.; E. F. Klein, Jr., M.D.; Dave Desautels, A.R.I.T.; Jerome H. Modell, M.D., F.C.C.P.; and Robert R. Kirby, M.D.

Respiratory Care Journal – 1976



Intermittent Demand Ventilation (IDV): A New Technique for Supporting Ventilation in Critically Ill Patients

Barry A Shapiro MD, Ronald A Harrison MD, John R Walton BS CRTT ARRT, and Richard Davison MD

The origin of VC-SIMV using the Searle Ventilator

1976: Ads in Respiratory Care Journal

1976: Ads in Respiratory Care Journal

The CV 2000 provides optimum patient care with every significant ventilatory technique.

If the ventilator you're considering doesn't offer all these features, consider the one that does: the CV 2000.

- **Synchronized IMV** prevents asynchronous mandatory breaths.
- **Demand Valve** eliminates cumbersome reservoir system.
- **T_I and T_E Independently Controllable,** providing precise calibrated control over the components of ventilation.
- **Uninterrupted Continuous Flow (CPAP) Mode** with rapid switch-over to control modes when necessary.
- **Custom-Calibrated Controls** for wide and accurate ranges.
- **All Pneumatic** for extended life and reliability.
- **A Price Well Below** that of other ventilators with fewer capabilities.

Don't settle on any ventilator until you judge the CV 2000 for yourself. Simply write or call for a trial evaluation.

The IMV Machine

1976: Ads in Respiratory Care Journal

EMERSON

IMV Ventilator

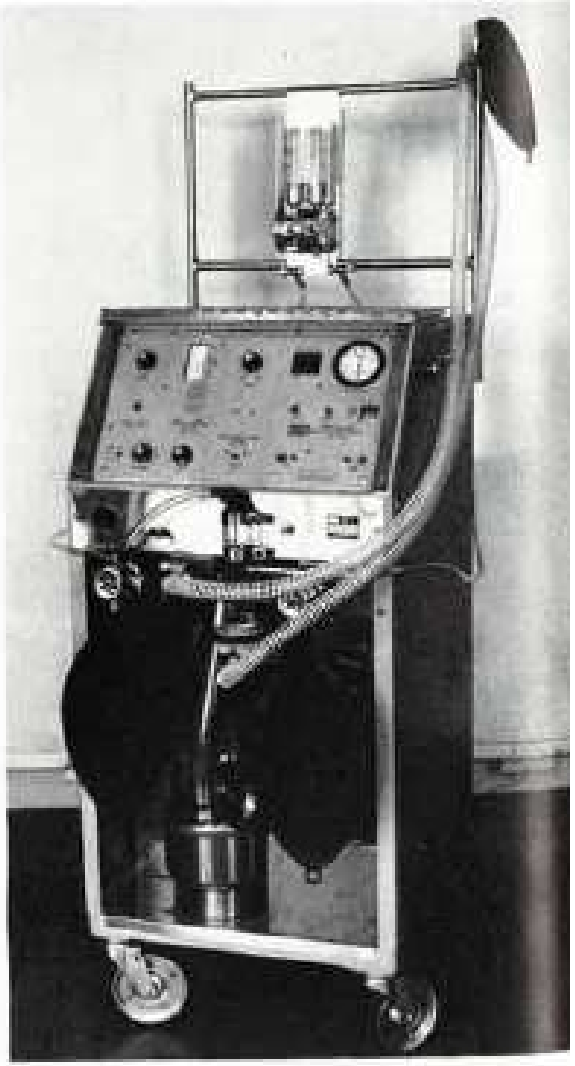
Designed specifically for IMV, to gain the maximum benefit from this new concept.

Air fully humidified flows continuously to a reservoir bag, and is available for unobstructed inspiration by the patient. PEEP may be added to keep the lungs expanded. At intervals the ventilator delivers a "mandatory" breath, which supplements the patient's own breathing and increases minute volume. The patient maintains his own homeostasis, without interference from drugs or hyperventilation.

At first the ventilator is generally set to supply mandatory breaths at a normal controlled rate. This is then gradually changed, by lengthening the interval between breaths as the patient's condition improves. Eventually mandatory breaths are spaced so far apart that the patient scarcely relies on them at all — and "weaning" is completed.

J. H. EMERSON COMPANY

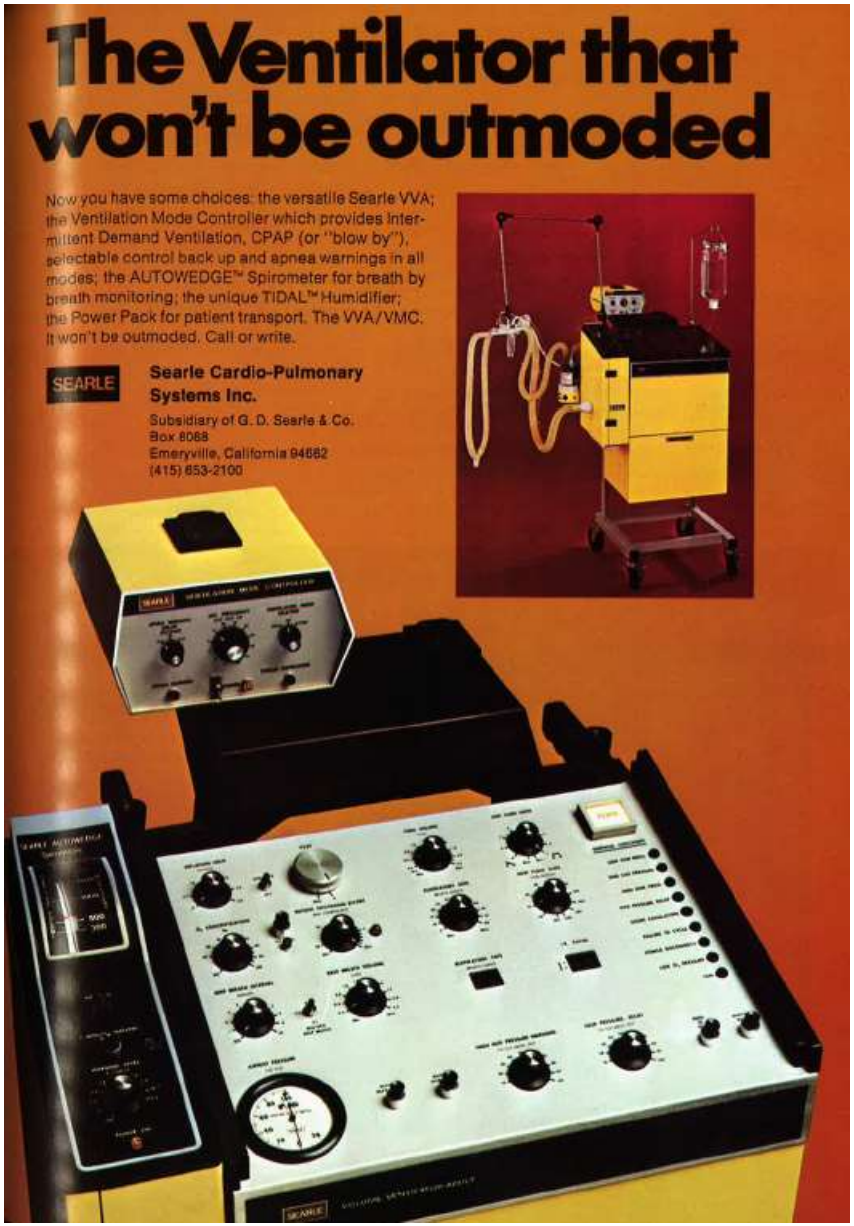
22 COTTAGE PARK AVENUE, CAMBRIDGE, MASSACHUSETTS 02140



Please request Form 3-MV

1976: Ads in Respiratory Care Journal

1976: Ads in Respiratory Care Journal



1976: Ads in Respiratory Care Journal

1976: Ads in Respiratory Care Journal

1976: Ads in Respiratory Care Journal

The FOREGGER® 210 Volume Ventilator.

1. IMV: IMV lets you remove a patient from the ventilator through a gradual weaning process. With most ventilators, you must add extra equipment to attain this benefit. But with the new FOREGGER 210 Volume Ventilator, IMV is built-in, not added on. So you can administer IMV without taping or untangling wires.

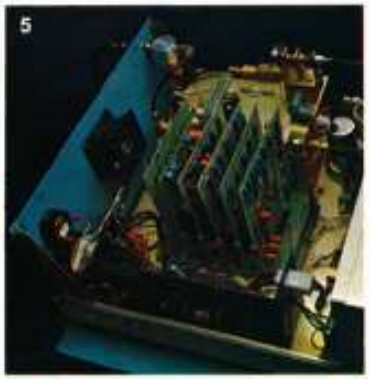
2. I:E Ratio: The unique cluster of Inspiratory: Expiratory Time ratio, Inspiratory Time, and Airway Flow rate dials, enables you to maintain a preset I:E ratio (1:1 to 1:4). You can also adjust Breaths Per Minute and Tidal Volume independently. Gives you greater flexibility in critical patient care.

3. Alarm System: The FOREGGER 210 Volume Ventilator has an alarm for all anticipated clinical contingencies. THESE ALARMS INCLUDE HIGH AIRWAY PRESSURE, HIGH SIGH PRESSURE, APNEA, INTERNAL FAILURE, POWER FAILURE, LOW GAS PRESSURE, AND HIGH AND LOW MINUTE VOLUMES. Alarms are both audible and visual so the operator can ascertain ventilator status from a distance and react quickly if a change occurs. In addition, press-to-test and audio-off controls are included.

4. Multiple Function: We provide the latest state of the art versatility. This includes Manual Start, IMV, I:E Ratio, Sigh, Multiple Sigh, Manual Sigh, Assist, Inspiratory Pause and PEEP.

5. Service: Because of all-electronic circuitry, most factory servicing can be done right in the hospital. And, emergency response can be provided within 48 hours on a regional level by specialized technicians. So you get fast, expert service.

6. In-Service Training: To help you become more familiar with our new Volume Ventilator, we've put together



1976: Ads in Respiratory Care Journal

What's New?

BIO-MED IC-2 VENTILATOR. The IC-2 Adult Intensive Care/ Transport Ventilator is said by the

BOURNS BP200 VENTILATOR. An electronically controlled and pneumatically operated time-cycled device, the Bourns Model BP200 Infant Pressure Ventilator is a continuous flow generator that serves as a controller. It provides ZEEP, PEEP, CPAP, IMV, or inspiratory pause. Pressure limit may be controlled in any mode. Rate is adjustable from 1 to 60/min, I/E from 4/1 to 1/10, flow from zero to 20 l/min, CPAP/PEEP

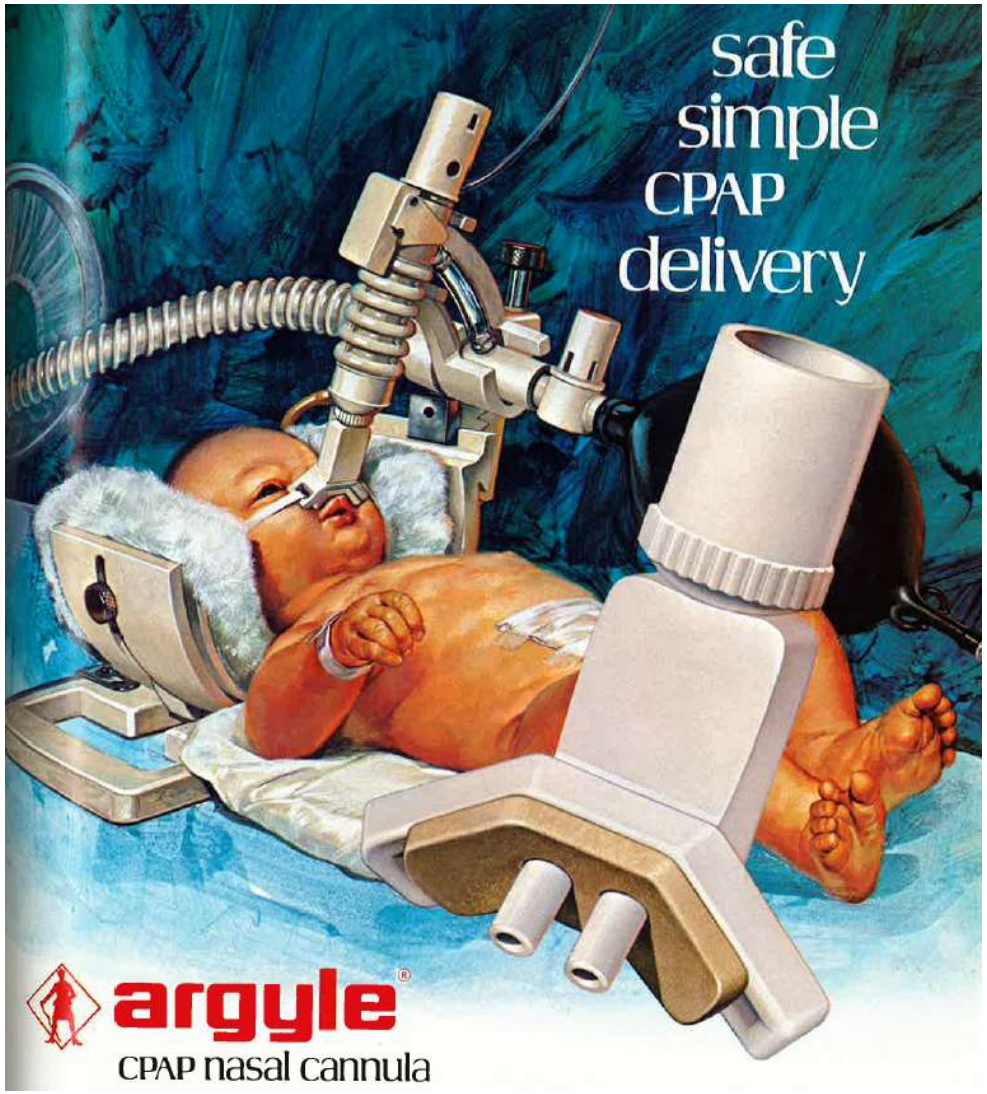
from zero to 20 cm H_2O, pressure limit from 10 to 80 cm H_2O. The ventilator has a heated humidifier, integral oxygen blender, manual breath capability, and audible alarms for gas supply pressure failure and power failure. It weighs 35 lbs, measures 9" high by 9" wide by 13" deep, and can be placed on a table or counter or mounted on a castered stand. *Bourns Inc Life Systems Division.*

IMVbird. The IMVbird is pneumatically powered, time cycled, and offers tidal volume determination by inspiratory time and flow-

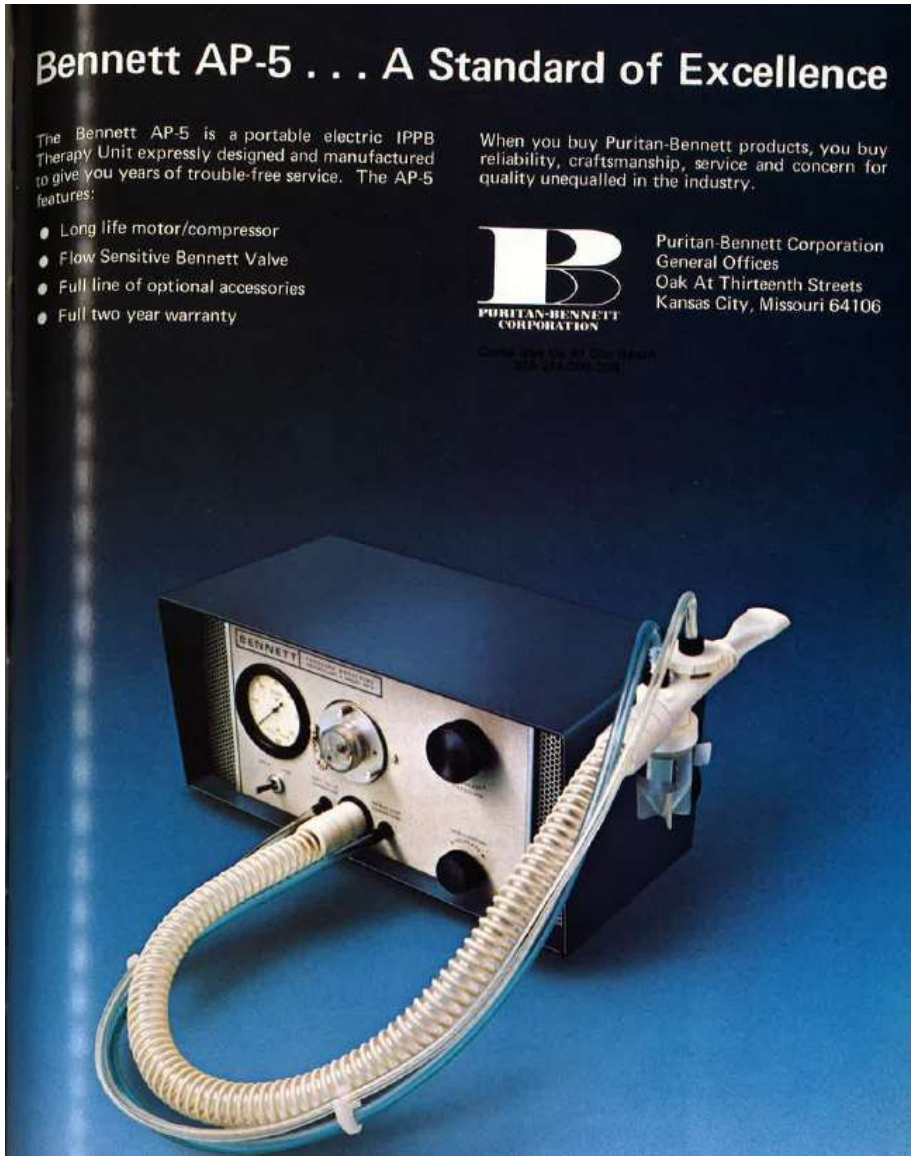
rate, pressure limiting, CPAP, PEEP, IMV, demand acceleration and flow acceleration, with a minimum of controls and absence of gadgetry. **bird** *Corporation.*

1976: Ads in Respiratory Care Journal

Over-engineered at Case Western Reserve University

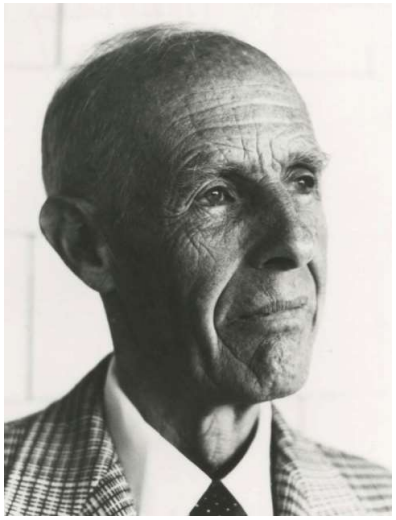


1976: Ads in Respiratory Care Journal



High Frequency Ventilators

First High Frequency Oscillator (1950s)



Jack Emerson

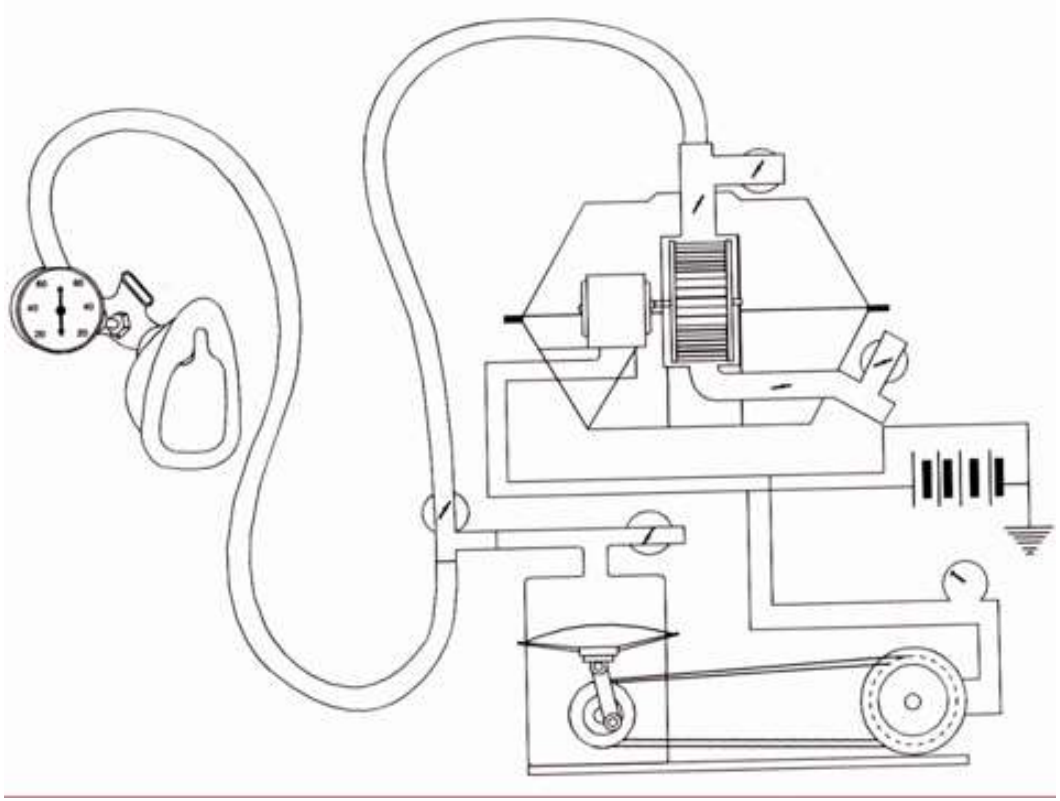


photo courtesy of Rich Branson

Rainbow Jet Makes the News

Niles Man's Respirator Device Hailed by Medical Society

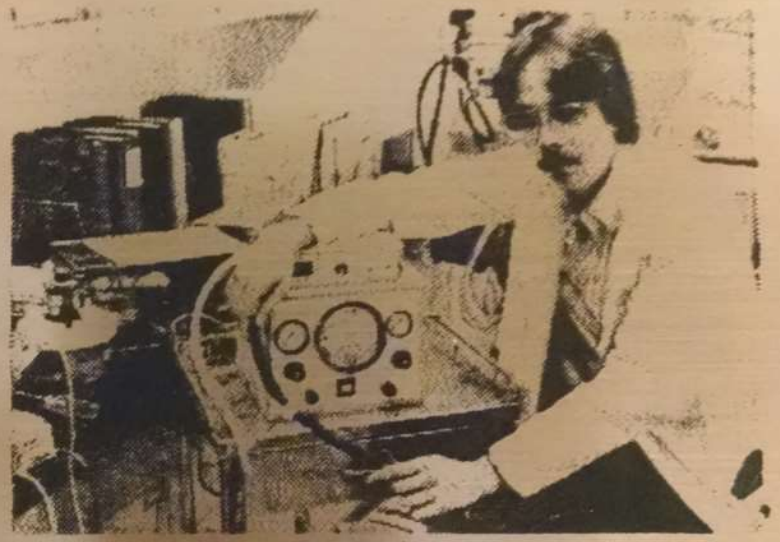
EMILY WEBSTER
Vindicator Trumbull County Staff

NILES — A city resident is receiving credit for developing a new respirator for use on premature and newborn babies.

Rob Chatburn's "high-frequency jet ventilation" device has already been credited with saving the life of at least one baby. It has been the subject of articles in several professional journals and has generated an expanding lecture tour for the Niles McKinley High School graduate.

He is currently director of clinical research in the respiratory department at Rainbow Babies and Children's Hospital in Cleveland.

Put in simple terms, the HFJV device warms and humidifies air and then ad-



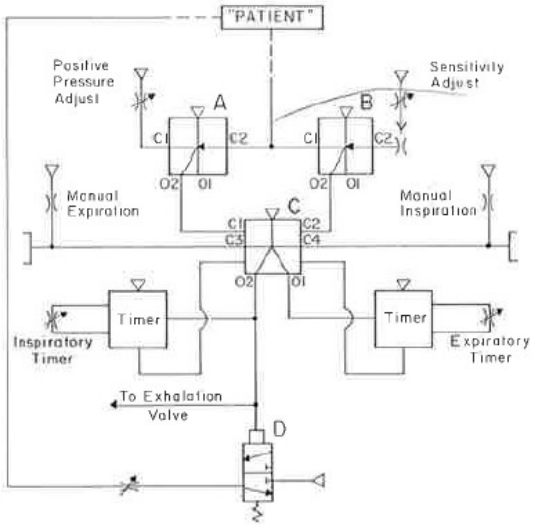
Rob Chatburn

people with great success," he says, and uses the case of an 8-month-old patient as illustration.

The child was hospitalized with bronchitis and placed

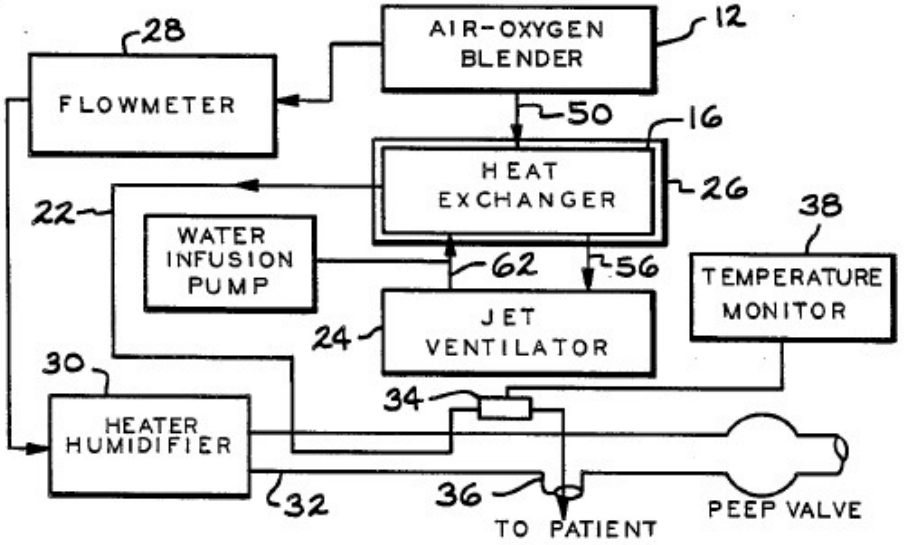
gineer, he transferred his ideas into a reality that has made a positive impression on fellow researchers — some of whom thought the idea of heating and humid-

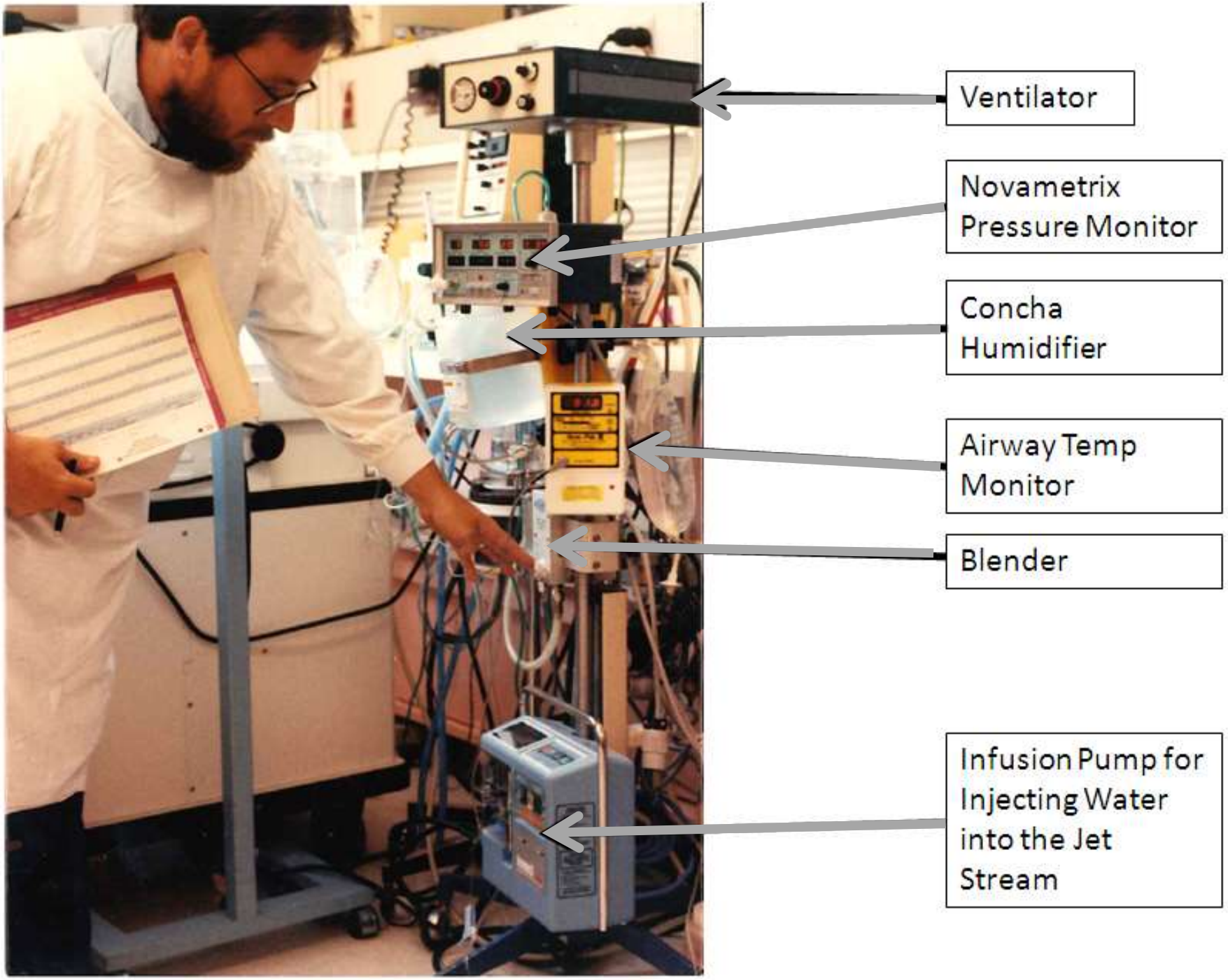
Fluidic logic control circuit



Rainbow Jet Ventilator 1980s

United States Patent [19] [11] **Patent Number:** 4,589,409
Chatburn et al. [45] **Date of Patent:** May 20, 1986




Ventilator
Novametrix Pressure Monitor
Concha Humidifier
Airway Temp Monitor
Blender
Infusion Pump for Injecting Water into the Jet Stream

First Commercial Jet Ventilator (1980s)

Second Commercial Jet Ventilator (1980s)

Bunnell LifePulse Infant Jet Ventilator

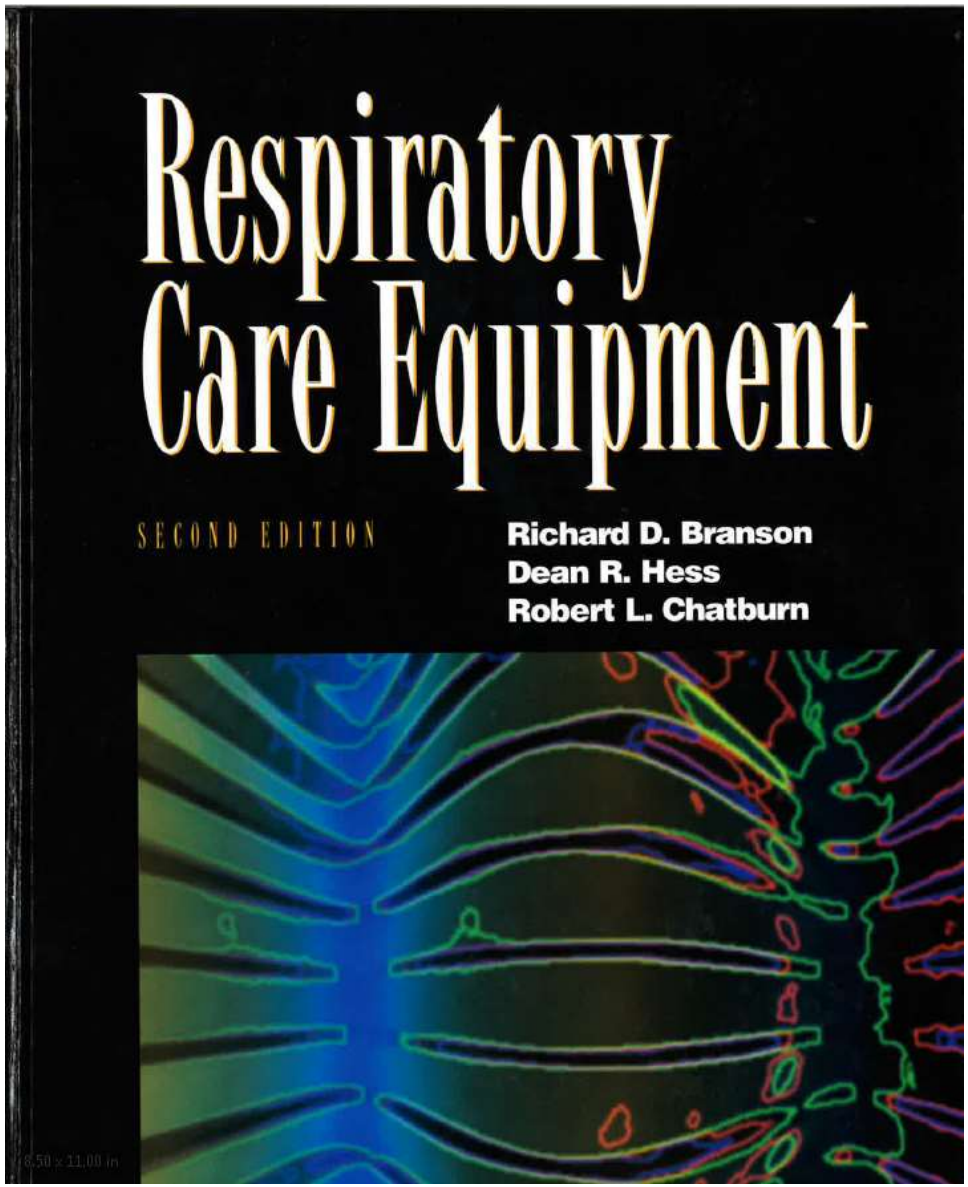
First Commercial Oscillator (1980s)

Dr. Bird - Sinusoidal Percussionator

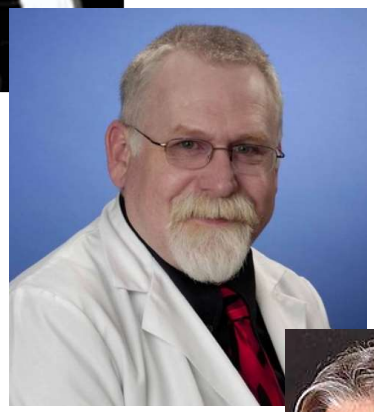
First

Last

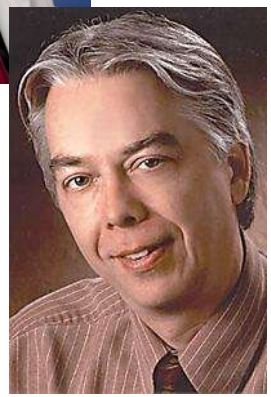
The Leading Equipment Book of 1990s



Rich Branson



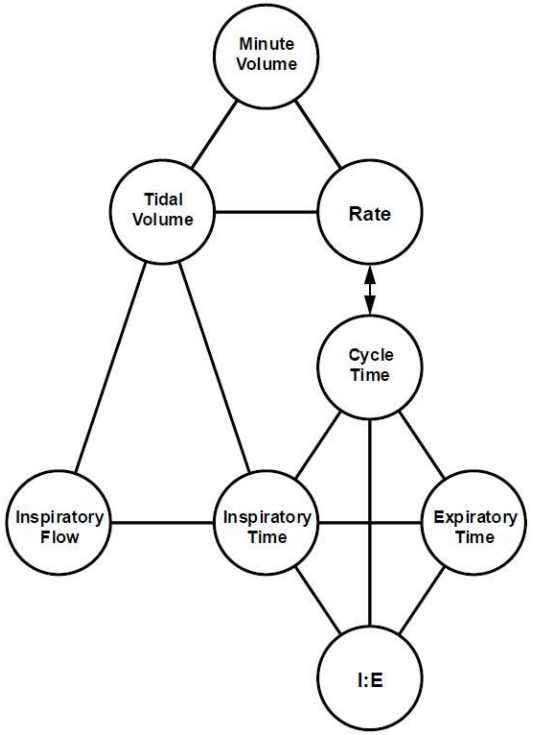
Dean Hess



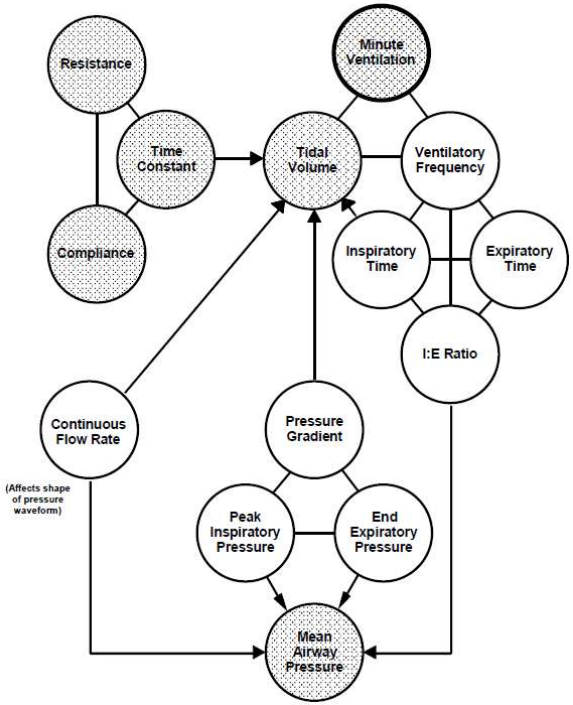
Rob Chatburn

Branson Book Innovations

Volume Control

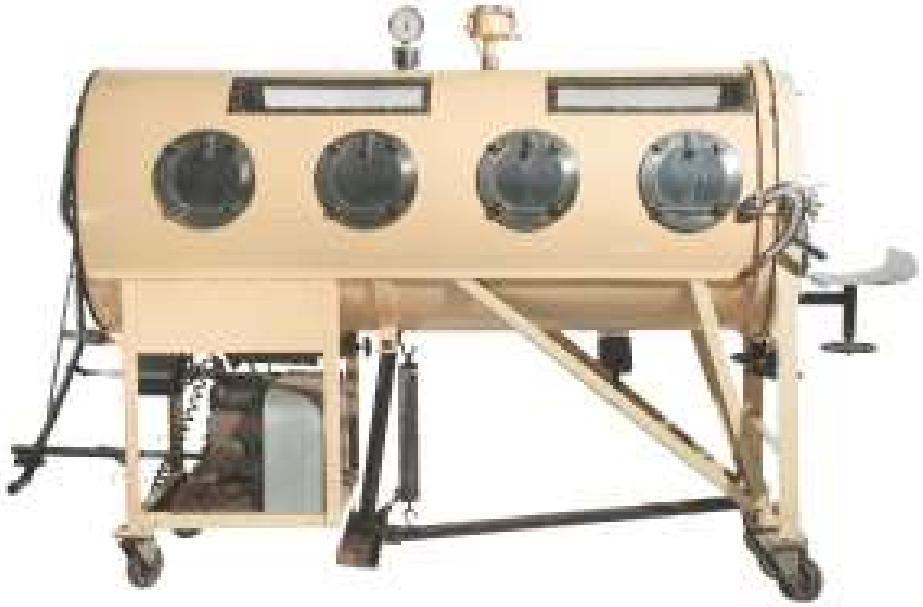


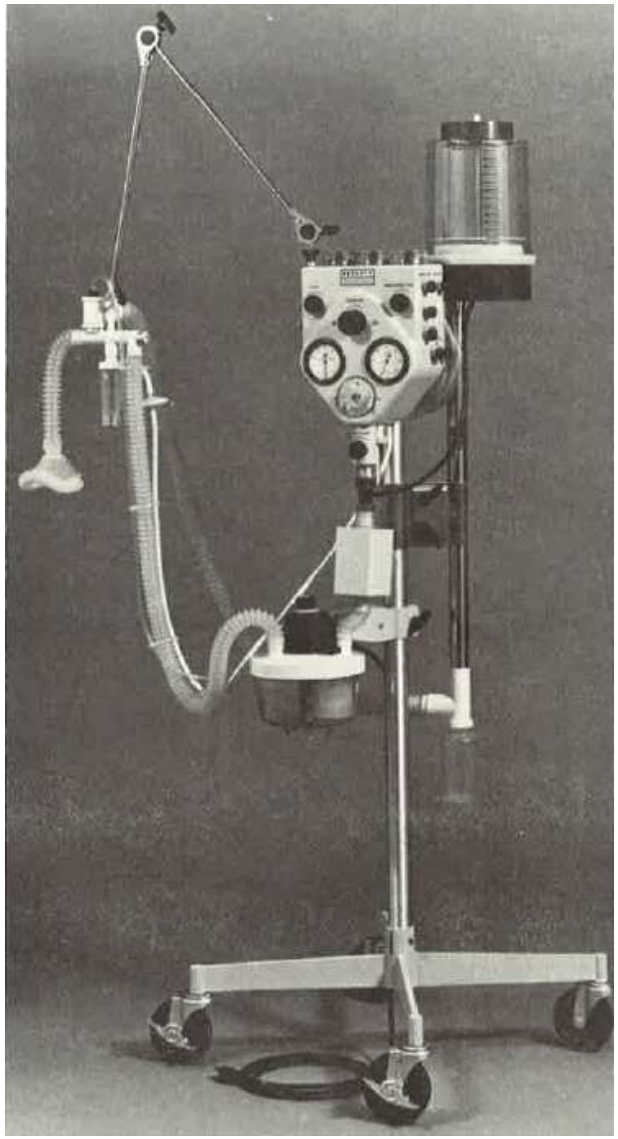
Pressure Control



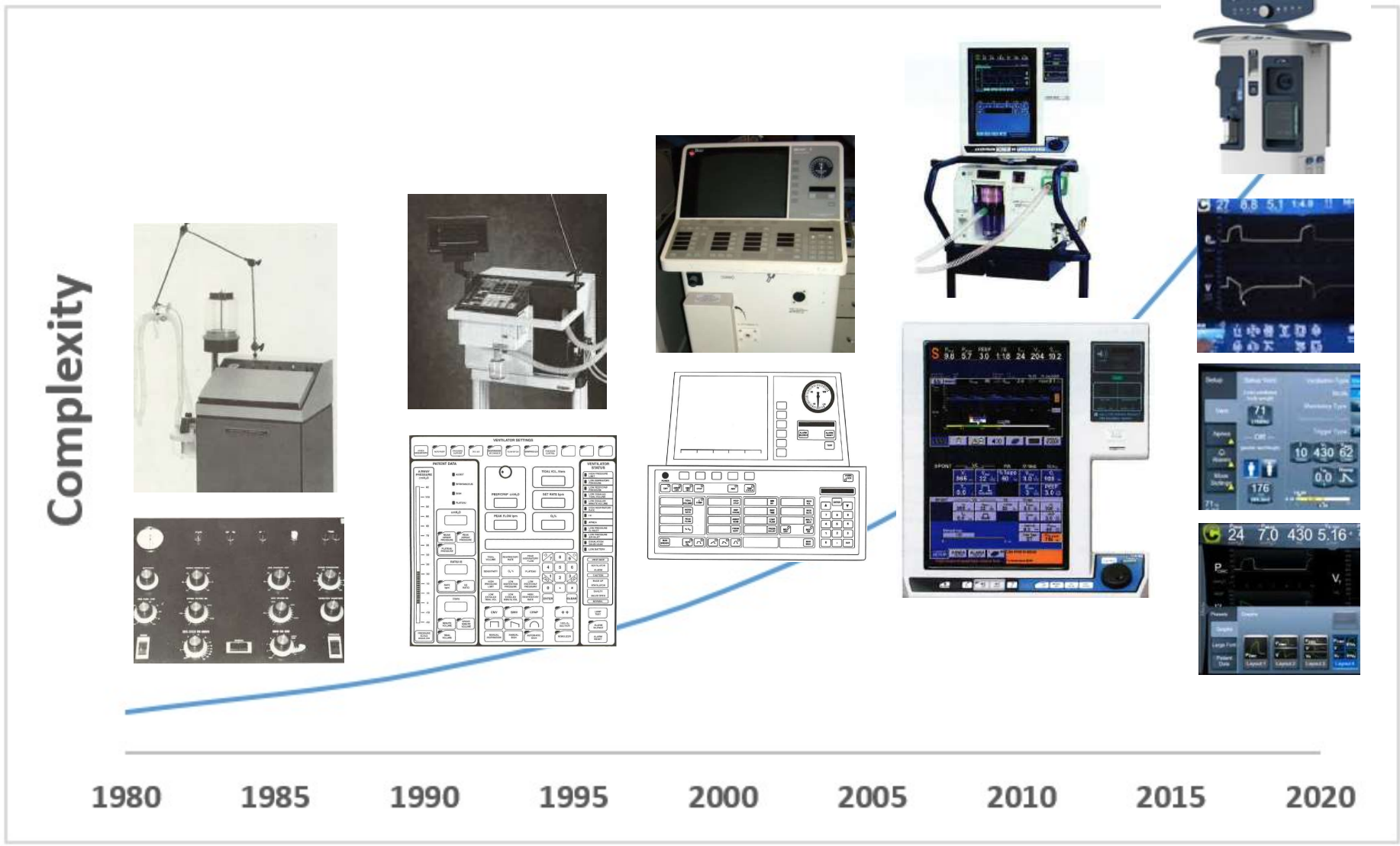
$$P_{vent} + P_{mus} = E \times V + R \times \dot{V}$$

First Generation Ventilators (early 1900s)



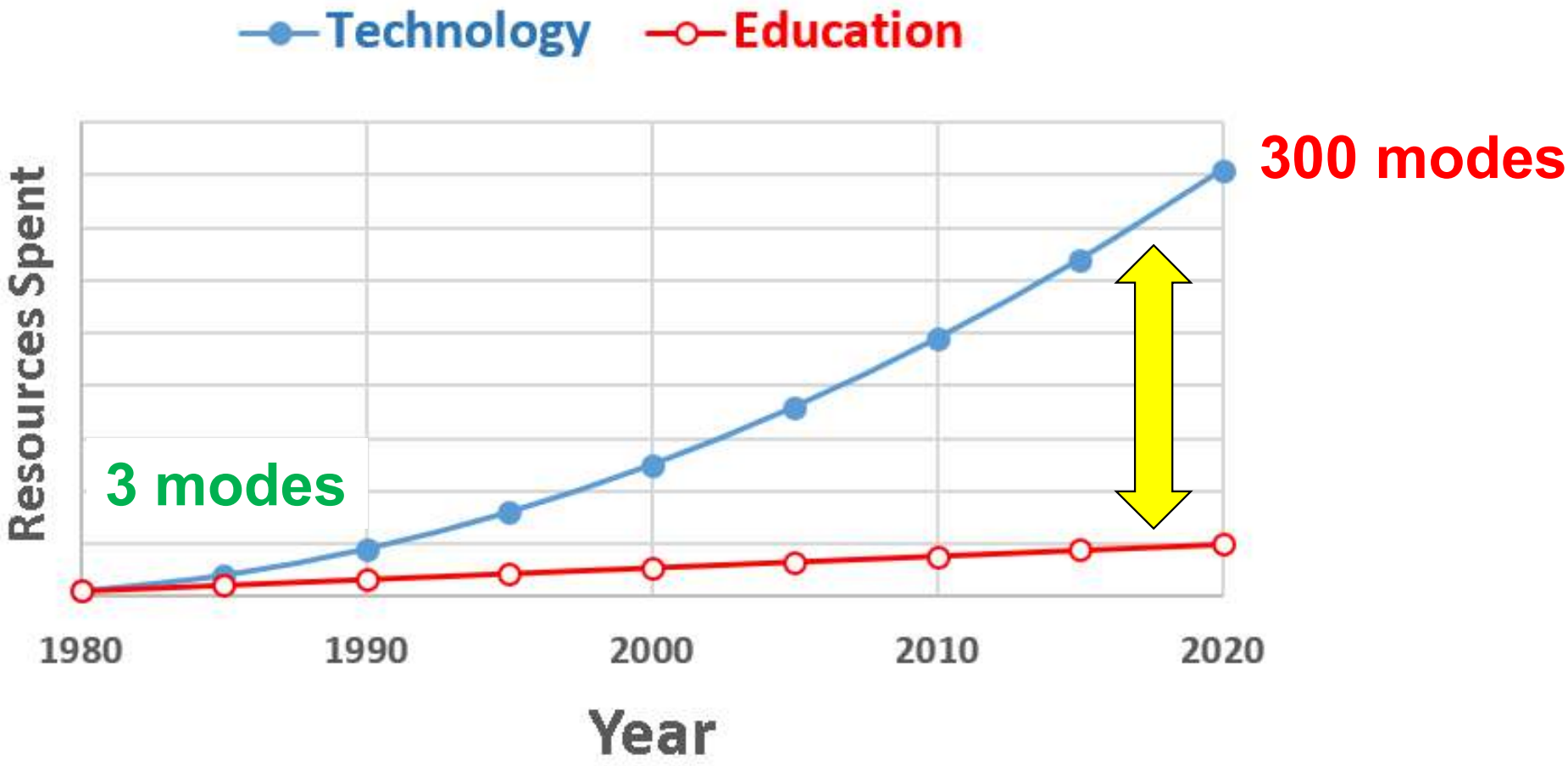


Growth in Ventilator Complexity



2nd gen 3rd gen 4th gen 5th gen 6th gen

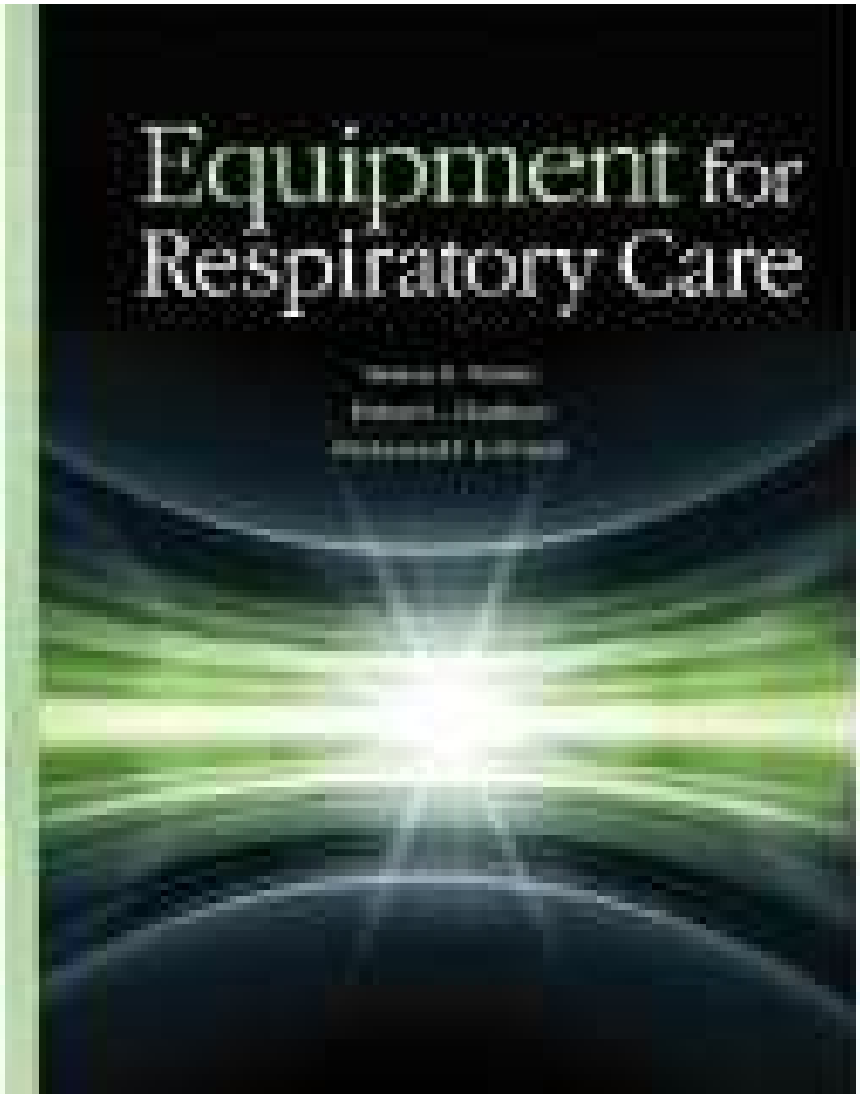
Growing Knowledge Gap



Like Driving a Sports Car in 1st Gear Only

Most Recent RC Equipment Book (2016)

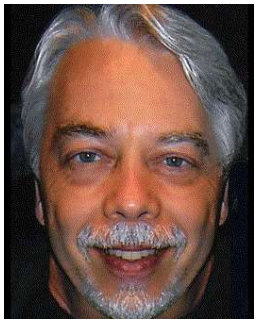
AC PCV
Adaptive Flo
Adaptive Su
Airway Press
APV SIMV
Assist/Contr
Automatic Tu
Automode (F
AutoMode(V
BiLevel
BiPAP S/T
CMV
CMV+AutoF
CMV+Pressu
CPAP
DuoPAP
Flow Adaptiv
Mandatory M
PC-A/C
PCV+



35 ventilators
300 modes

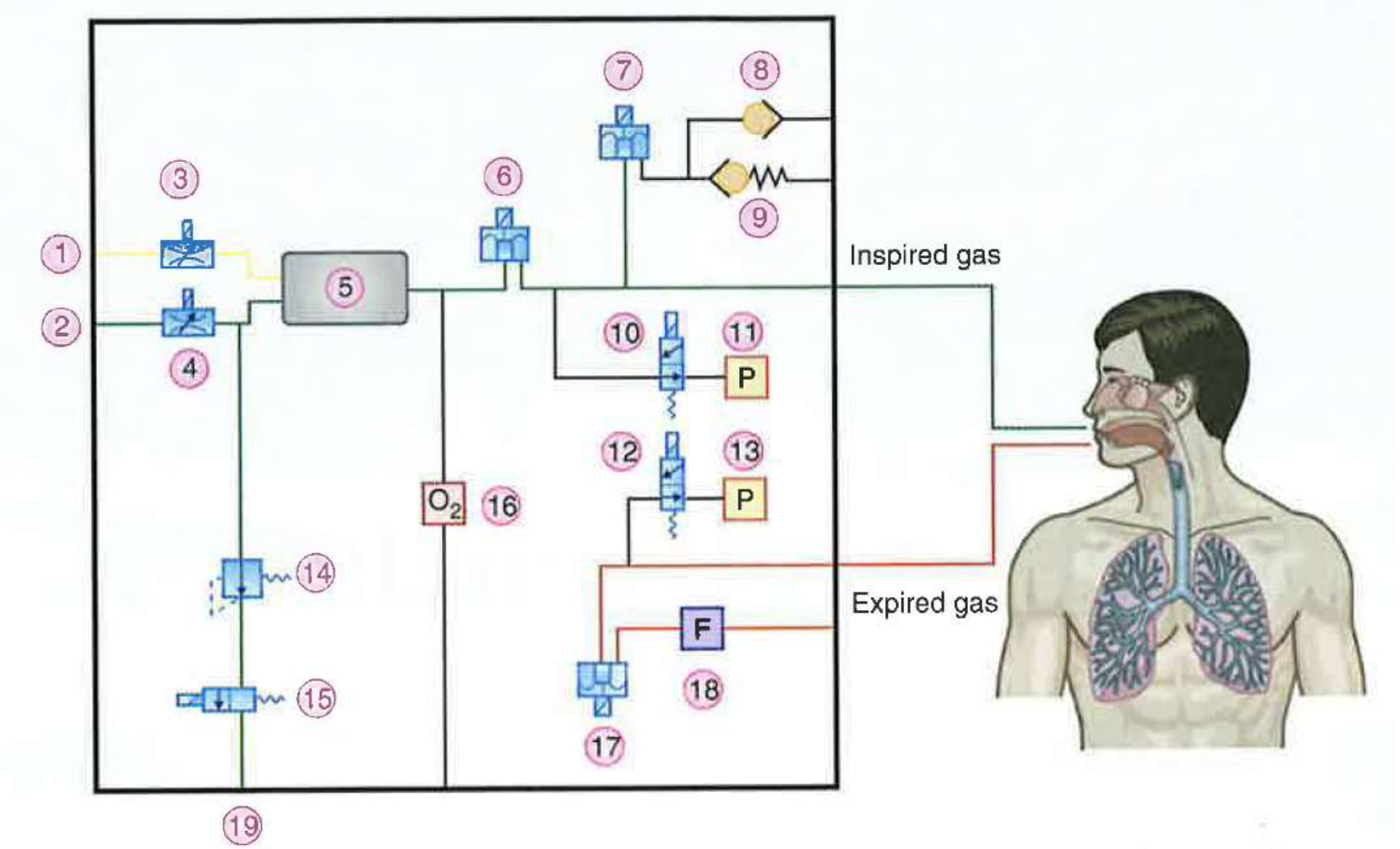
Terry Volsko

Mohamad El Khatib

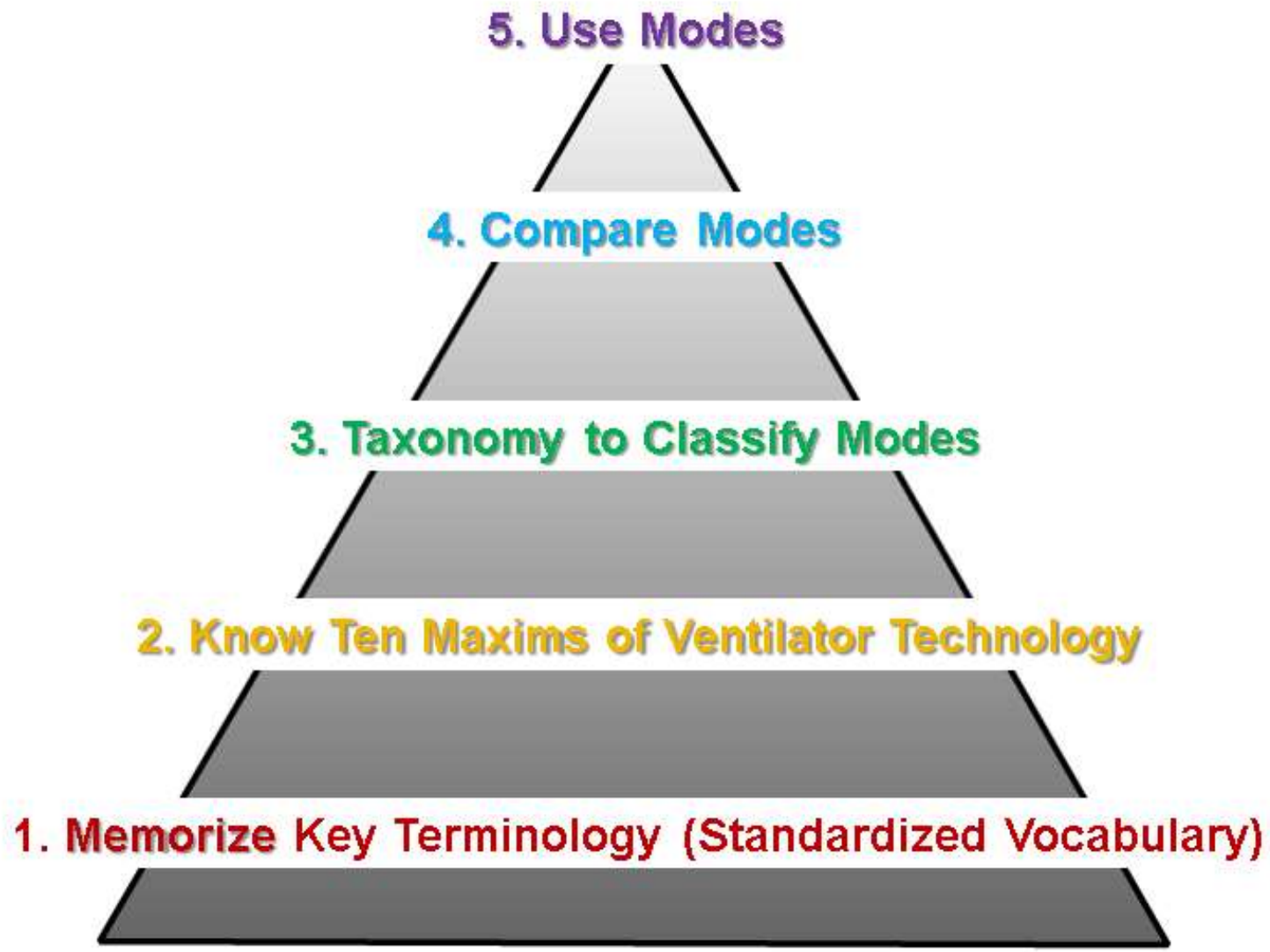


Rob Chatburn

No More Schematics!

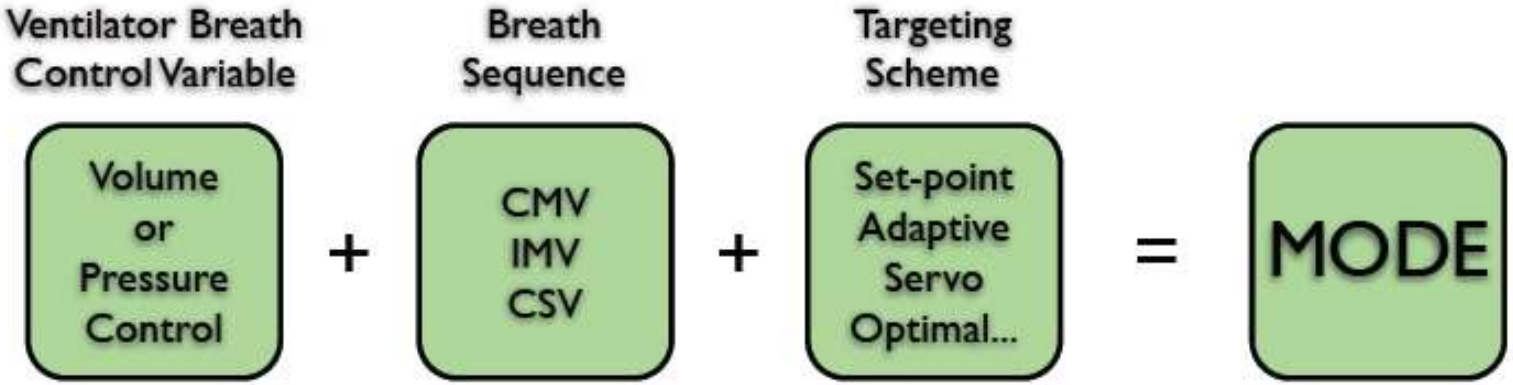


Volsko Book Innovations



Ventilator Mode Taxonomy

- **Mode:** predetermined pattern of patient-ventilator interaction
  - Mode name: arbitrary name coined by vendor
  - Mode tag: classification of mode using a taxonomy

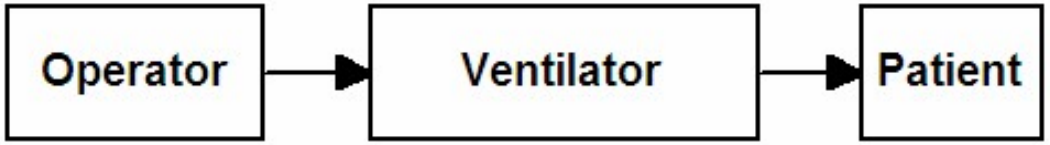


Targeting Schemes

Manual

- *setpoint (PC-IMV)*
- *dual (Pmax, Flow Adapt)*

operator-selected, static setpoints

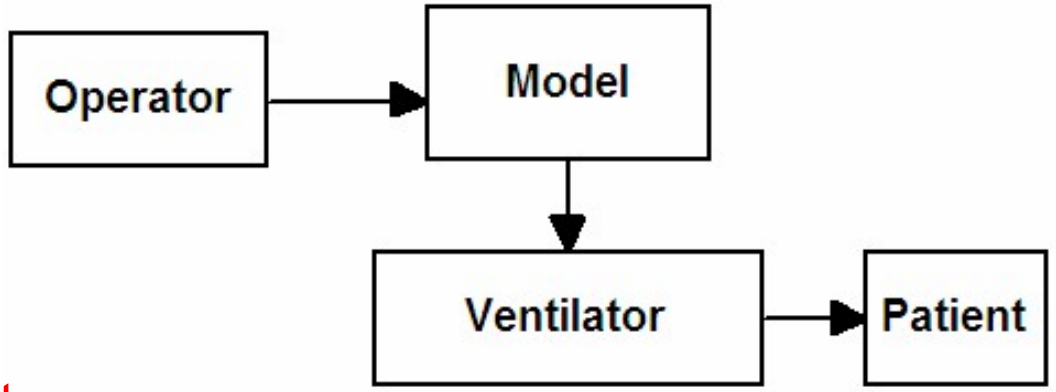


Semi-Automatic

- *servo (proportional assist)*
- *bio-variabole*
- *adaptive (CMV+AutoFlow)*
- *optimal (ASV)*

ventilator-selected, dynamic setpoints

static model

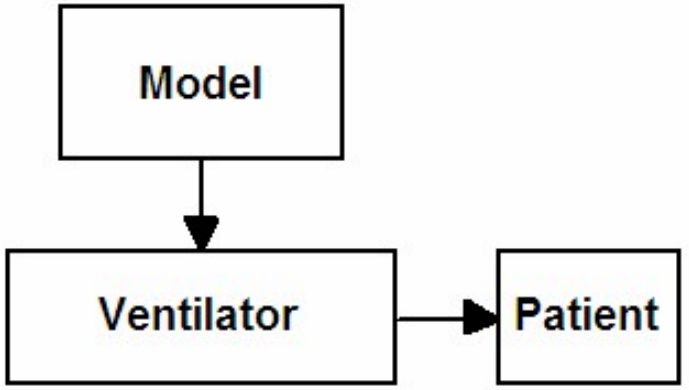


Advanced Total Automatic

- *intelligent (SmartCare, IntelliVent)*

ventilator-selected, dynamic setpoints

dynamic model



The Ultimate in Targeting Schemes

The Future is Now

Riemannian Geometry Applied to Detection of Respiratory States from EEG Signals: the Basis for a Brain-Ventilator Interface

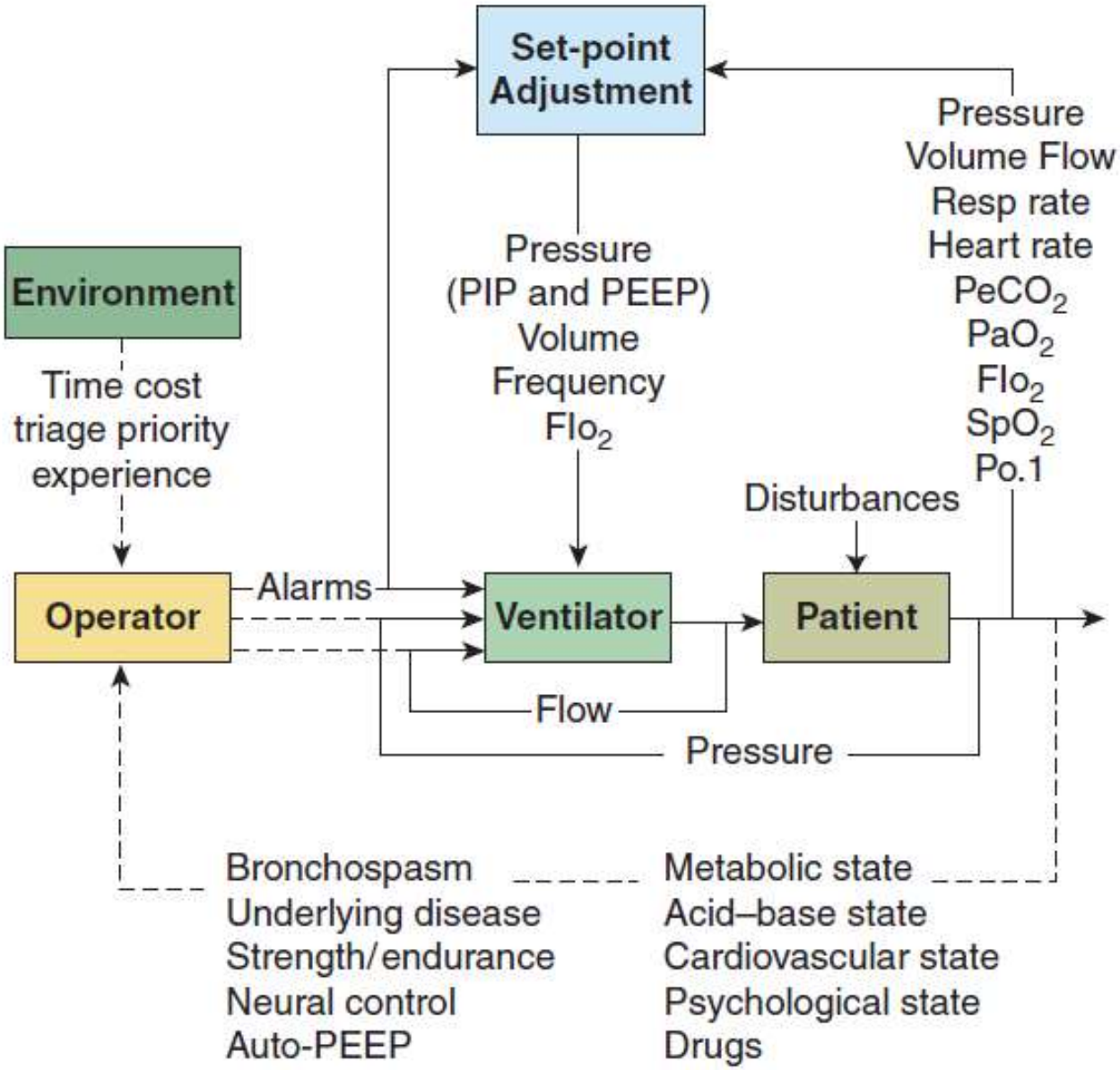
X. Navarro-Sune, A.L. Hudson, F. De Vico Fallani, *Member, IEEE*, J. Martinerie, A. Witon, P. Pouget, M. Raux, T. Similowski and M. Chavez

IEEE transactions on bio-medical engineering (2016)

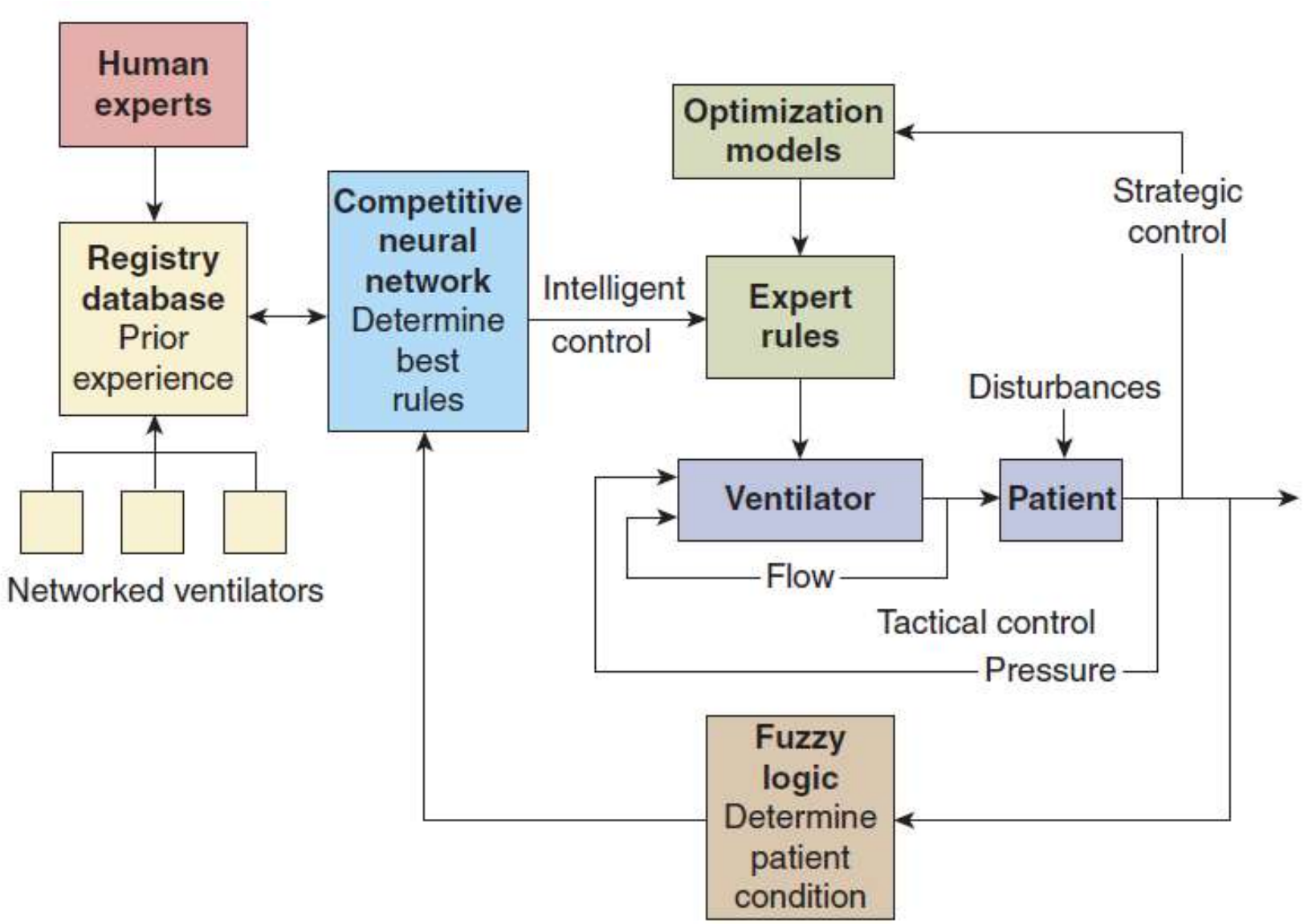
Significance: The proposed framework opens the door to brain-ventilator interfaces for monitoring patients' breathing comfort and adapting ventilator parameters to patient respiratory needs.

Rewriting the Books

The Challenge of Total Computer Control



The Ventilator of the Future (black box)



Ventilator AI Becomes Self-Aware

The Newest Kid on the Block

VS

Ventilation **O**xygenation **C**ough-assist **S**uction **N**ebulization

Rainbow B&C Legacy

Pediatric Respiratory Therapy

Neonatal Respiratory Therapy

Marvin Lough
Father of pediatric
and neonatal respiratory care

Robert L. Chatburn
Your Humble Narrator

Tom Kallstrom
CEO of AARC

Tim Myers
CBO of AARC

Terry Volsko
Director Respiratory Care, Transport Com Cntr
Akron Children's Hospital