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)
The Real Reason Trump-Care Failed
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)

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)

(1951) The original Mark 7, built inside a coffee can. This was the first Bird breathing device to use magnets for the control of gas movement.

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.

photo courtesy of Rich Branson

• positive pressure
• nebulization
• both
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
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

- **V (L/min):** Flow rate
- **P_{Mo} (cm H_2O):** Pressure at mouth
- **P_A (cm H_2O):** Pressure in alveoli
- **V (ml):** Volume

(a) Standard conditions
(b) Compliance halved
(c) Resistance doubled
1977 Textbook on Mechanical Ventilation
Described 10 ventilators
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

The graph shows the relationship between time (in seconds) and pressure (in cmH₂O) for different flow rates (in liters/second). The graph highlights the difference in waveforms between 'fast' and 'slow' flow rates.
Bennett MA-1 (USA)
Engström (Denmark)
Servo 900 series Sweden (1970s)
Vanguard Pad-1 Fluidic
Bird Mark V11
The First RT Equipment Book (1977)

Respiratory therapy equipment
STEVEN P. McPHERSON

Respiratory therapist author

Detailed descriptions of 31 ventilators

Only mentions 3 modes!
Fluidic Logic Control Circuits (again)
Emerson Cuirass
1980s philosophy: Normalize blood gases no matter what the inspiratory pressure
Monaghan 225
Bourns BEAR Series (1980s 1990s)

Bear 1

Bear 5

Bear 1000
The First Infant Ventilators
First US Infant Ventilator (1974)

Dr. Forrest Bird

patent courtesy of Felix Khusid
Babybird Ventilator US (late 1970s)
Bourns LS104-150 US (1980s)
First ventilator with mode selection?

Assist
Control
Assist/Control

Set slide so that ventilator tidal volume is directly above breathing rate reading.

Read I/E ratio directly below flow rate.
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
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 administers it 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 in a respirator. The device was turned on, and within minutes, the child began to breathe more easily.

Fluidic logic control circuit
Rainbow Jet Ventilator 1980s


Diagram of Rainbow Jet Ventilator components:
- Flowmeter
- Air-Oxygen Blender
- Heat Exchanger
- Water Infusion Pump
- Jet Ventilator
- Heater Humidifier
- Temperature Monitor
- PEEP Valve
- TO PATIENT
First Commercial Jet Ventilator (1980s)
Second Commercial Jet Ventilator (1980s)

Bunnell LifePulse Infant Jet Ventilator
First Commercial Oscillator (1980s)
Dr. Bird - Sinusoidal Percussionator
\[ P_{vent} + P_{mus} = E \times V + R \times \dot{V} \]
Growing Knowledge Gap

3 modes vs. 300 modes

Year

Resources Spent
Most Recent RC Equipment Book (2016)

35 ventilators
300 modes
No More Schematics!
Volsko Book Innovations

1. Memorize Key Terminology (Standardized Vocabulary)
2. Know Ten Maxims of Ventilator Technology
3. Taxonomy to Classify Modes
4. Compare Modes
5. Use Modes
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 (*P_{max}, 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


*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

Termilator
The Newest Kid on the Block

Ventilation Oxygenation Cough-assist Suction Nebulization