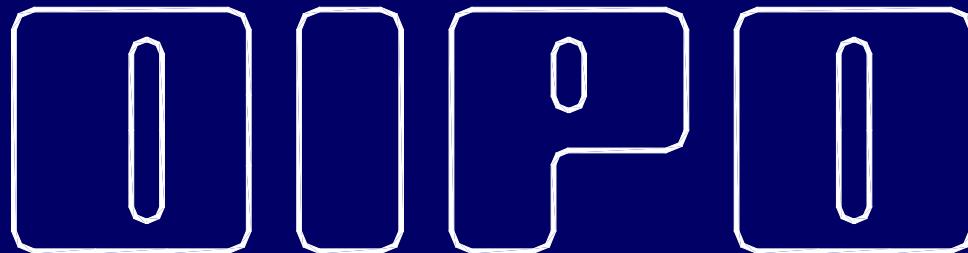


# HYDRAULICS & PNEUMATICS

DICK H. PLETTENBURG

Evolving Design WB3110





innovative upper extremity prostheses and orthoses

[www.dipo.3me.tudelft.nl](http://www.dipo.3me.tudelft.nl)

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# Hydraulic: etymology

- Latin *hydraulicus*,  
Greek *hydraulikos*, from *hydraulis* hydraulic organ  
[water organ], from *hydor* [water] + *aulos* [pipe]

# Hydraulic: definition

- 1 : operated, moved, or effected by means of water

# Hydraulic: definition

- **2 a :** of or relating to hydraulics <*hydraulic* engineer>  
**b :** of or relating to water or other liquid in motion  
<*hydraulic* erosion>

# Hydraulic: definition

- 3 : operated by the resistance offered or the pressure transmitted when a quantity of liquid (as water or oil) is forced through a comparatively small orifice or through a tube <*hydraulic* brakes>

# Hydraulic: definition

- 4 : hardening or setting under water <*hydraulic cement*>

# Pneumatic: etymology

- Latin *pneumaticus*,  
Greek *pneumatikos*, from *pneumat-*, *pneuma* air,  
breath, spirit, from *pnein* to breathe

# Pneumatic: definition

- **1** : of, relating to, or using gas (as air or wind): **a** : moved or worked by air pressure **b** (1) : adapted for holding or inflated with compressed air (2) : having air-filled cavities

# Pneumatic: definition

- 2 : of or relating to the pneuma : **SPIRITUAL**

# Pneumatic: definition

- 3 : having a well-proportioned feminine figure; *especially* : having a full bust



Merriam-Webster Dictionary

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Hydraulics  
Pneumatics }  
Fluid Power

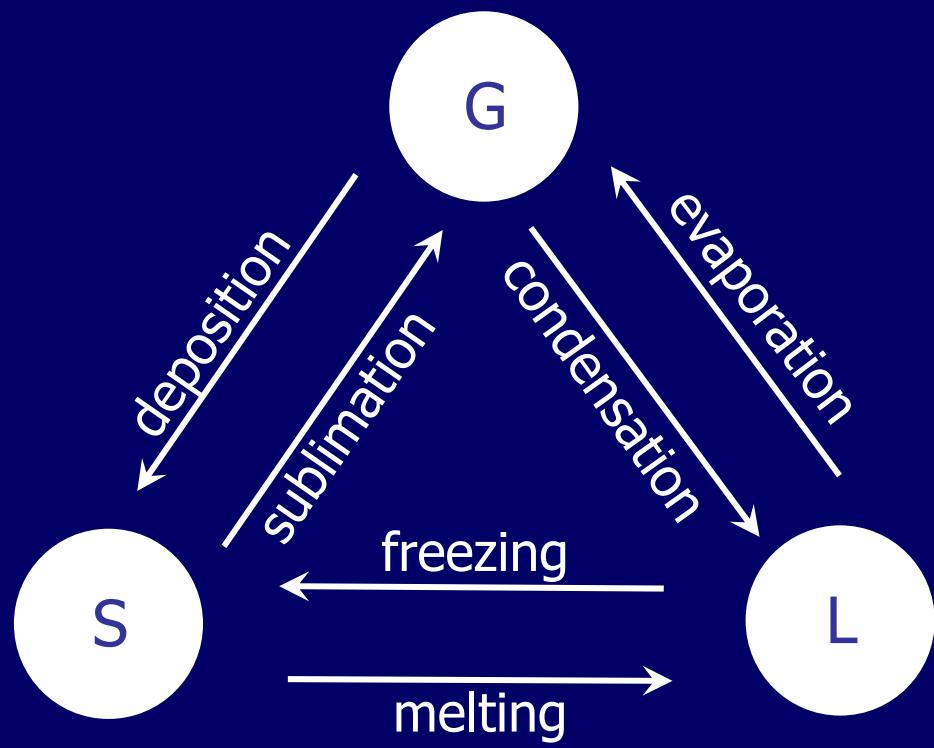
©2010 Dick H. Plettenburg



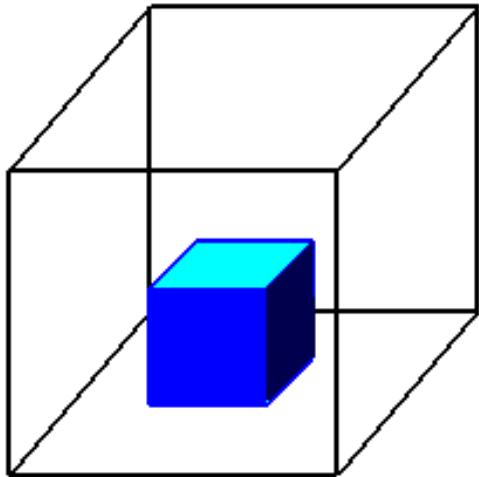
# Basic Principles

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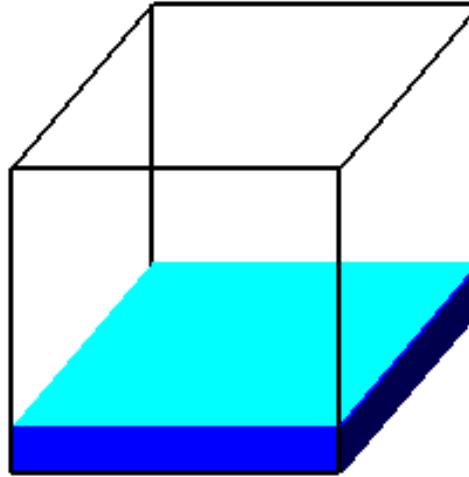
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### Solid

Holds Shape

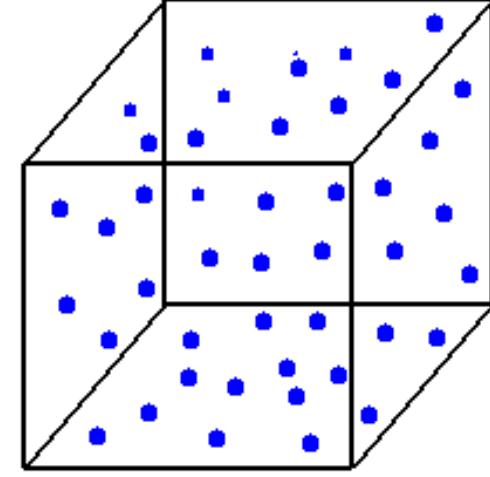
Fixed Volume



### Liquid

Shape of Container  
Free Surface

Fixed Volume



### Gas

Shape of Container

Volume of Container

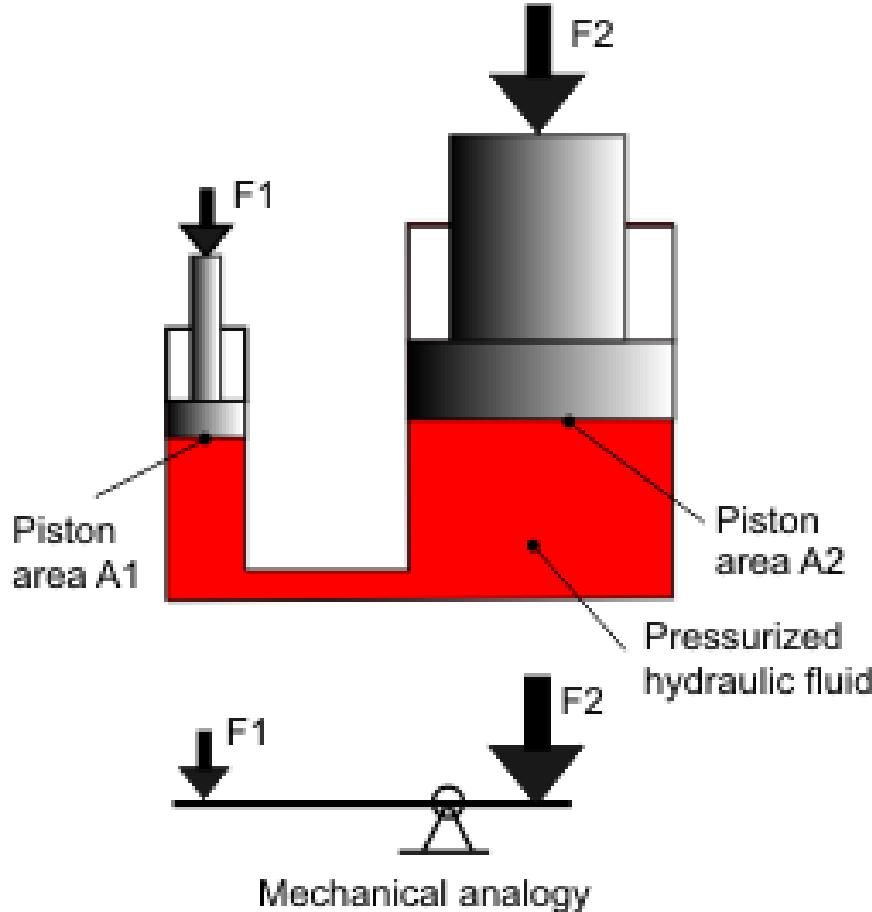
Blaise Pascal, 1623 - 1662



Pascal's Law:

"a change in the pressure of an enclosed incompressible fluid is conveyed undiminished to every part of the fluid and to the surfaces of its container"

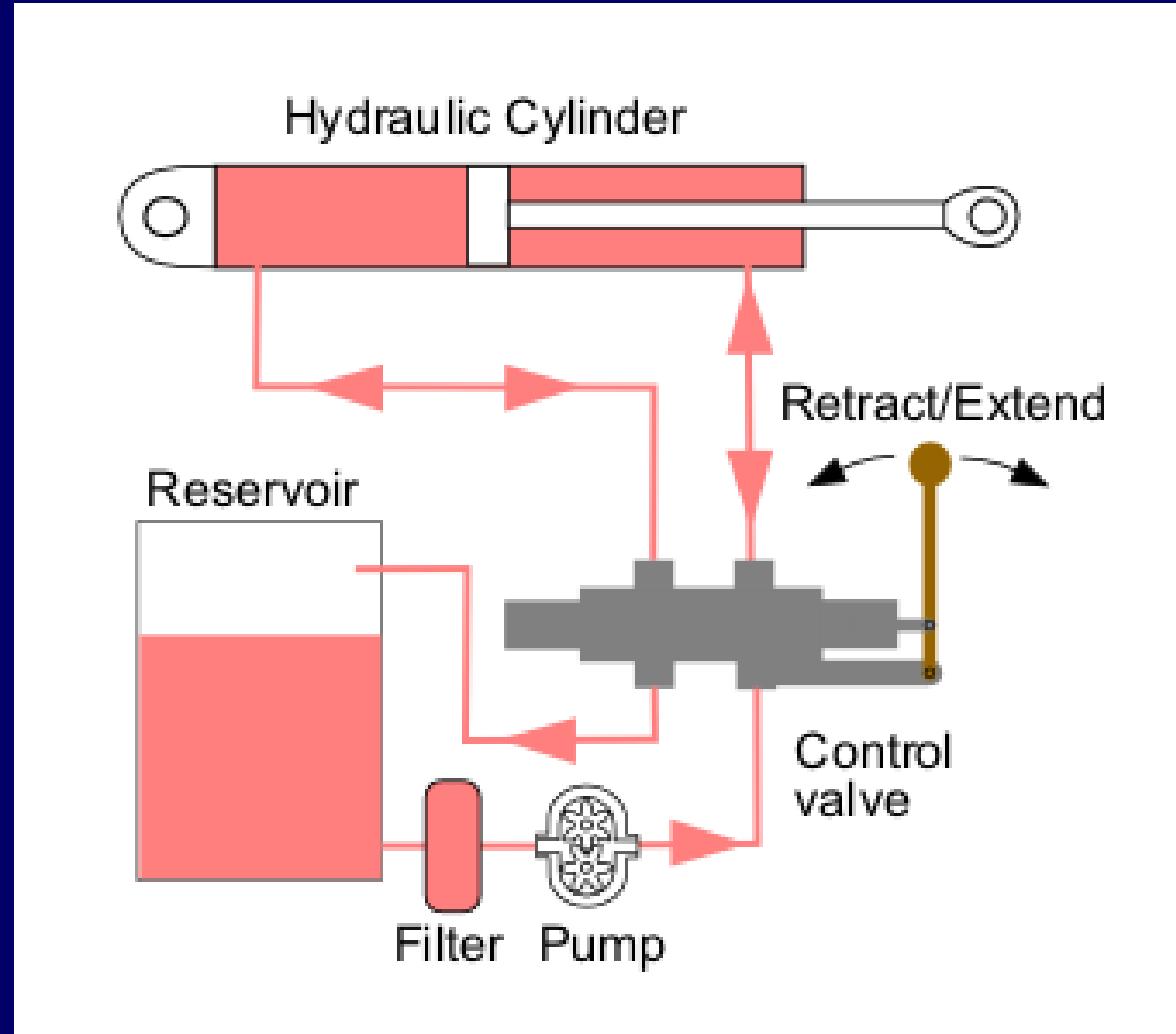
Force increase with hydraulics  
 $F_2 = F_1 \cdot (A_2/A_1)$



SI unit of pressure or stress:

$$1 \text{ Pa} = 1 \text{ N / m}^2$$

$$100 \text{ kPa} \approx 1 \text{ bar}$$

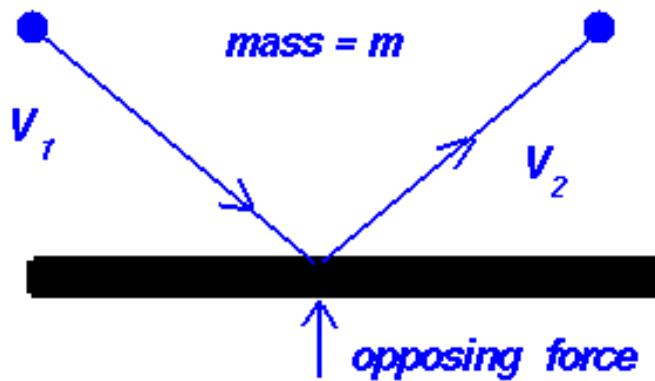






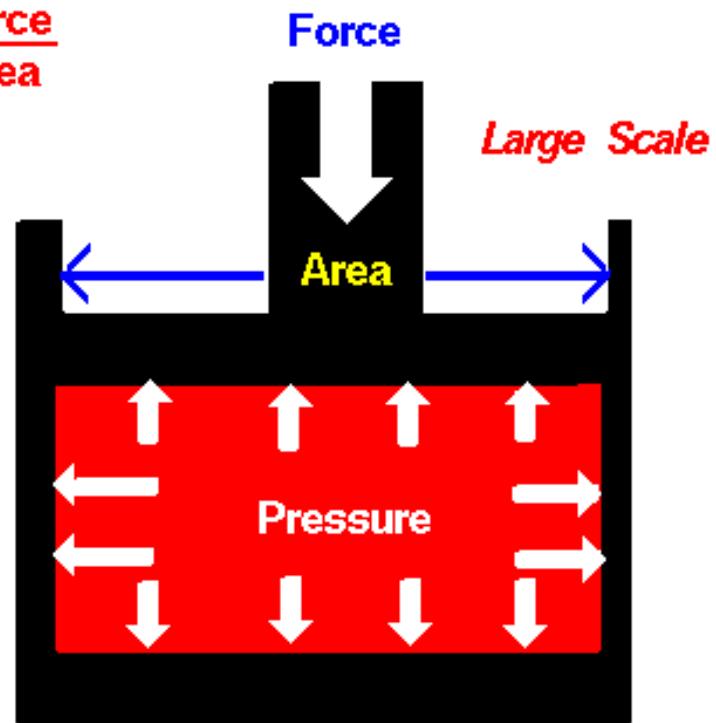
Pressure is  $\frac{\text{Force}}{\text{Area}}$

*Small Scale*



Pressure is a measure of the linear momentum of the gas molecules.

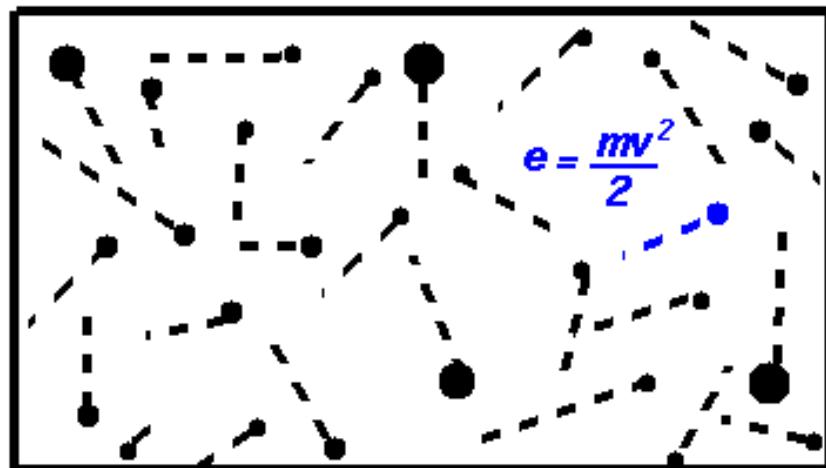
Pressure is a scalar quantity.  
(magnitude, no direction)



Pressure force acts perpendicular to enclosing surfaces.

*Small Scale*

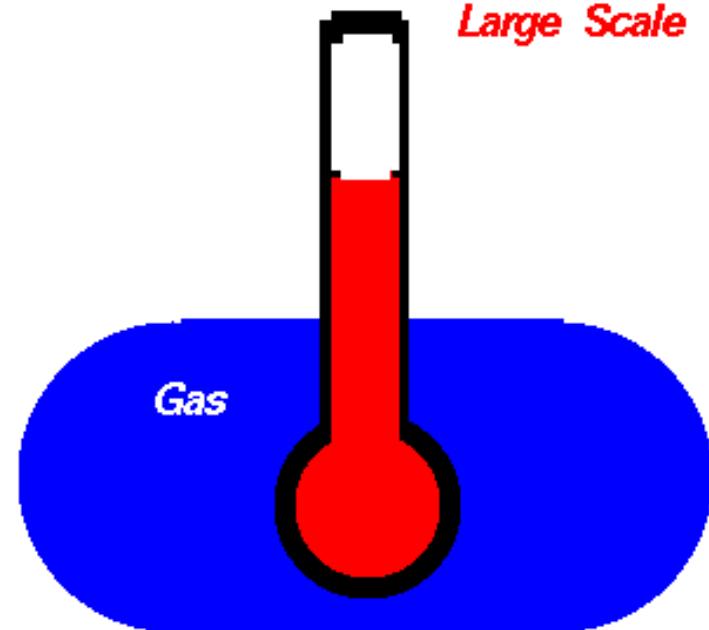
*m = mass    v = velocity  
e = kinetic energy*



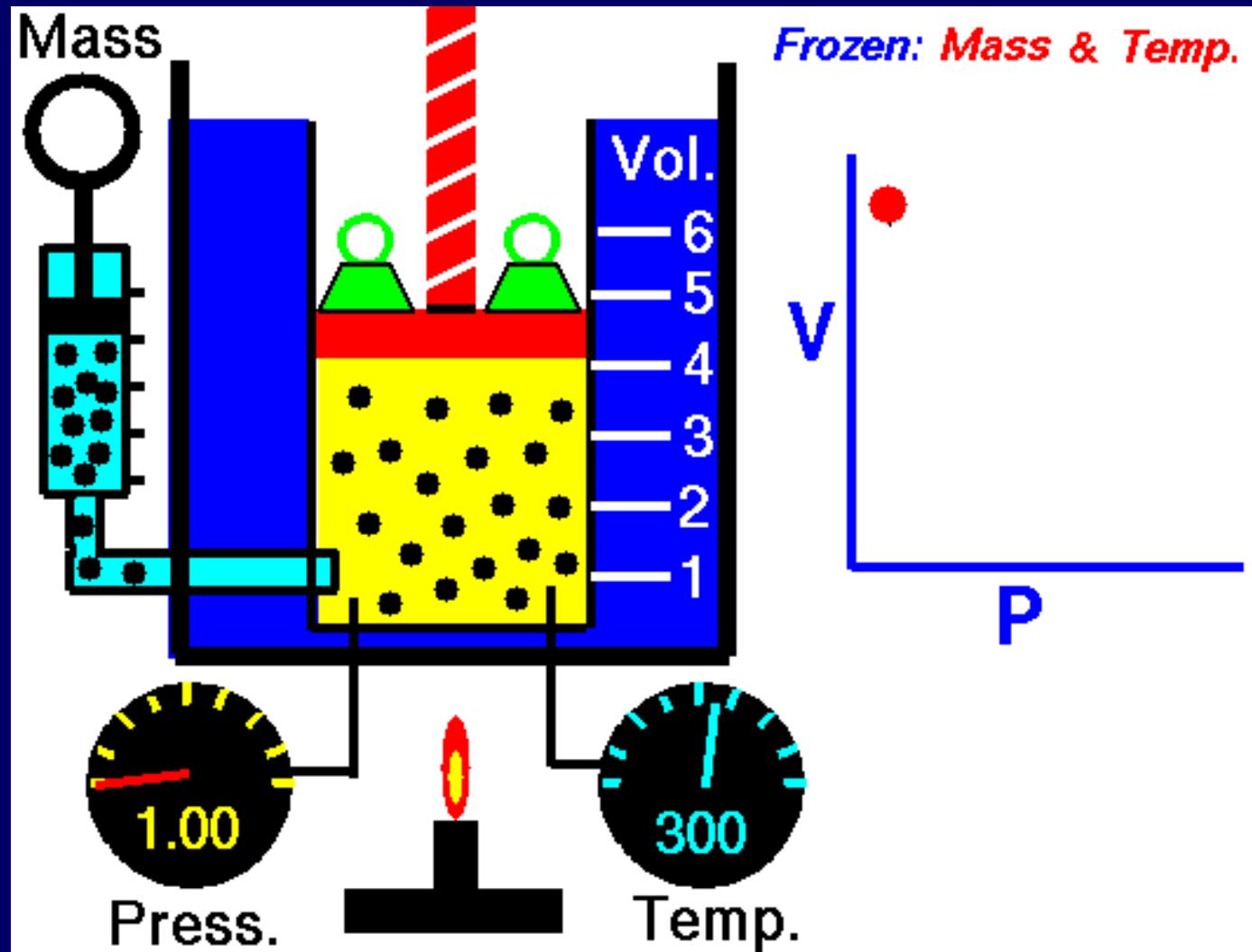
Temperature is a measure of the average kinetic energy of translation of the gas molecules.

**Temperature is a scalar quantity.  
(magnitude, no direction)**

*Large Scale*



Objects in thermal equilibrium have the same temperature.

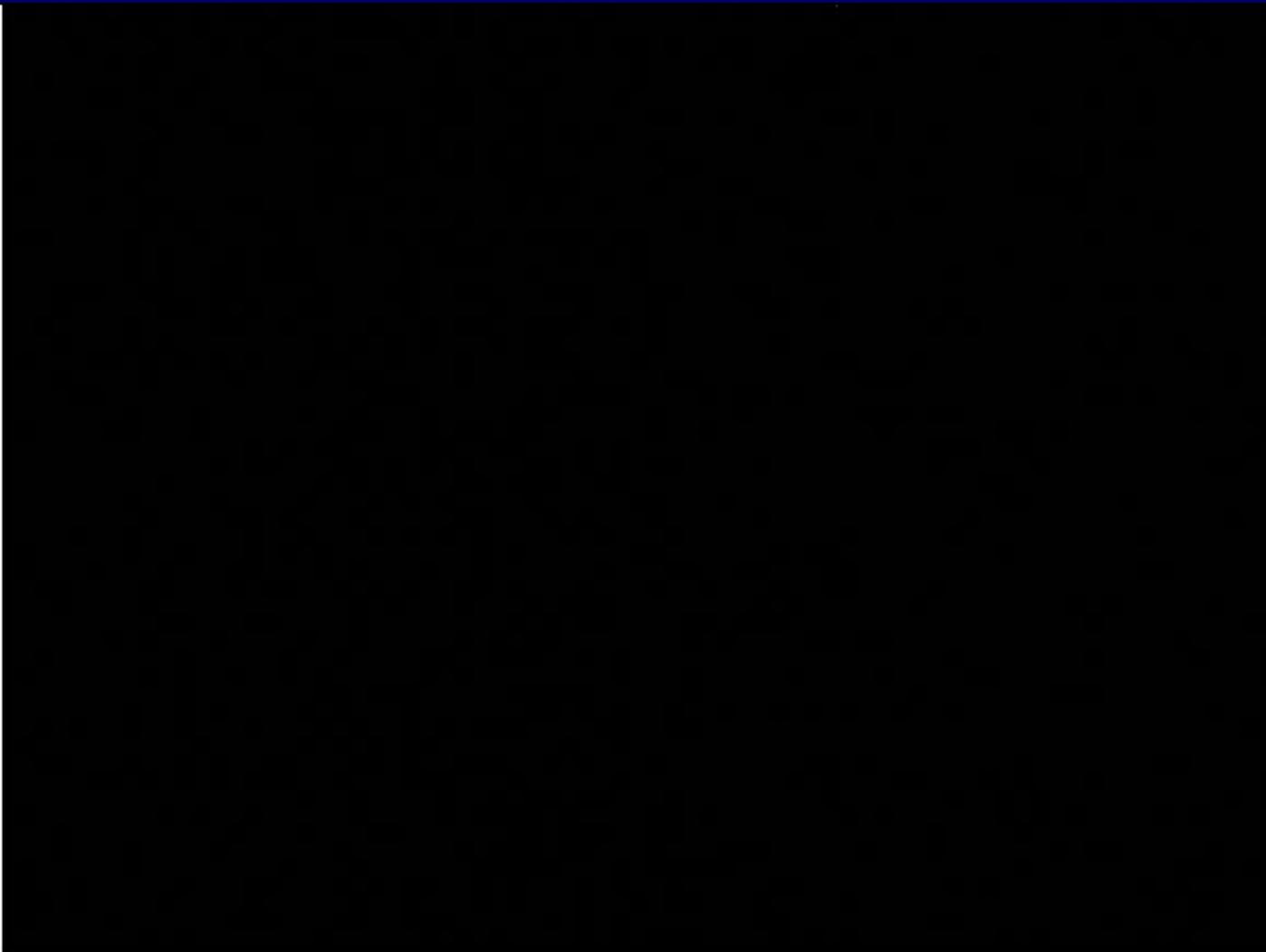




Simona - TUDelft

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## Advantages of hydraulics

Fluid does not absorb any of the supplied energy.

The hydraulic working fluid is basically incompressible, leading to a minimum of spring action. When hydraulic fluid flow is stopped, the slightest motion of the load releases the pressure on the load; there is no need to "bleed off" pressurised air to release the pressure on the load.

## Advantages of pneumatics

### Clean

Air is used by a machine & is then exhausted to the atmosphere - no return line necessary.

Any leaks will be of air (which is much less of a problem than oil leaks in Hydraulics).

### Availability

Air is freely available in the pneumatics

Most factories are pre-plumbed for compressed air distribution - which makes it very easy to set up a manufacturing process

### Simplicity of Design And Control

Machines are easily designed using standard cylinders & other components. Control is as easy as its simple ON - OFF type control

## Advantages of pneumatics (cont.)

### Reliability

Pneumatic systems tend to have long operating lives and require very little maintenance.

Because air is compressable, the equipment is less likely to be damaged by shock. The air in pneumatics absorbs excessive force, whereas the fluid of hydraulics directly transfers force.

### Storage

Compressed Air can be stored, allowing the use of machines when electrical power is lost.

### Safety

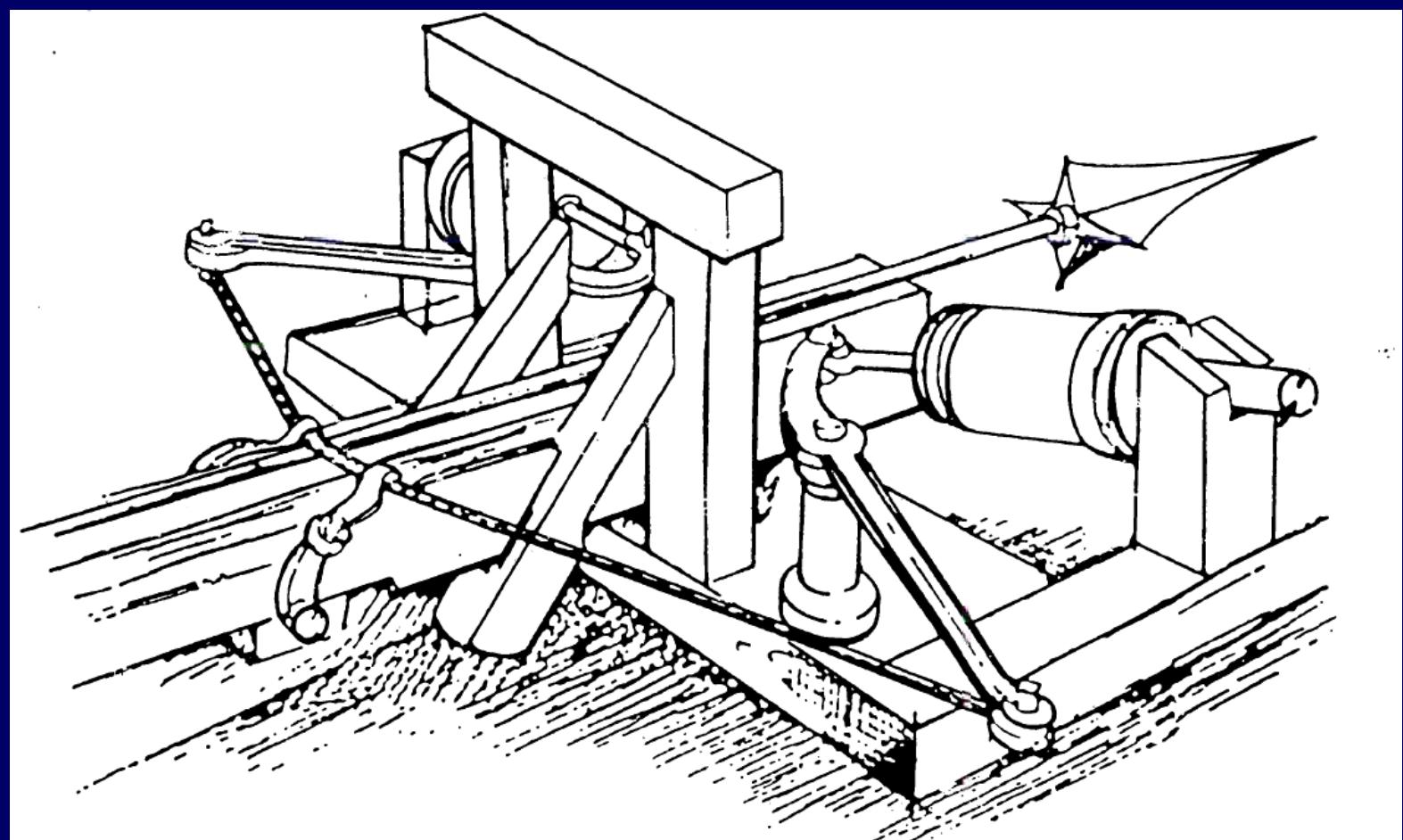
Very small fire hazard (compared to Hydraulic Oil)

Machines can be designed to be overload safe.

# THE AMAZING WORLD OF PNEUMATICS

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Ctesibius (Κτησίβιος) [285 – 222 bc]

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280 – 220 BC

*Philo of Byzantium*

## PNEUMATICA

The First Treatise on Experimental Physics:  
Western Version and Eastern Version

Facsimile and Transcript of the Latin Manuscript,  
CLM 534, Bayerische Staatsbibliothek, Munich

Translation and Illustrations of the Arabic Manuscript,  
A.S. 3713, Aya-Sofya, Istanbul

with Notes on other Manuscripts and Illustrations,  
Historical Introduction, and Technical Commentary  
by Frank David Prager

1798 2317



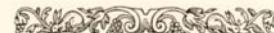
WIESBADEN 1974

DR. LUDWIG REICHERT VERLAG

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THE  
PNEUMATICS  
OF  
HERO OF ALEXANDRIA  
FROM THE ORIGINAL GREEK

TRANSLATED FOR AND EDITED BY  
BENNET WOODCROFT  
PROFESSOR OF MACHINERY IN UNIVERSITY  
COLLEGE LONDON



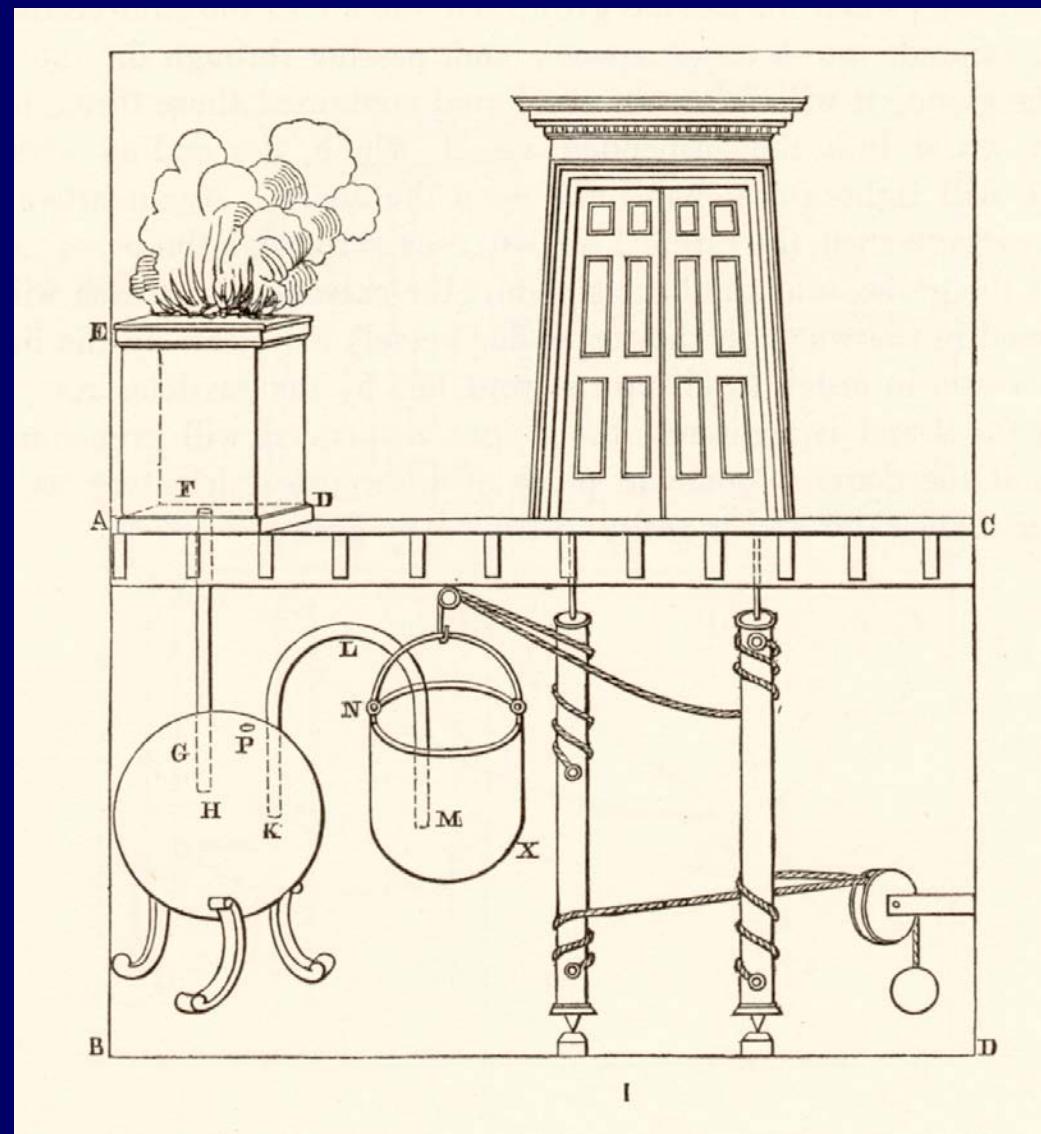
LONDON  
TAYLOR WALTON AND MABERLY  
UPPER GOWER STREET AND IVY LANE PATERNOSTER ROW  
1851

10 – 70 AD

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# Hero van Alexandrië

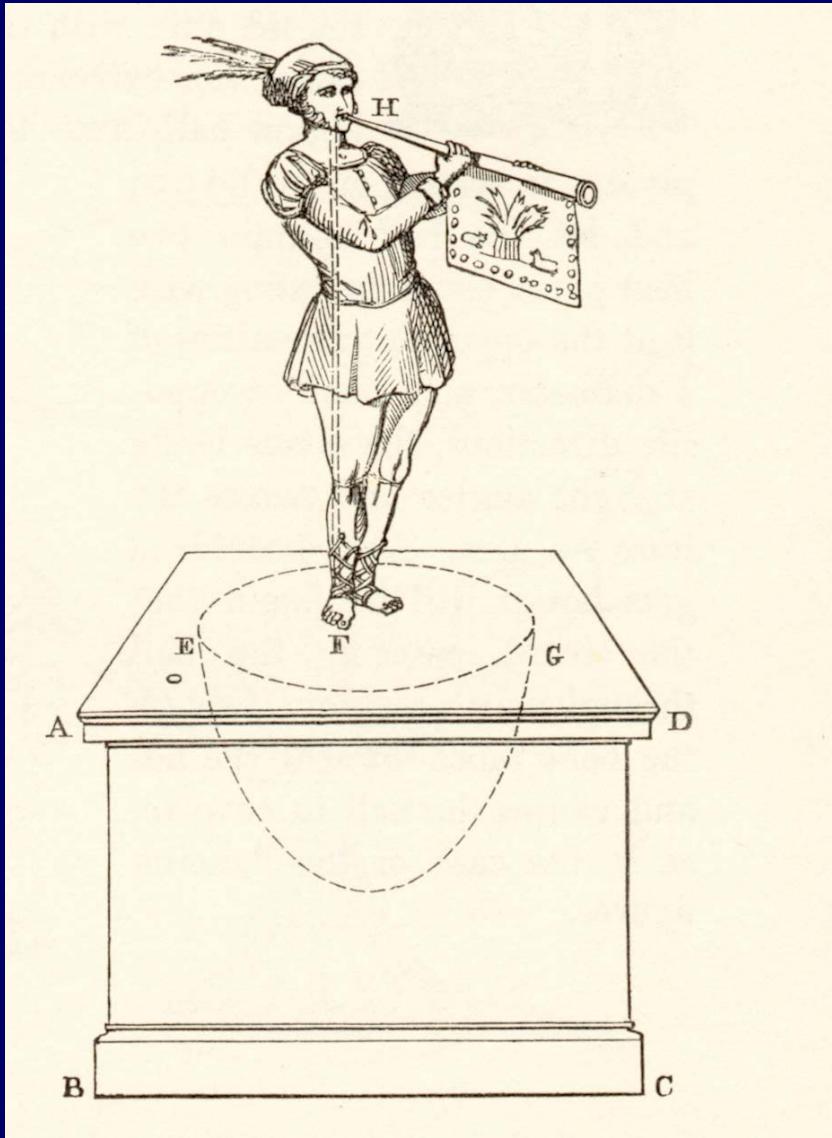


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# Hero van Alexandrië



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- aërofonen



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William Murdoch, 1754 - 1839



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William Murdoch:  
Engineer at Boulton & Watt  
Inventor of  
• gas lightning

William Murdoch:  
Engineer at Boulton & Watt  
Inventor of  
• gas lightning



William Murdoch:

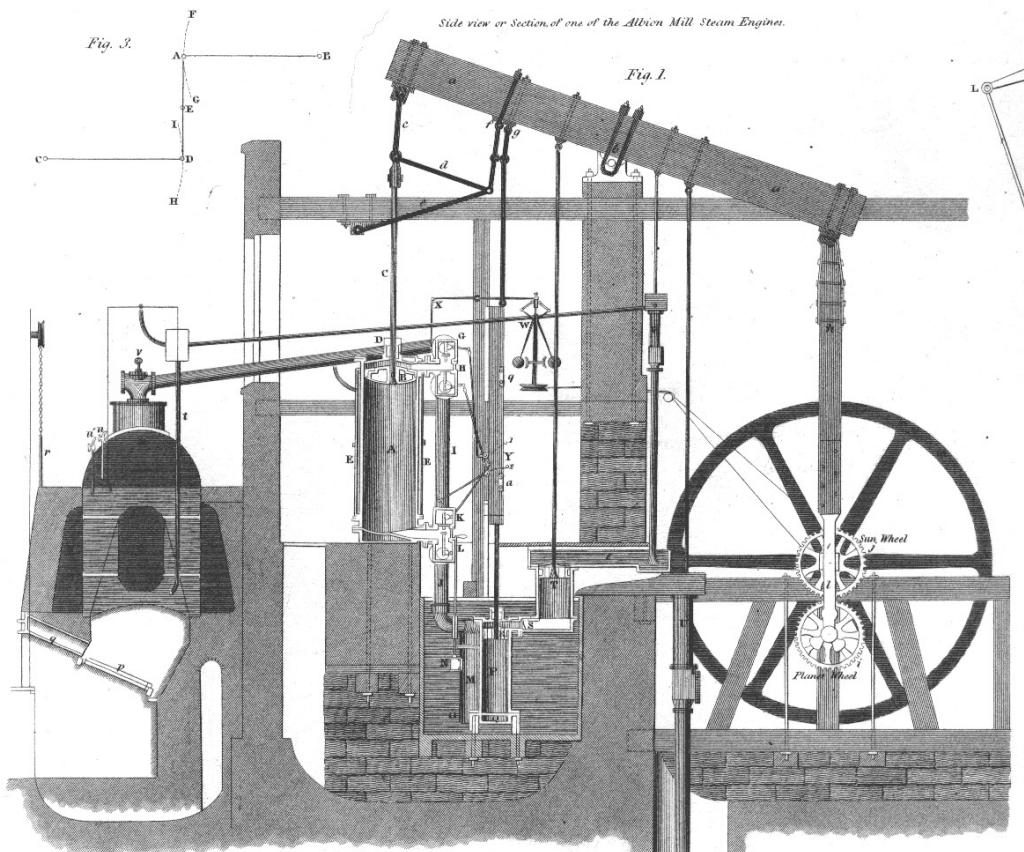
Engineer at Boulton & Watt

Inventor of

- gas lightning
- sun and planet gear

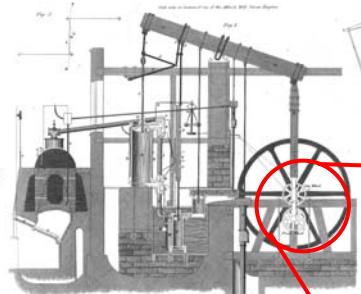
# Steam Engine (1776): James Watt

- **Efficient**
  - Higher Pressure
  - External Condenser
- **Needed Accuracy**
  - John Wilkinson's Boring Machine
  - 72 Inches Diameter
  - "6 Pence Coin" Accuracy



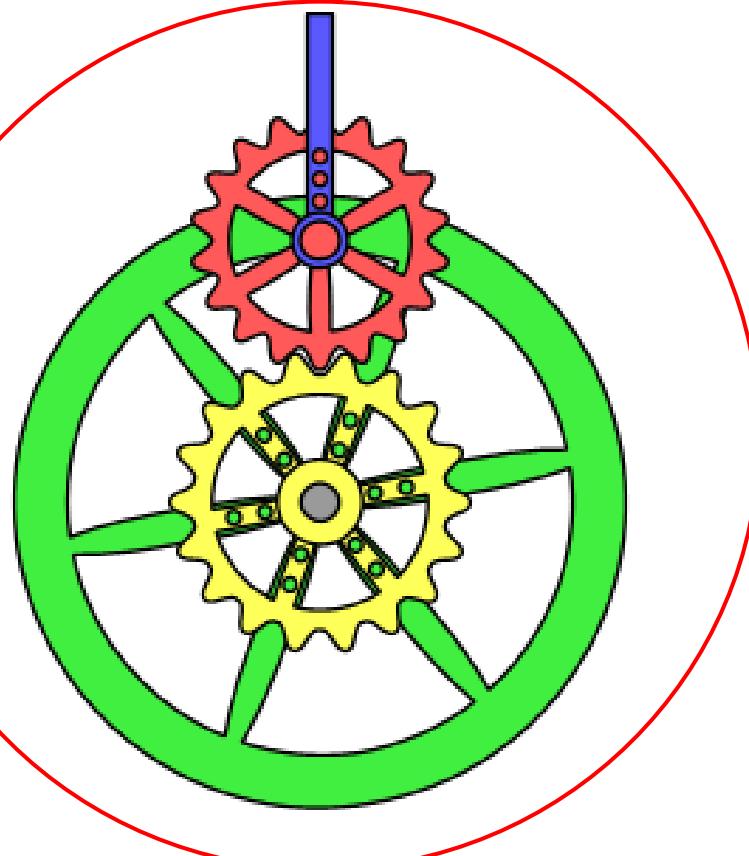
**Steam Engine  
(1776):  
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- Efficient
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  - External Condenser
- Needed Accuracy
  - John Wilkinson's Boring Machine
  - 72 Inches Diameter
  - "6 Pence Coin" Accuracy



W3110: Development of Machine Tools  
©2008 Tetsuo Tomiyama

TU Delft



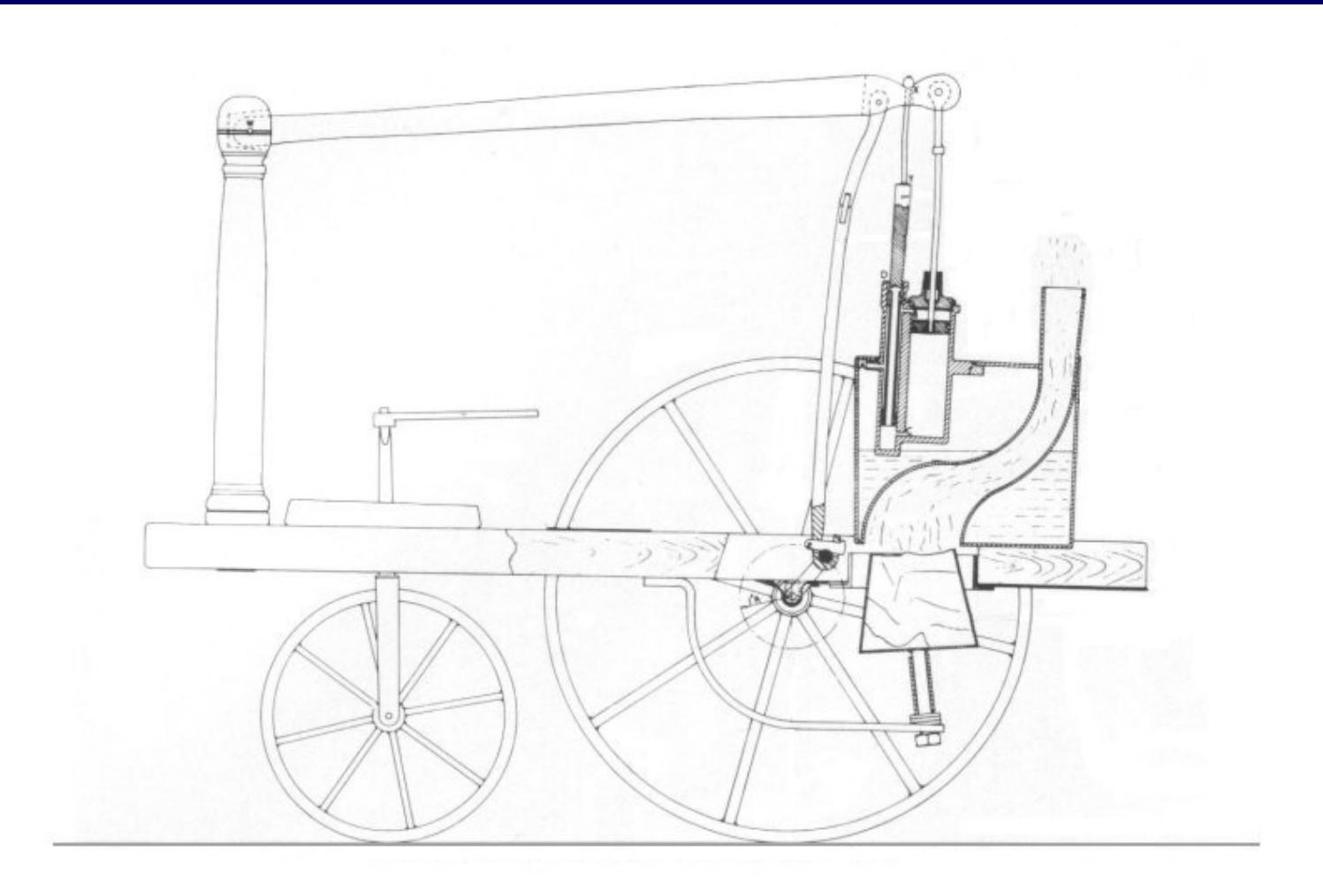
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William Murdoch:

Engineer at Boulton & Watt

Inventor of

- gas lightning
- sun and planet gear
- steam carriage



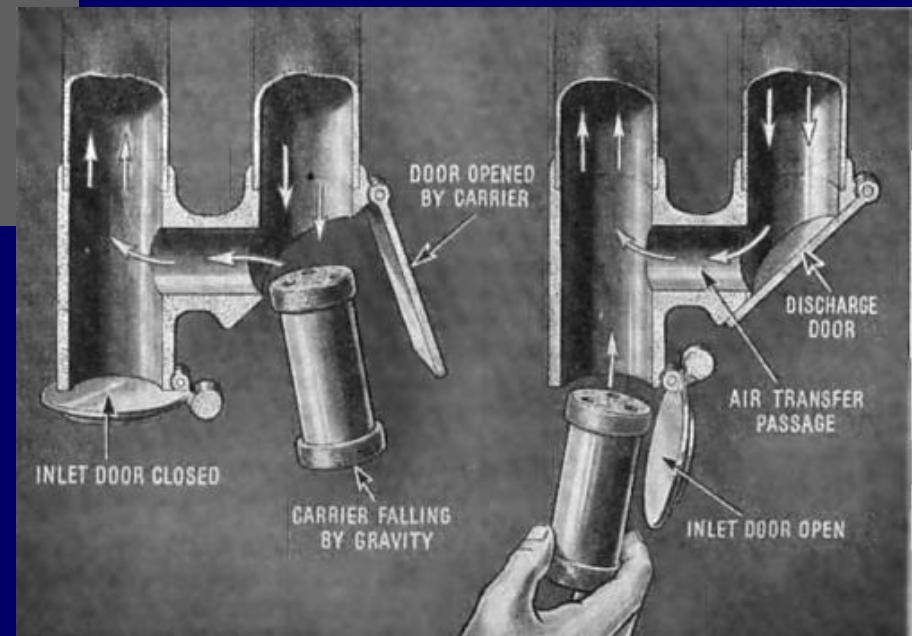
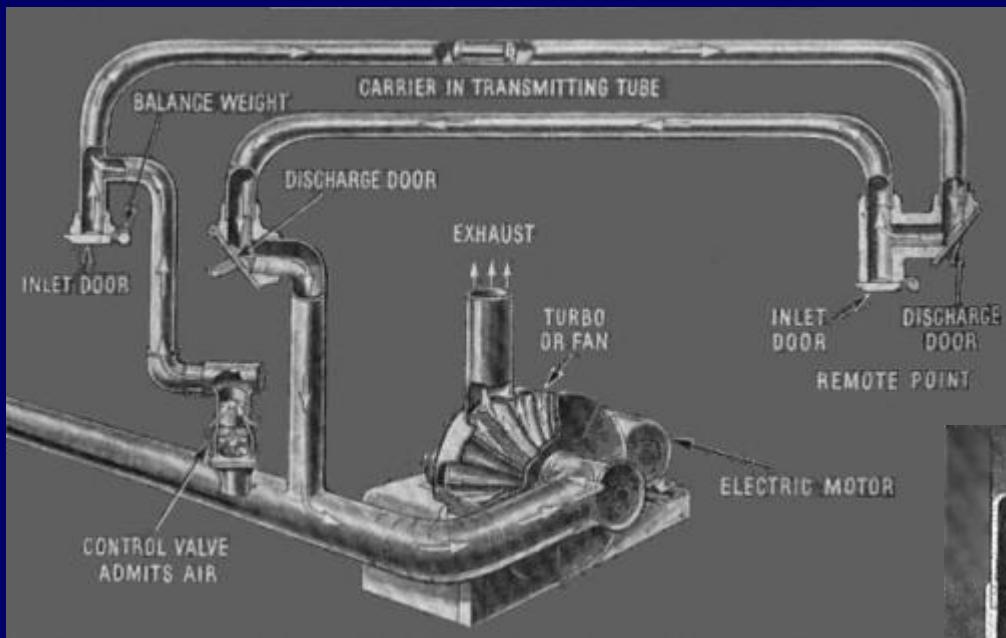
©2010 Dick H. Plettenburg

William Murdoch:

Engineer at Boulton & Watt

Inventor of

- gas lightning
- sun and planet gear
- steam carriage
- pneumatic tube message system
- and many more





The Central Telegraph Office of the GPO in  
London, Oct 1932

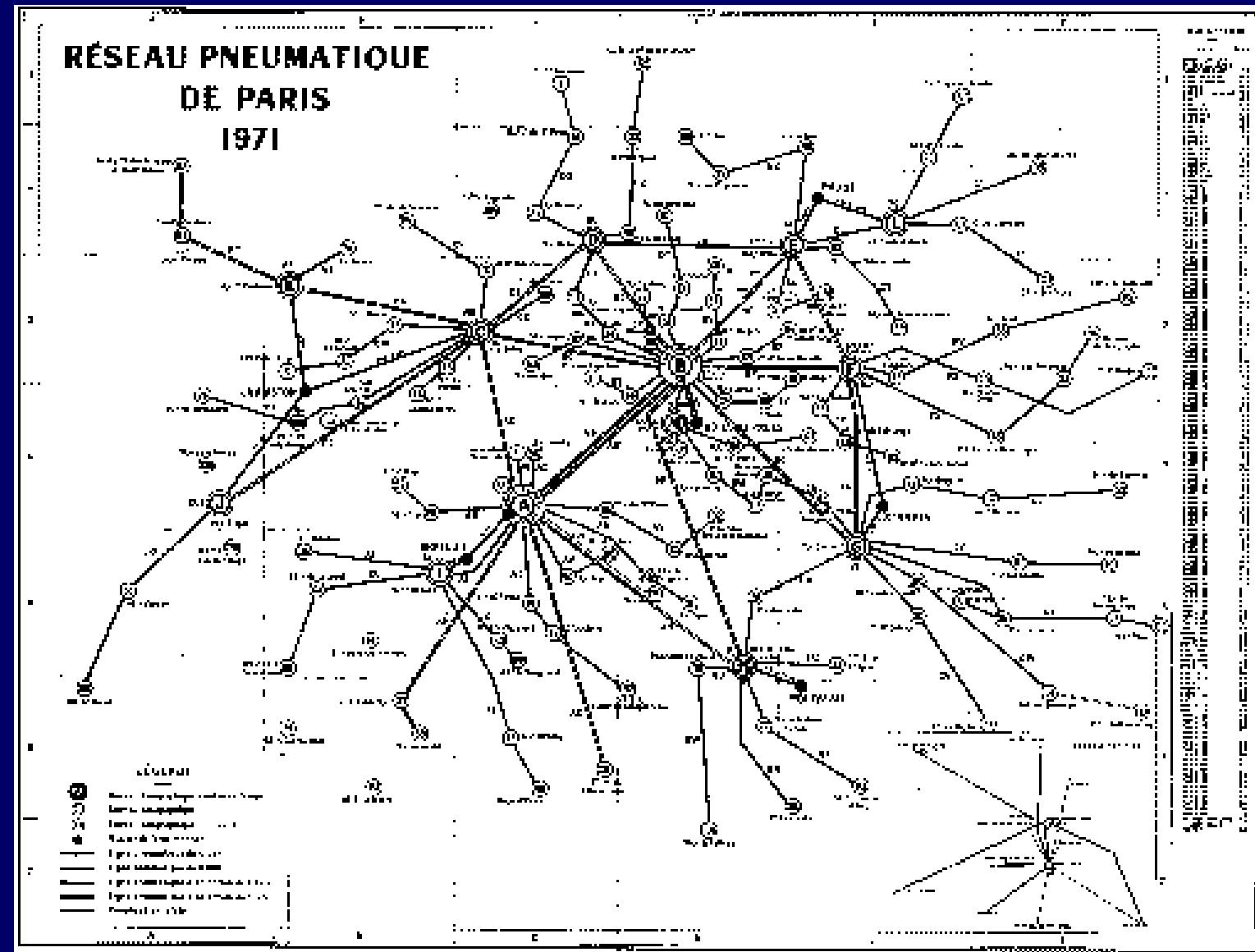
<http://www.dself.dsl.pipex.com>

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[http://www.trasa.ctrnactka.net/pod\\_doc/ppp.htm](http://www.trasa.ctrnactka.net/pod_doc/ppp.htm)

Mark H. Plettenburg



<http://www.cix.co.uk/~mhayhurst/jdhayhurst/pneumatic/book1.html>

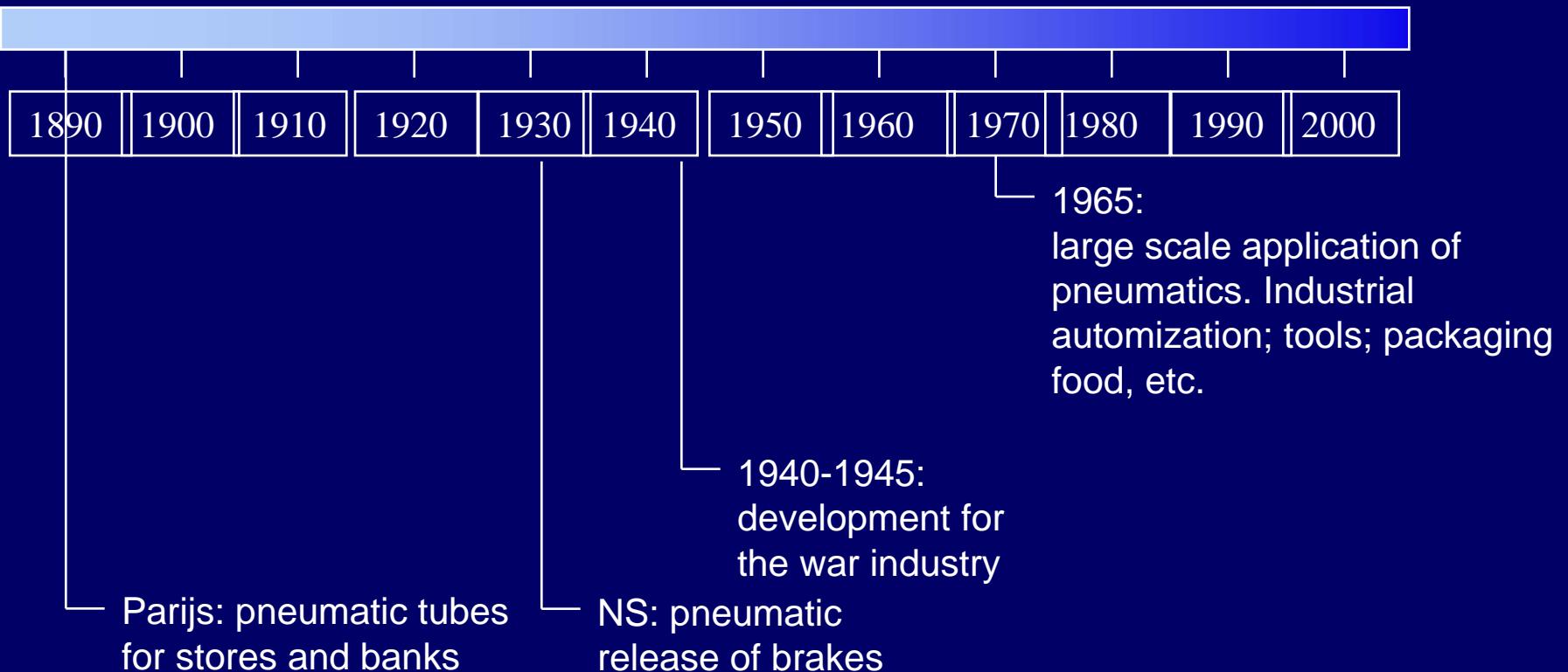
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<http://de.wikipedia.org/wiki/Rohrpost>

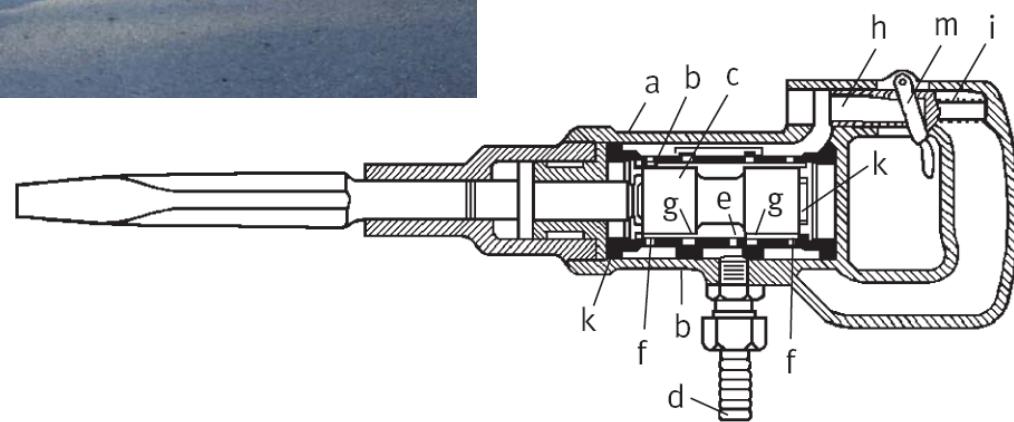
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# Pneumatics – time line





± 1900

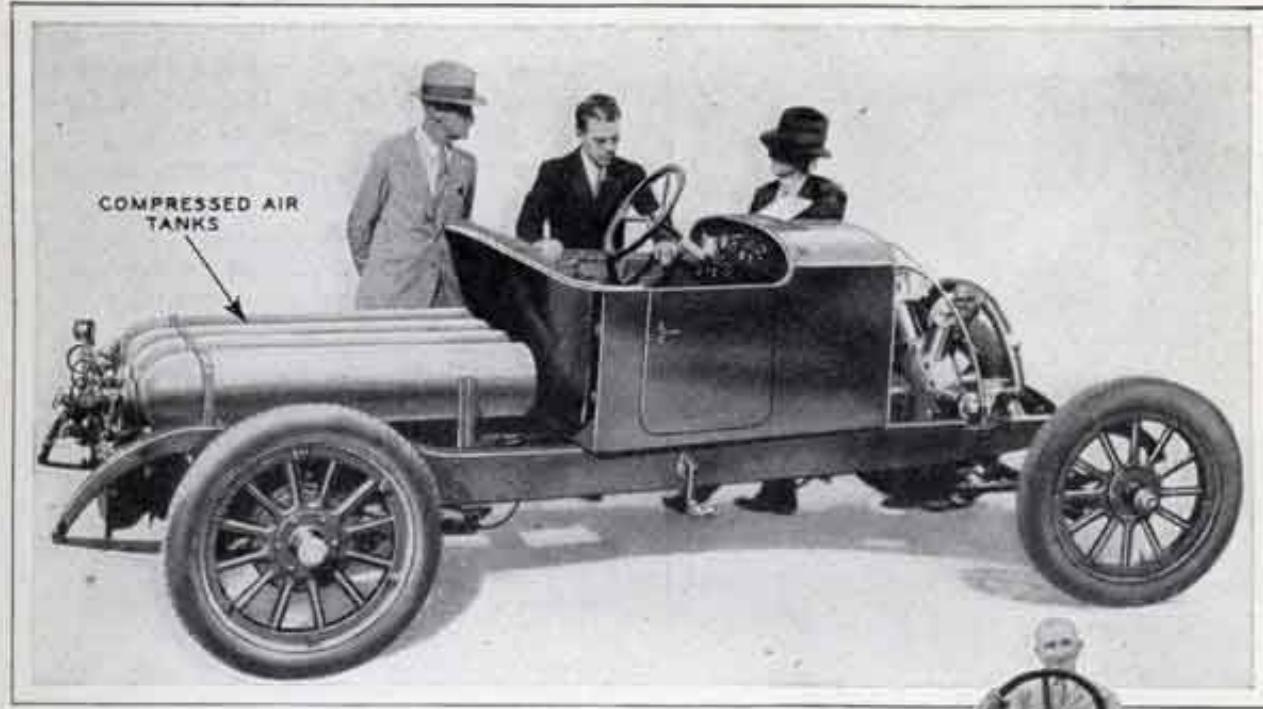




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1932

## Compressed AIR MOTOR Runs Car



A side view of the compressed air car, showing the four fuel tanks which will drive the car 500 miles at a speed of 35 miles an hour. The engine requires no cooling system, no ignition system, no carburetor, nor the hundreds of moving parts included in a standard gasoline motor.





Fill pressure: 30 MPa

Tank capacity: 0.3 m<sup>3</sup>

Range: 300km

Max speed: 110 km/h





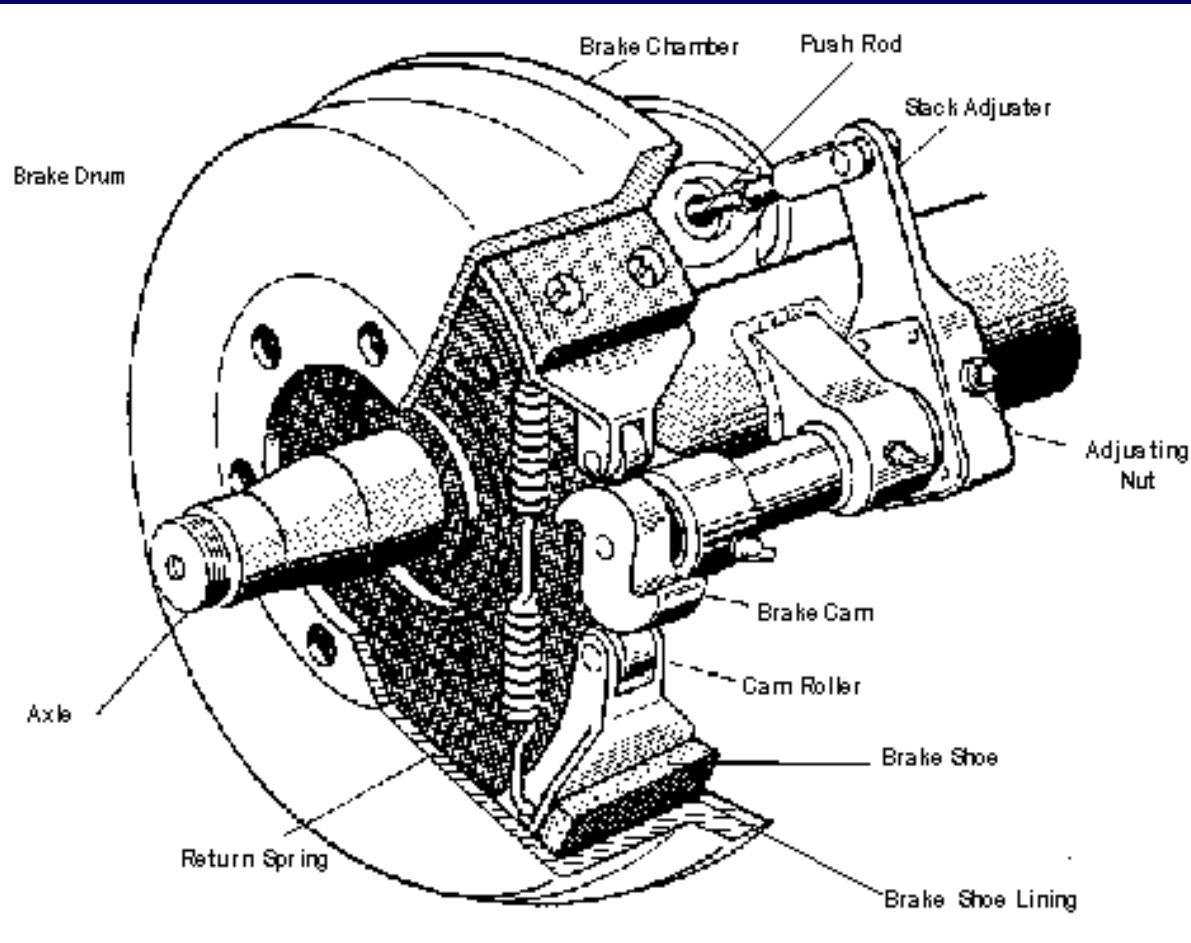
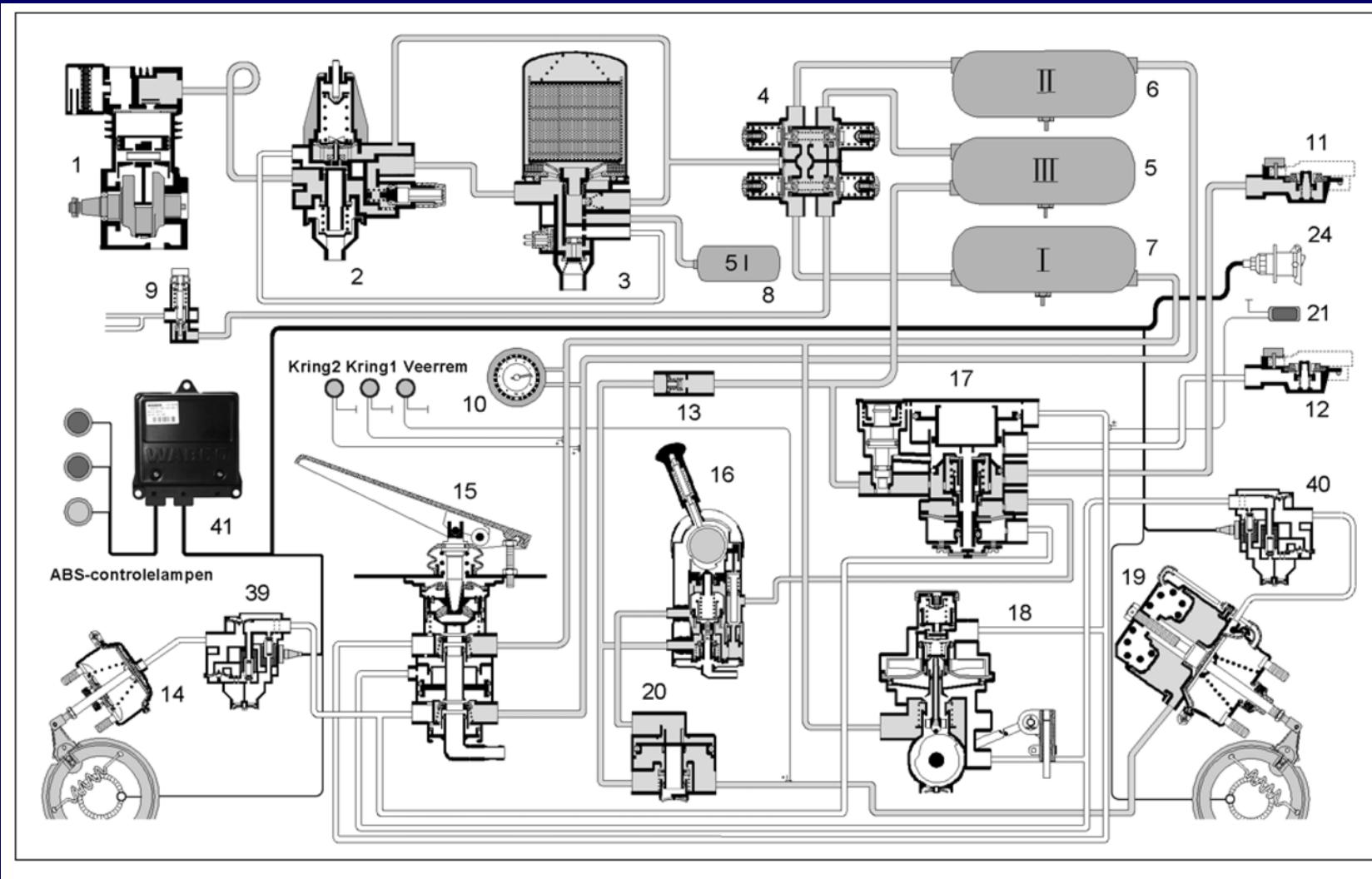
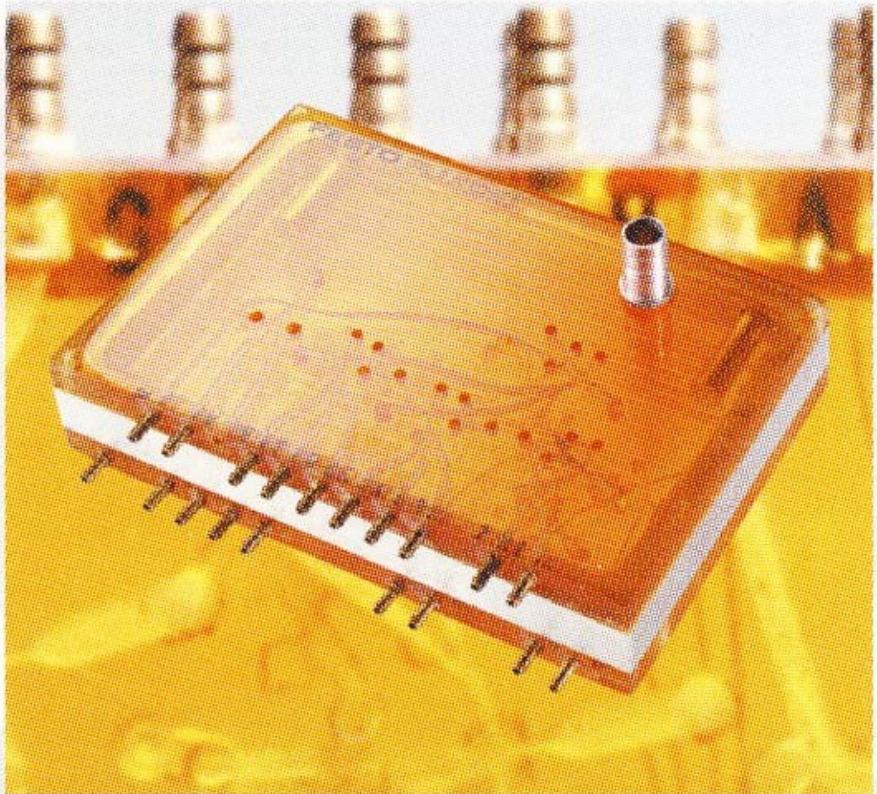


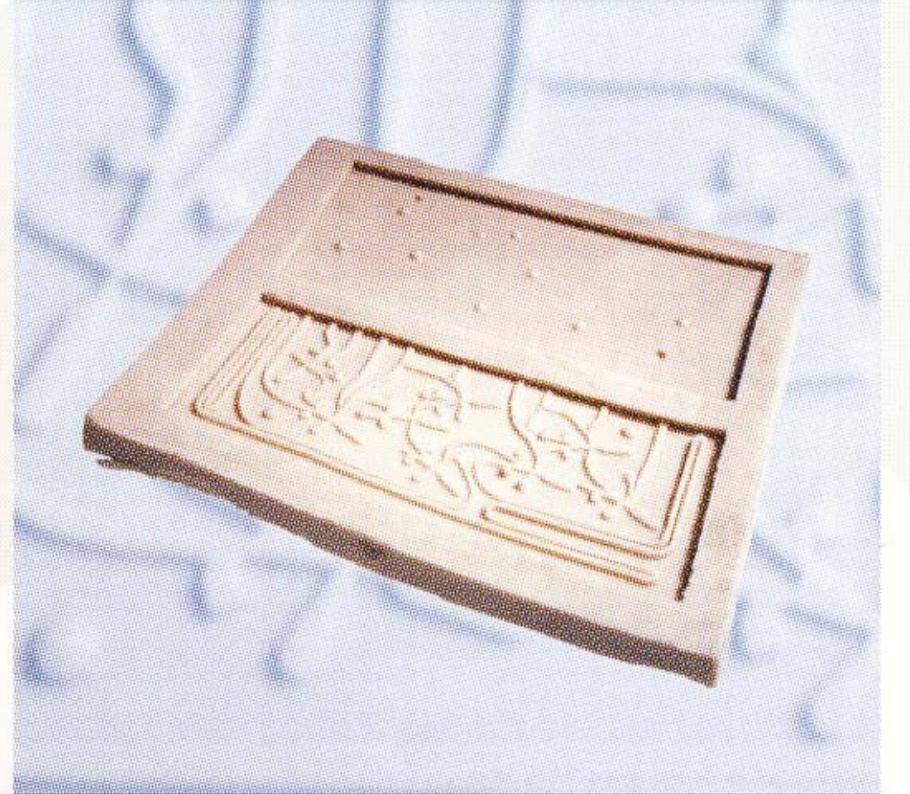
Figure 5-2 S-cam Air Brake

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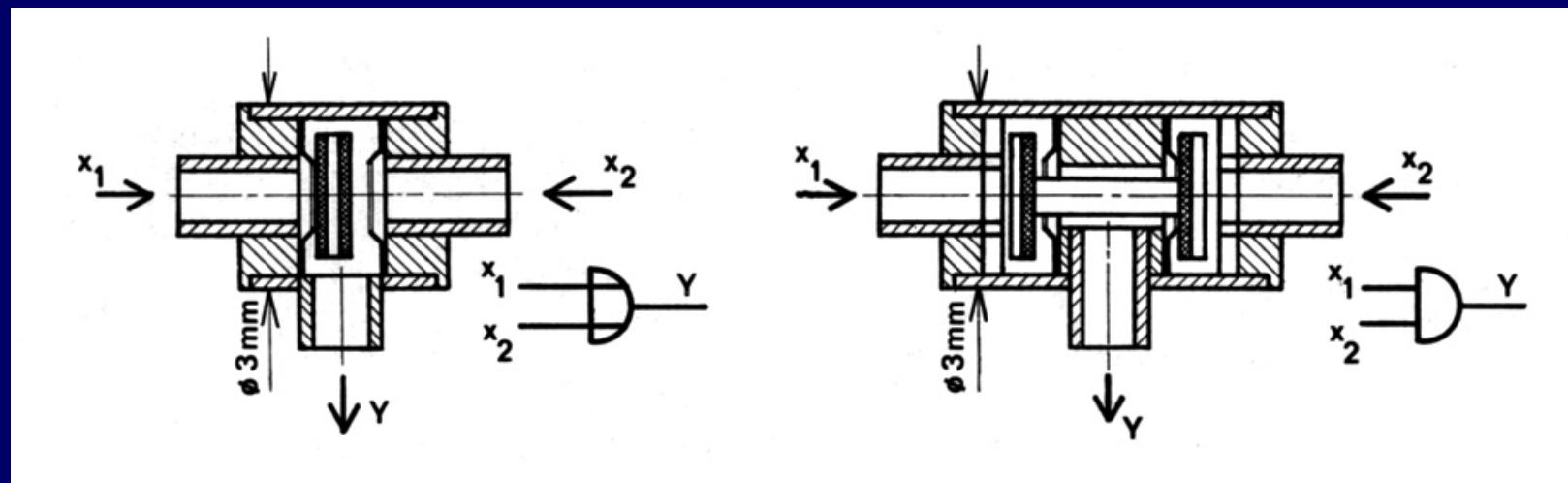




***Original-Fluidic aus den Sechziger-jahren. Mit 120 x 75 x 24 mm faszinierend klein, doch leider viel zu groß im Vergleich zur zeitgleich aufkeimenden Elektronik.***



***Originalform aus Silikon für das Gießen von Fluidics. Diese Formen wurden fotochemisch geätzt.***



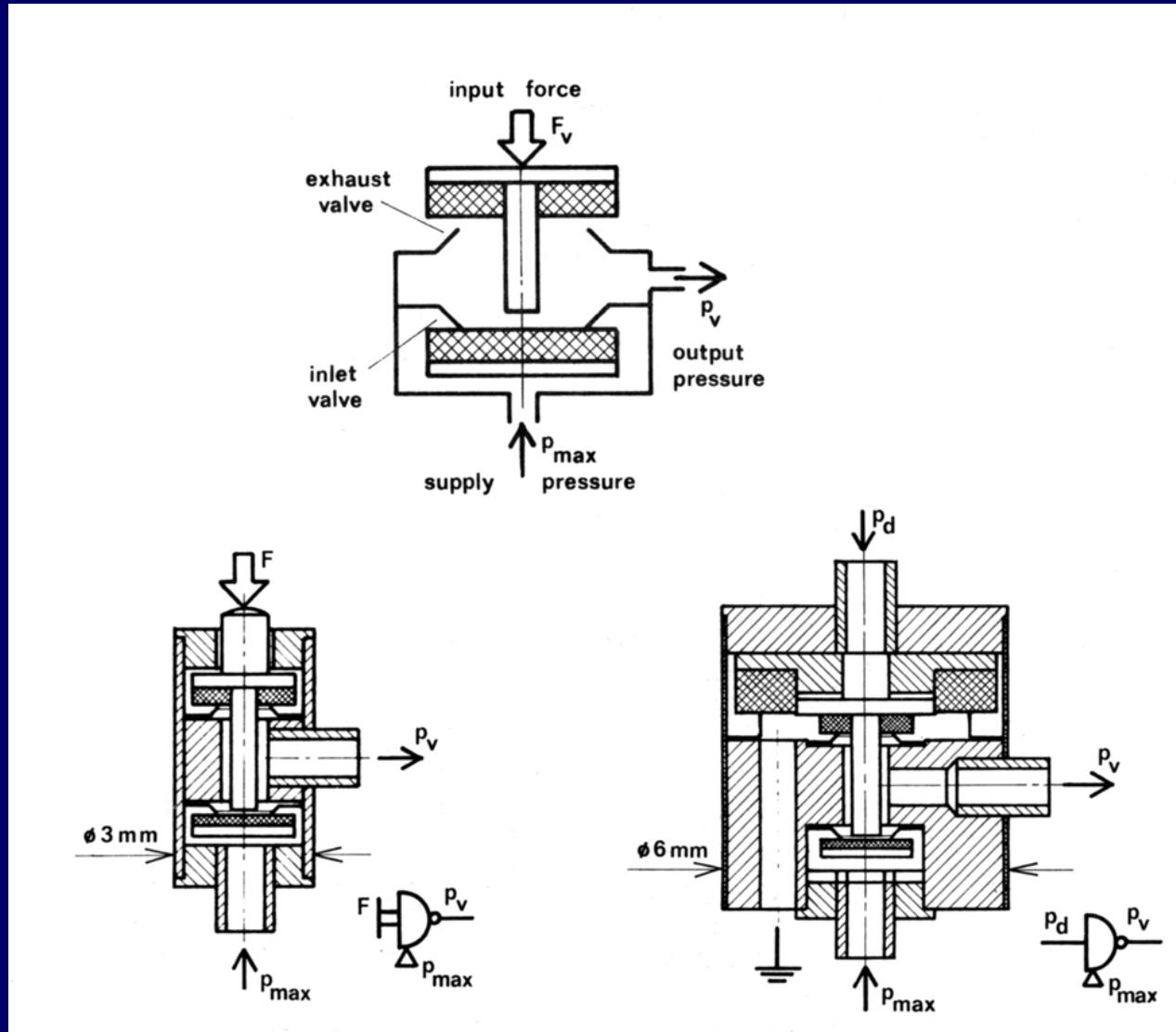
OR-gate

AND-gate

Pistecky, 1976

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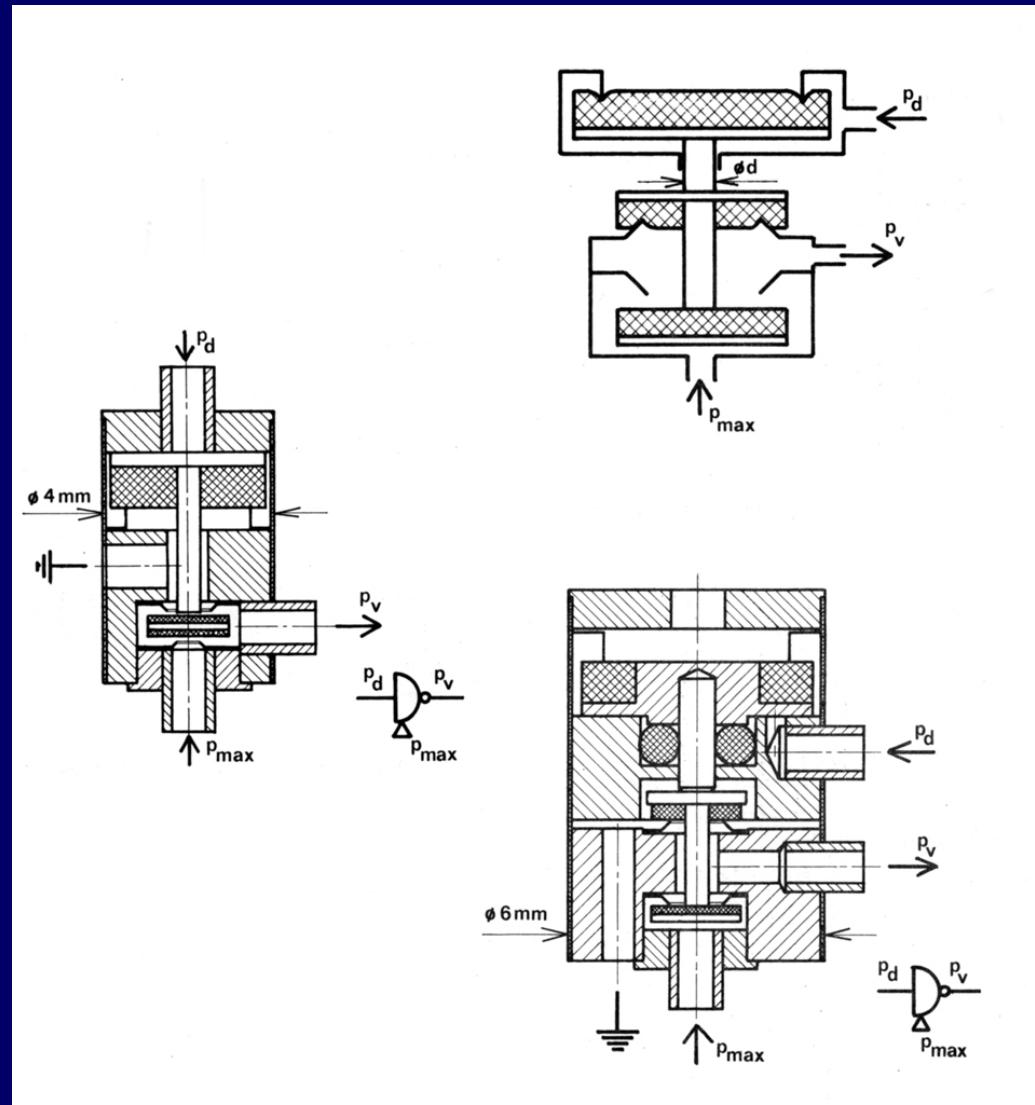
## YES-gate

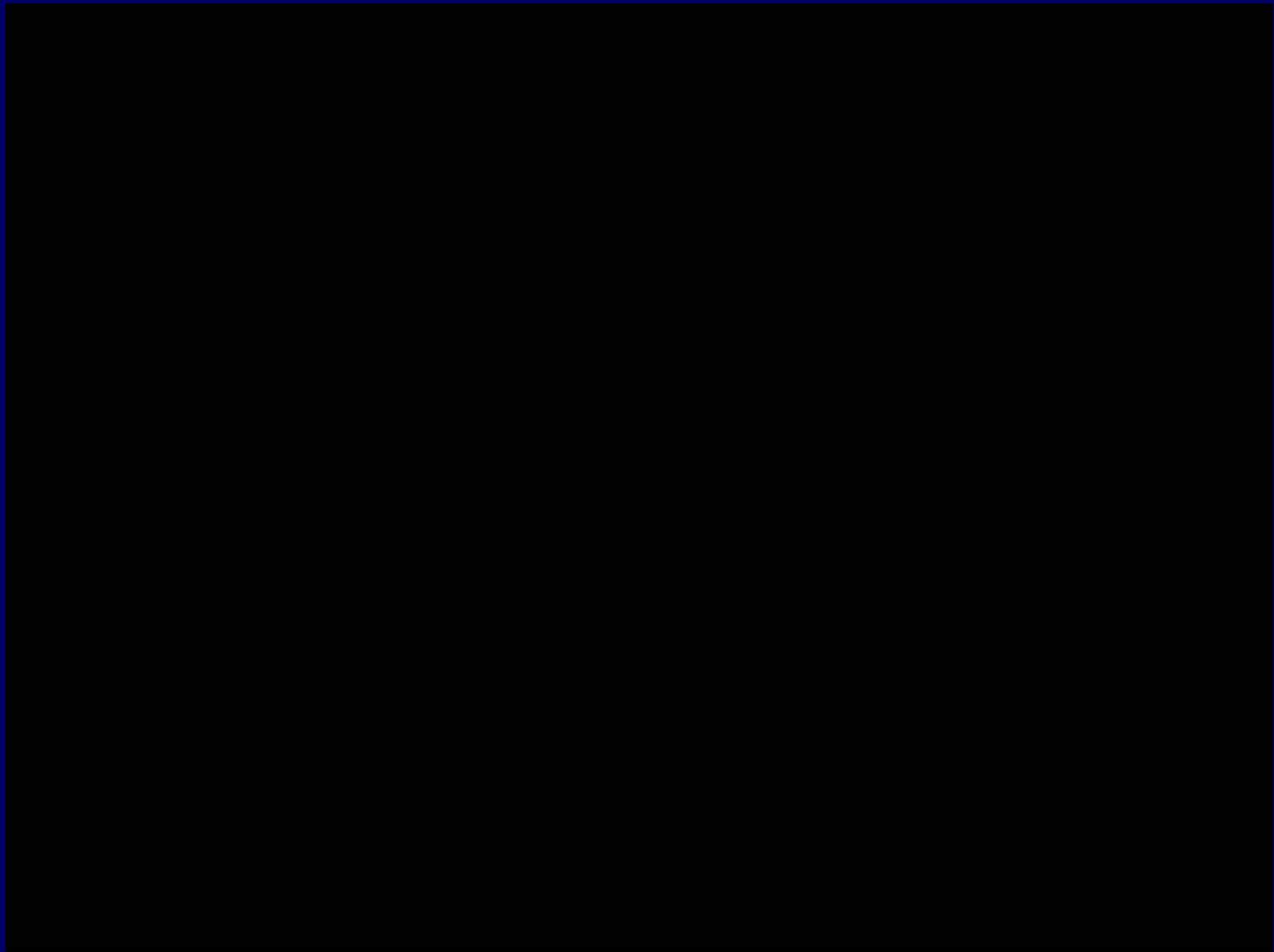


Pistecky, 1976

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## NOT-gate





[www.festo.com](http://www.festo.com)

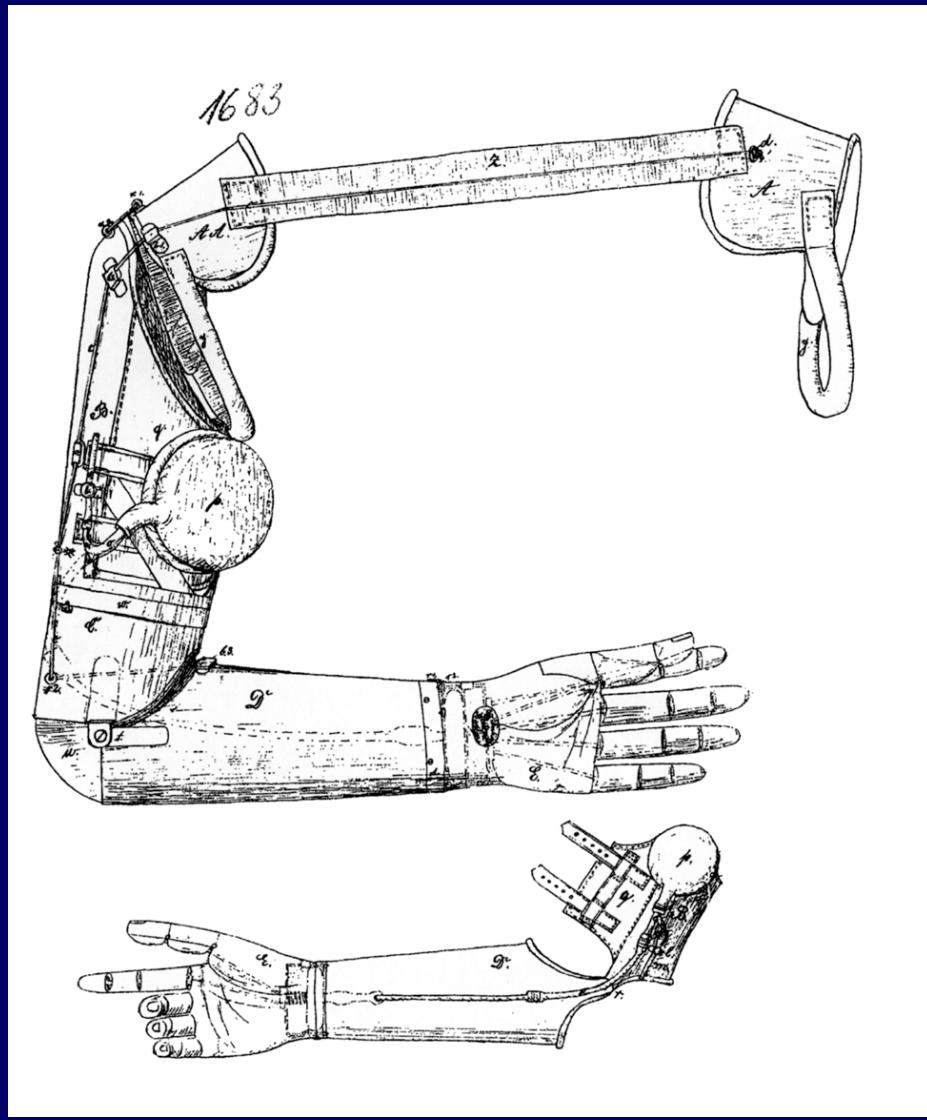
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# PNEUMATICALLY POWERED PROSTHESES

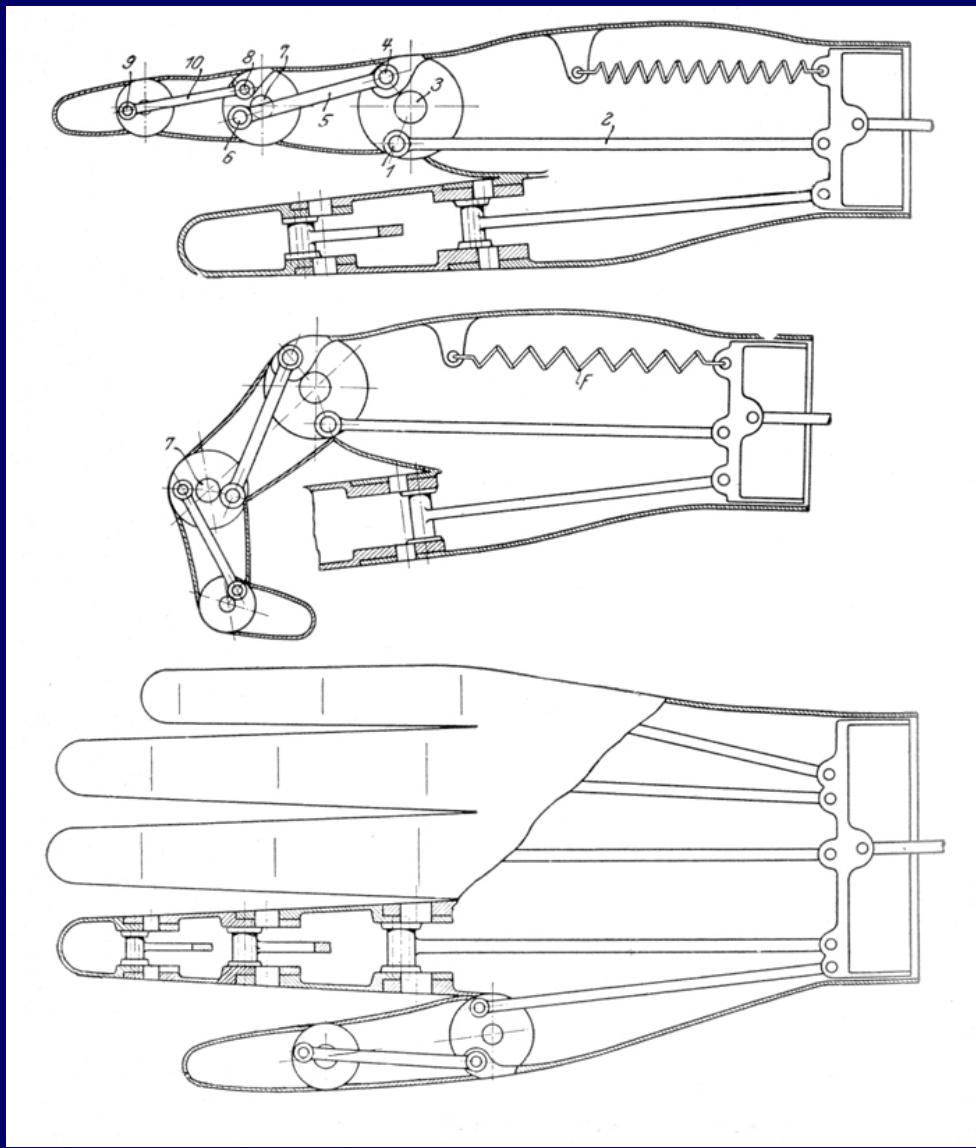
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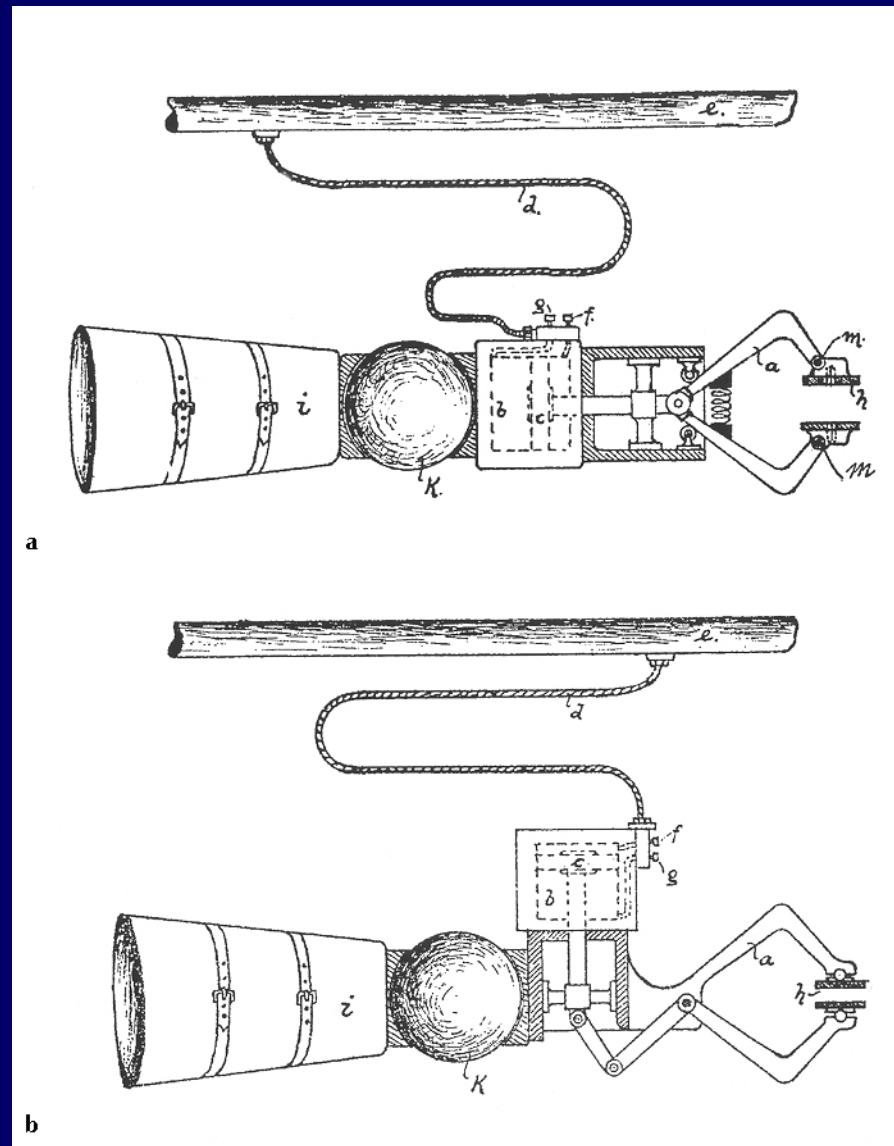
Dalish, 1877

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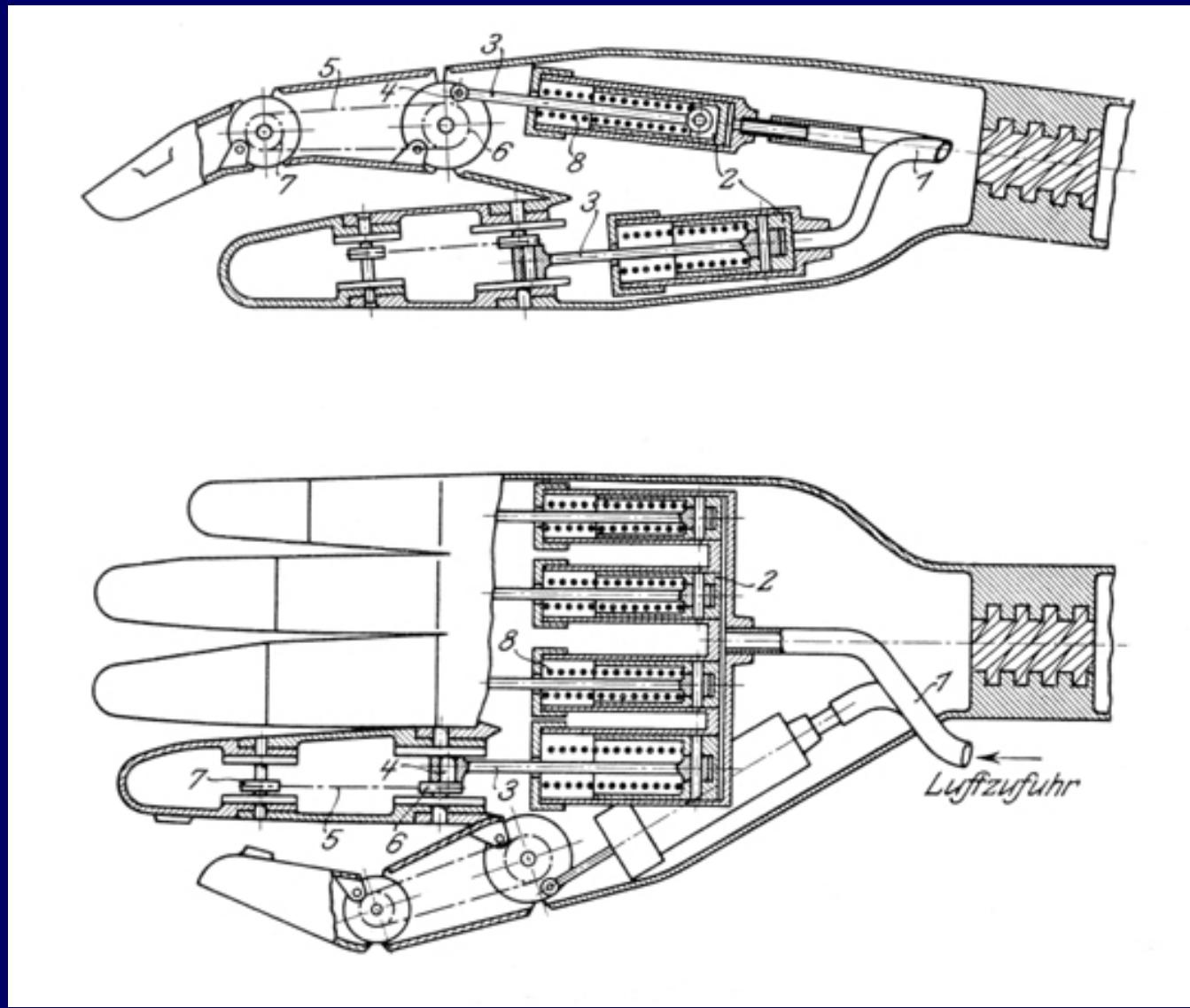
Dalish, 1877

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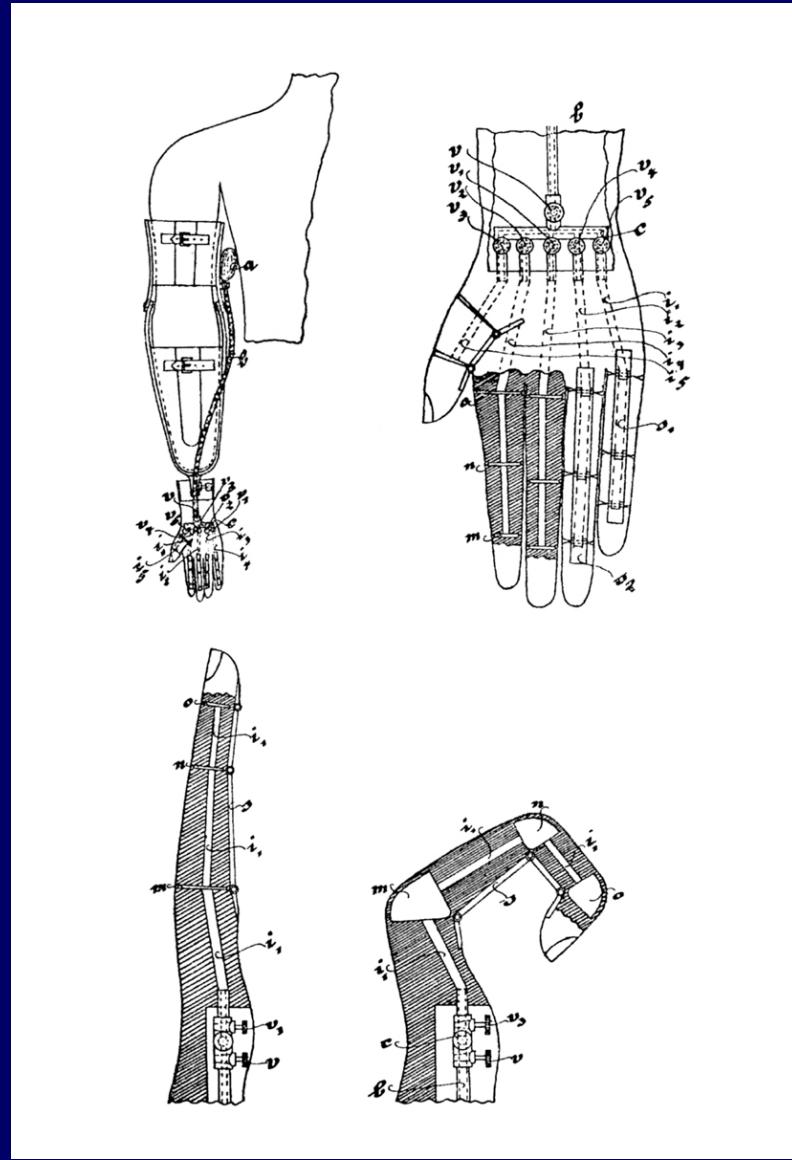
Dahlheim, 1915

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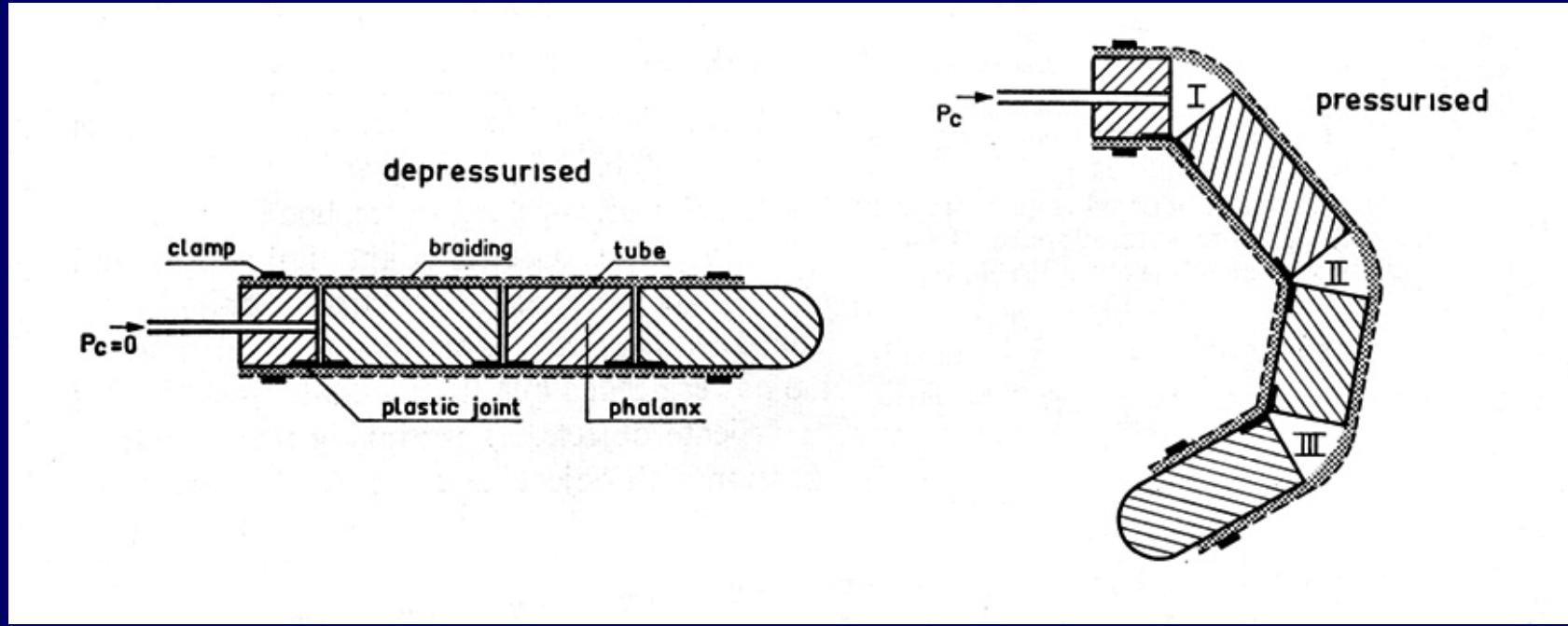
Anonymous, 1919

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Forcher, 1920

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Cool & Hooreweder, 1971

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Cool & Hooreweder, 1971

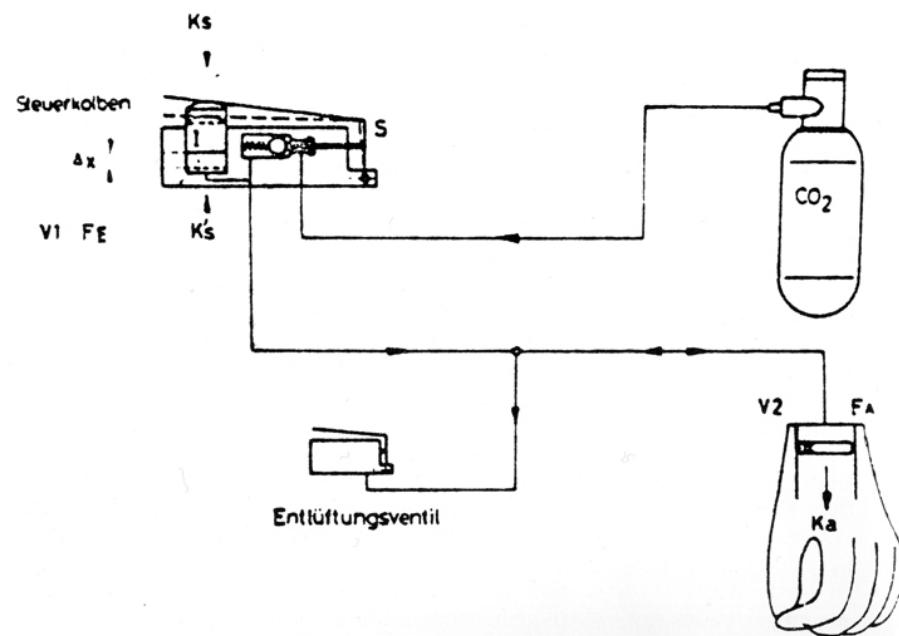
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**'Inventions in the field of orthopaedic technology are  
the proof of a missing reading list'**

Prof. G.G. Kuhn, University of Münster, Germany

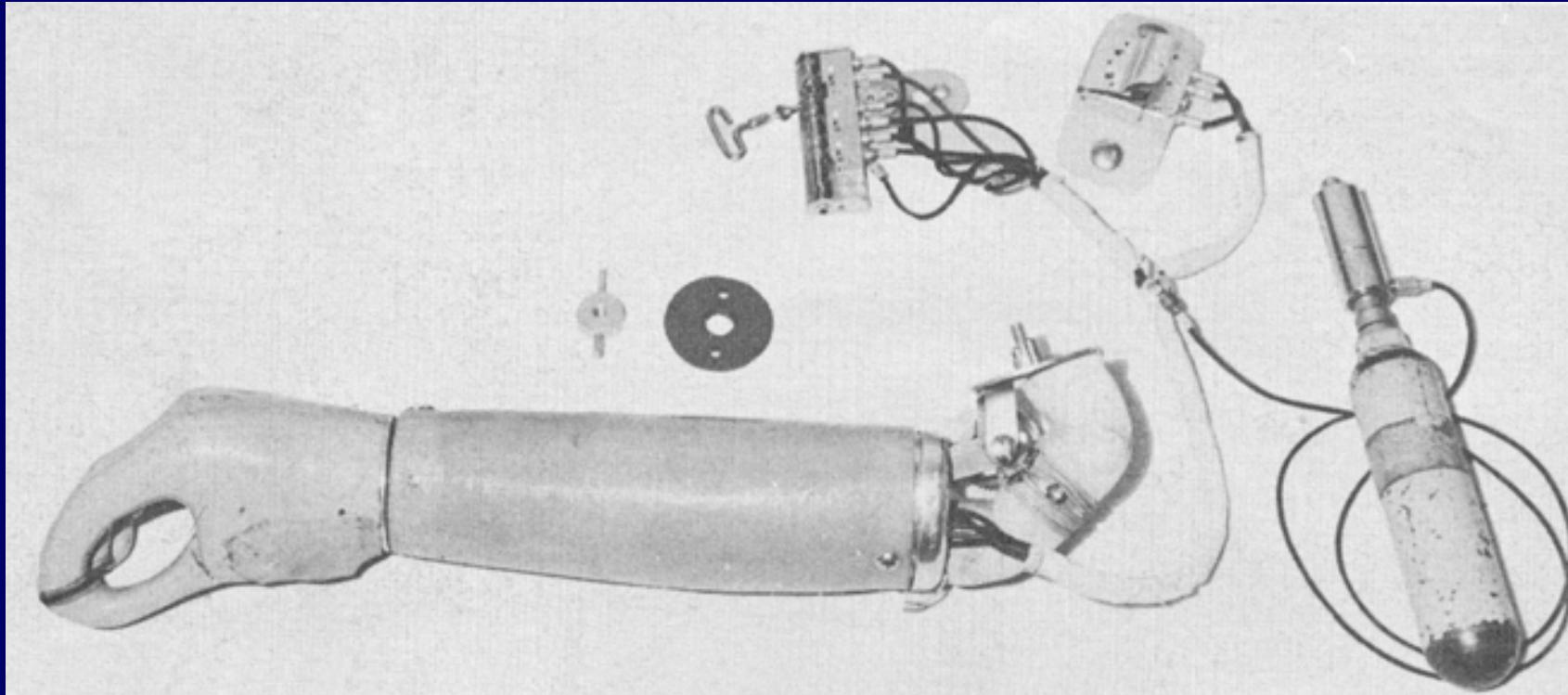
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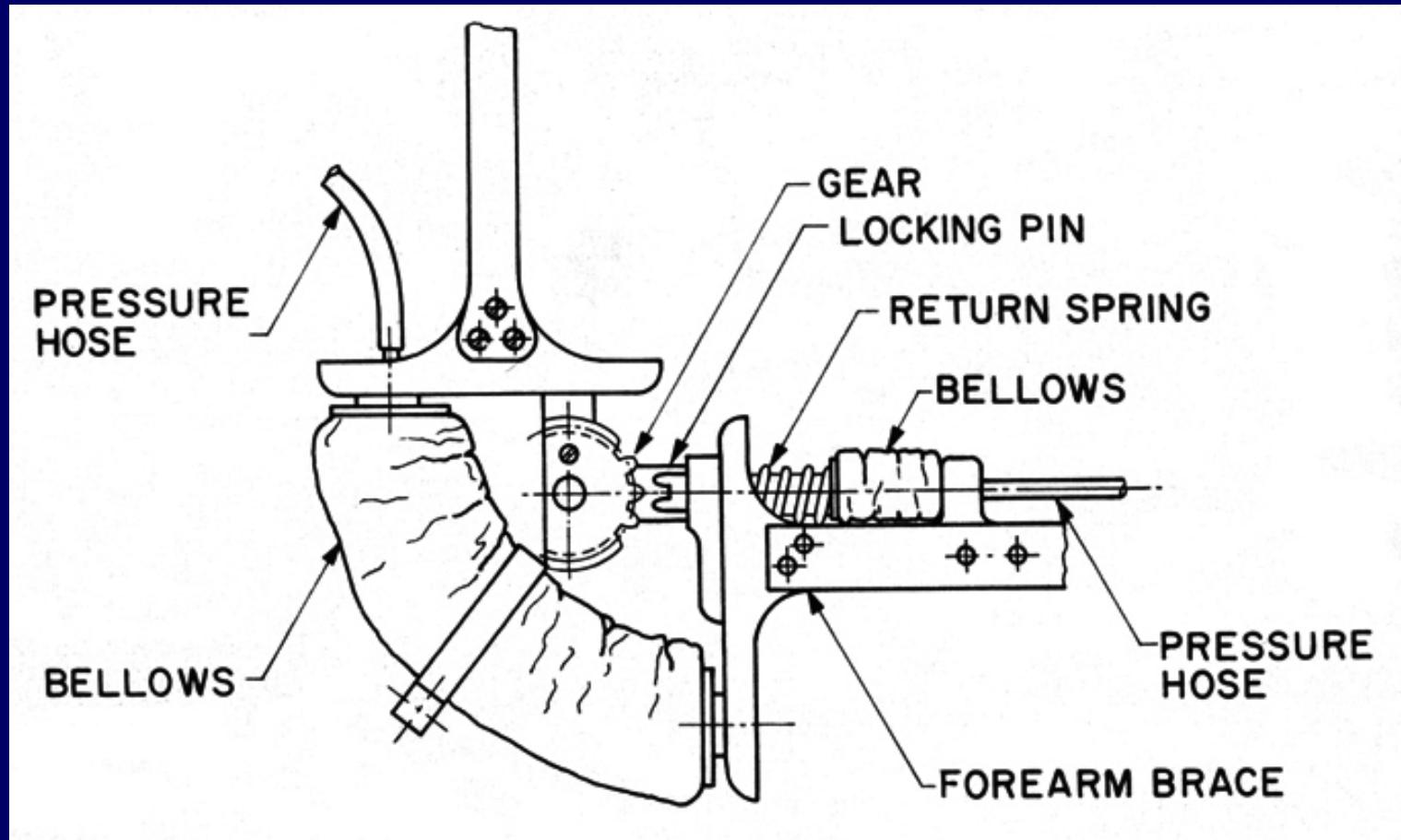
Häfner, 1948 [Löffler, 1984]

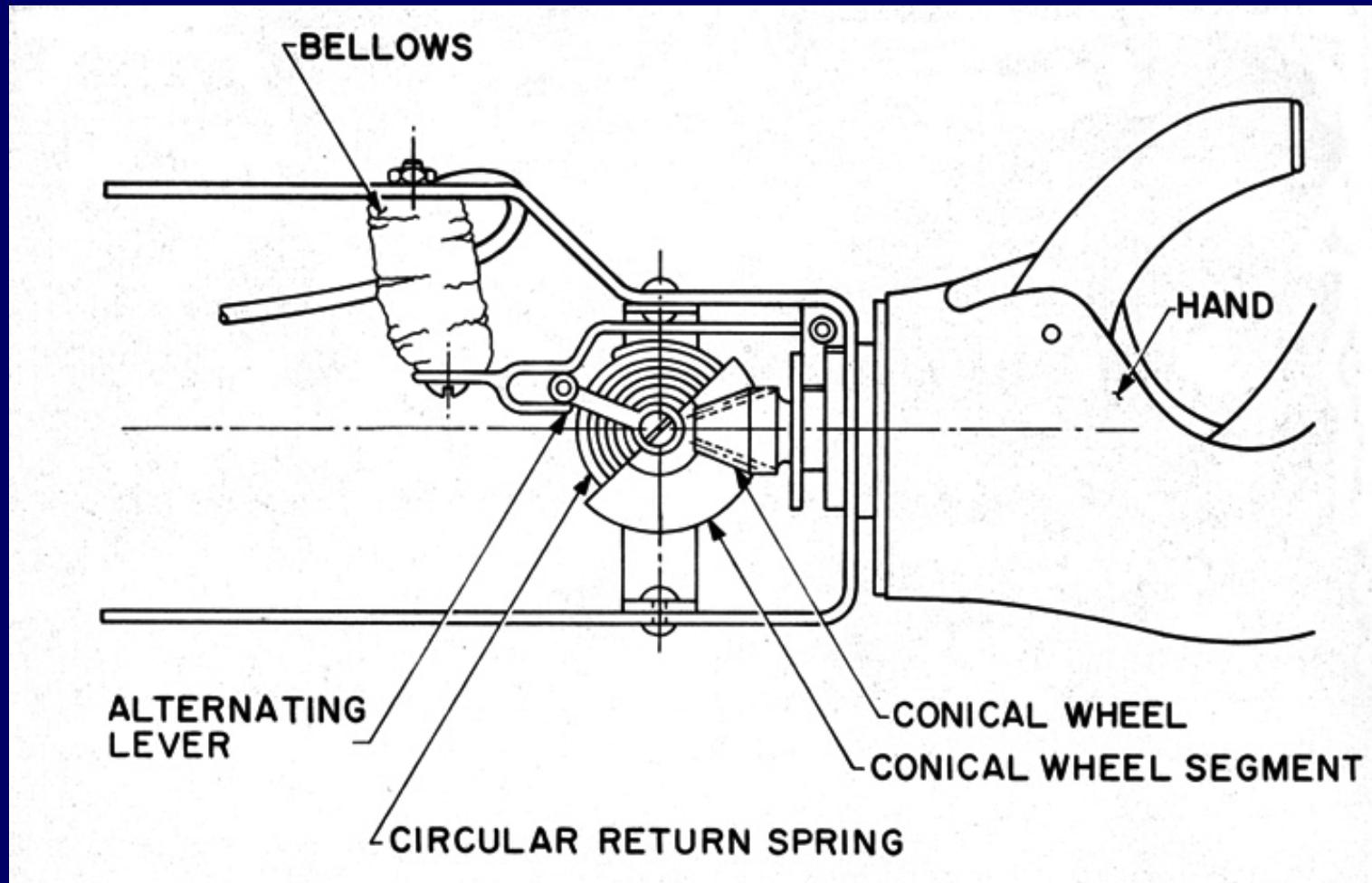
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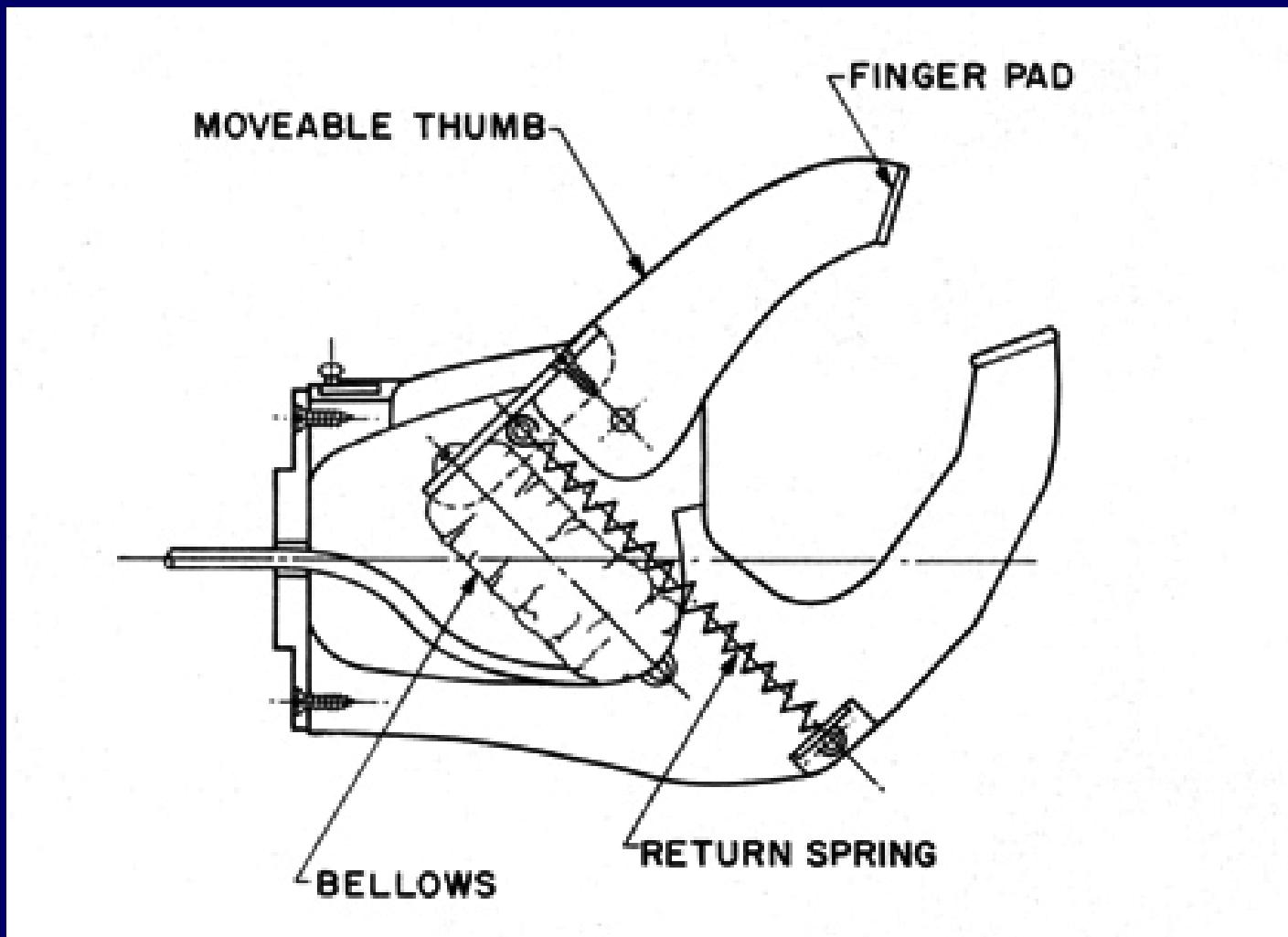


Lucaccini, 1966

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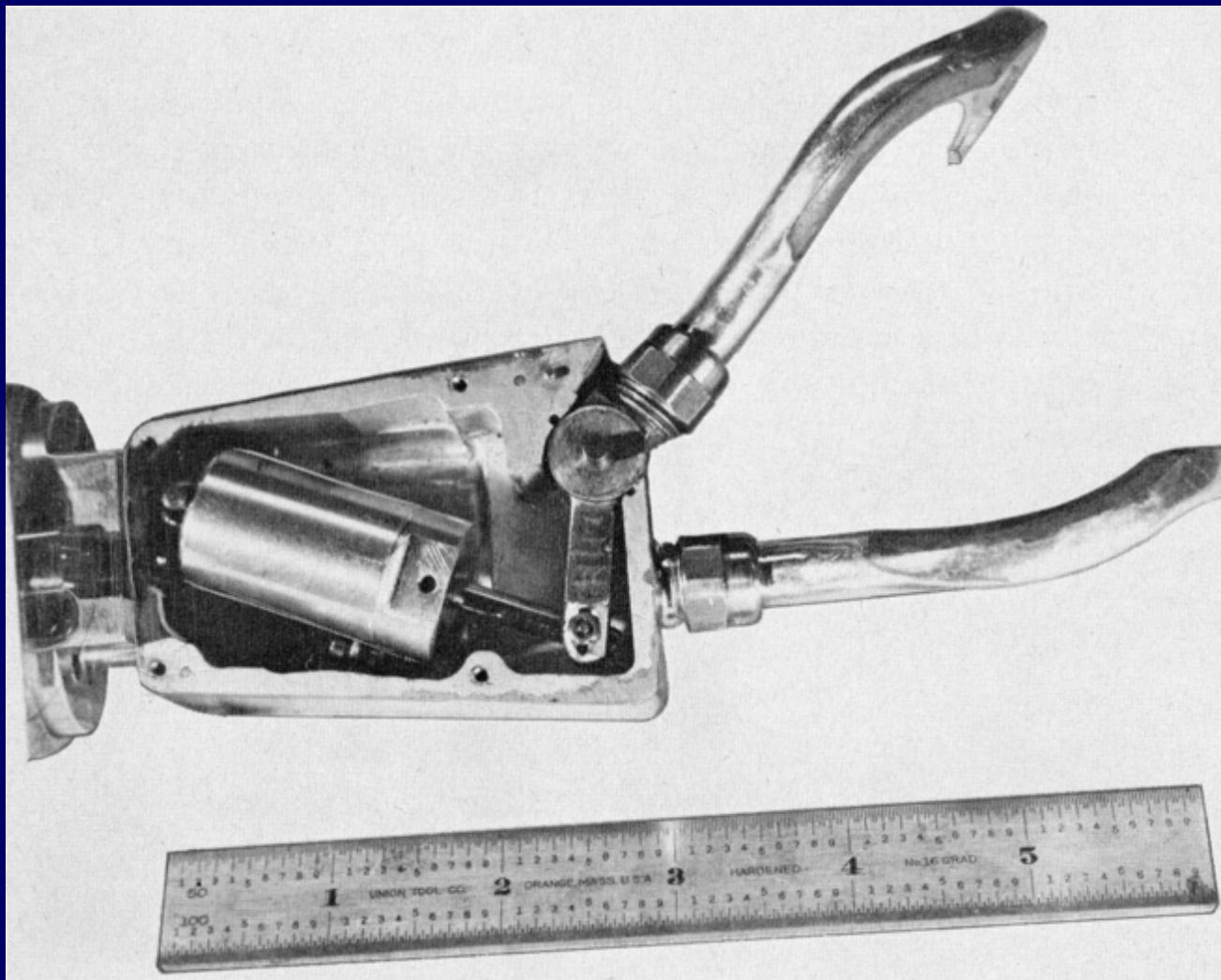






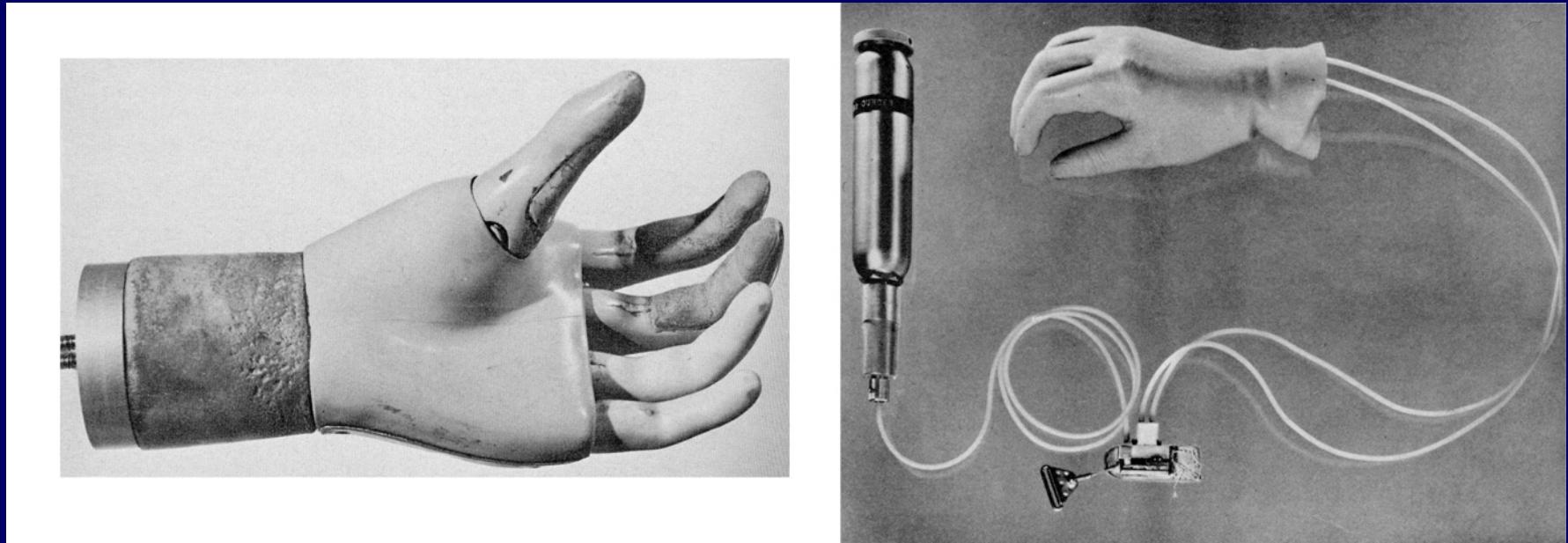
Otto Bock Healthcare GmbH

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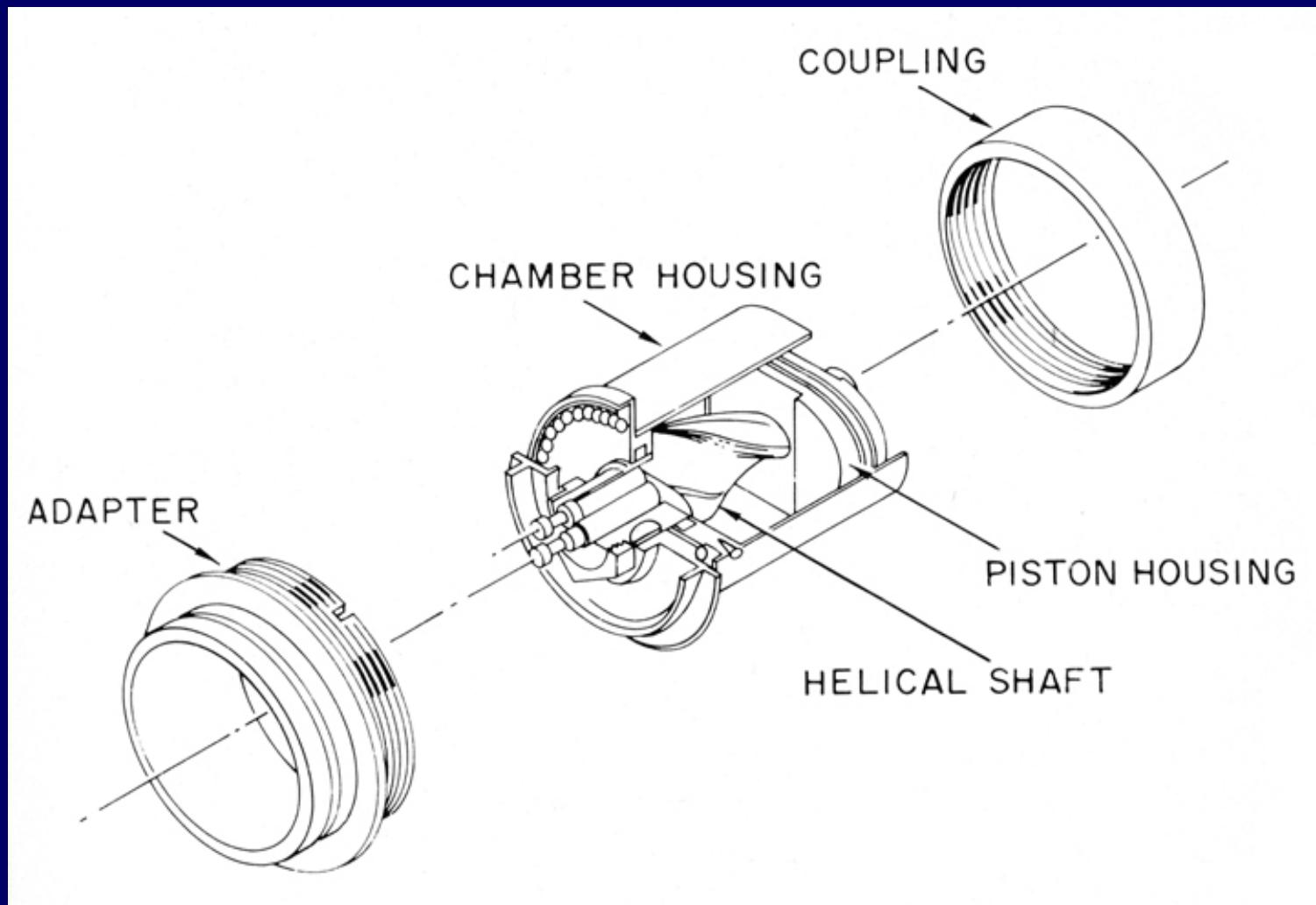
AIPR, 1961 - 1969

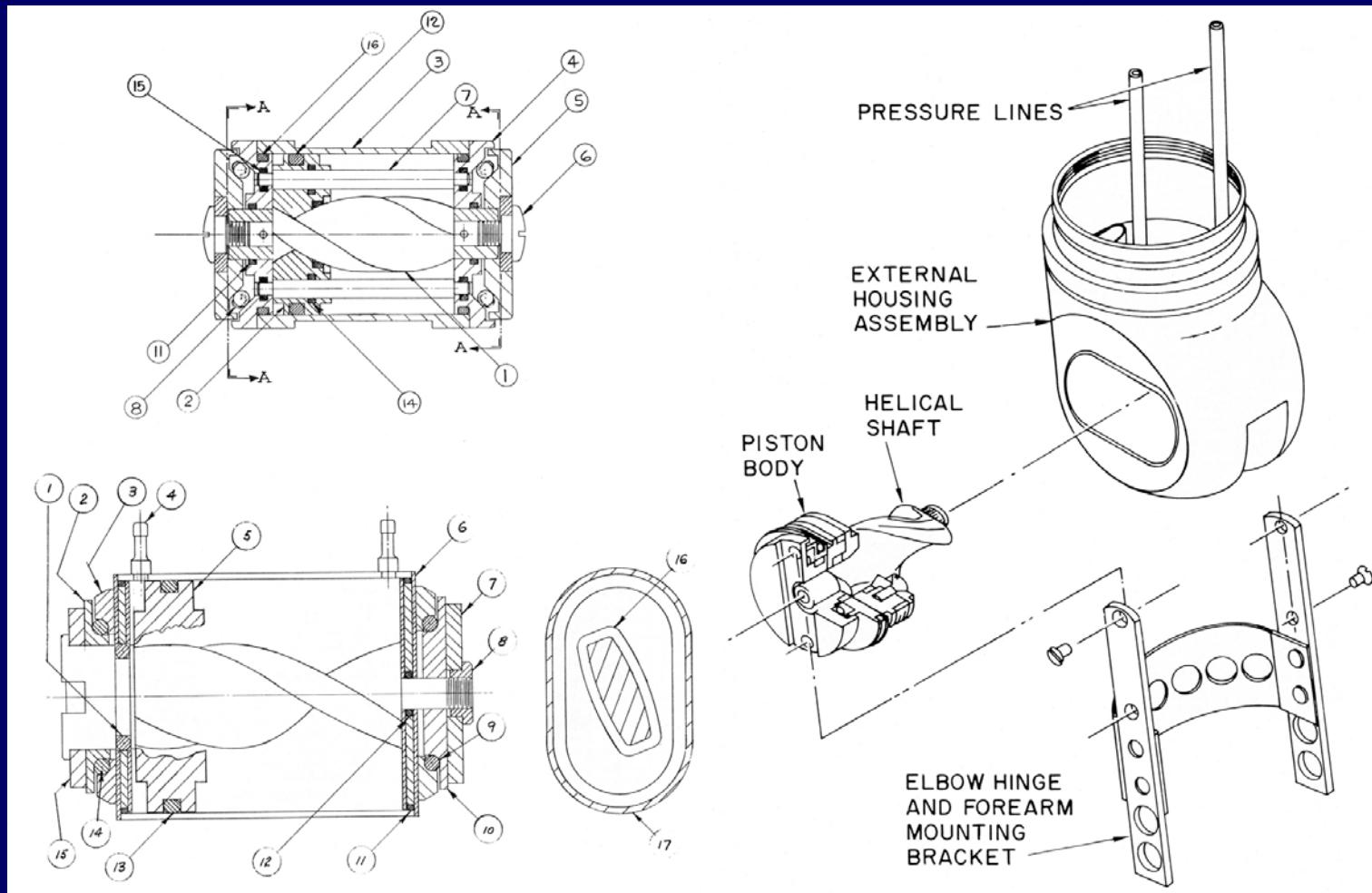
©2010 Dick H. Plettenburg

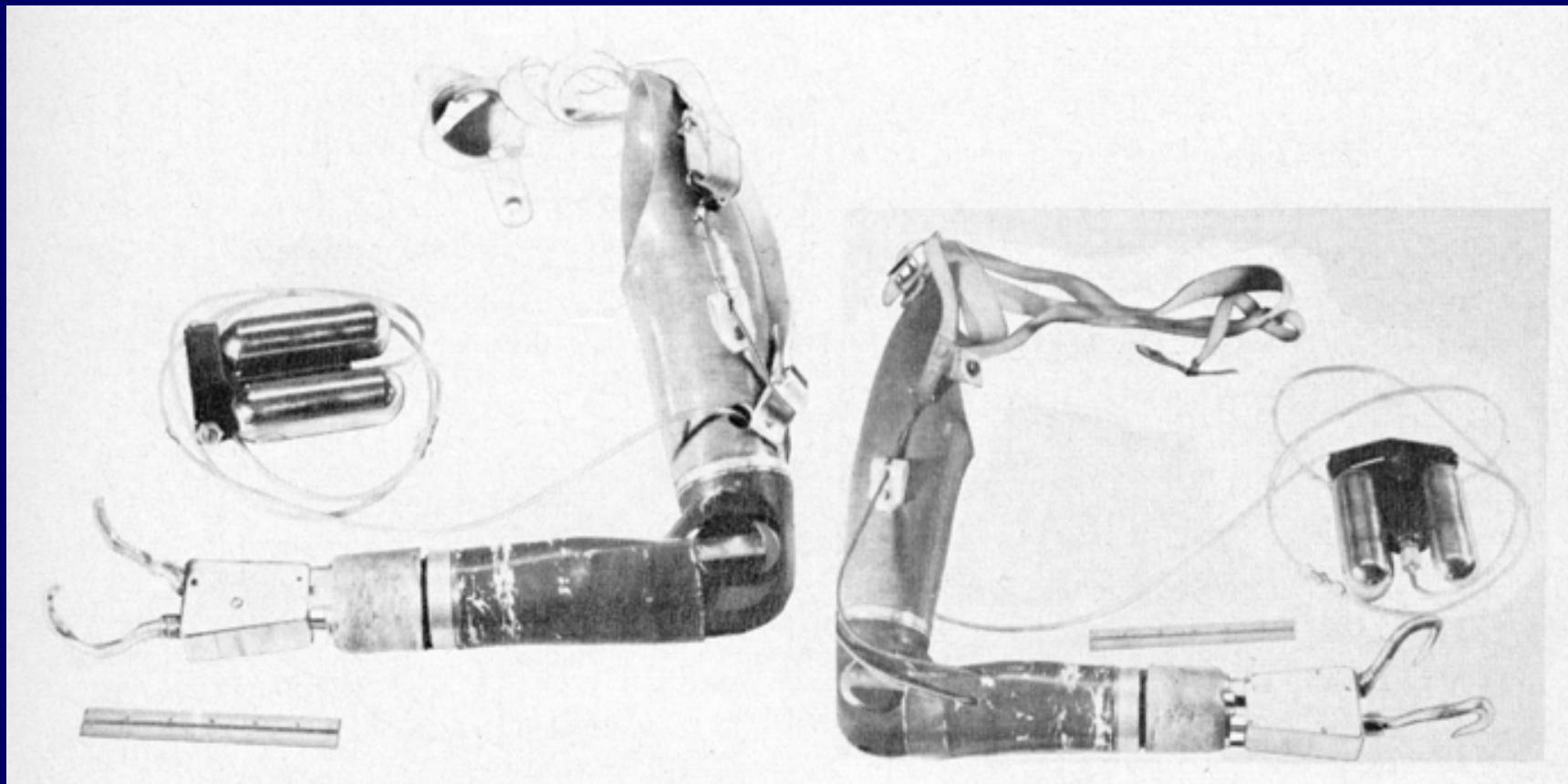


AIPR, 1961 - 1969

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AIPR, 1961 - 1969

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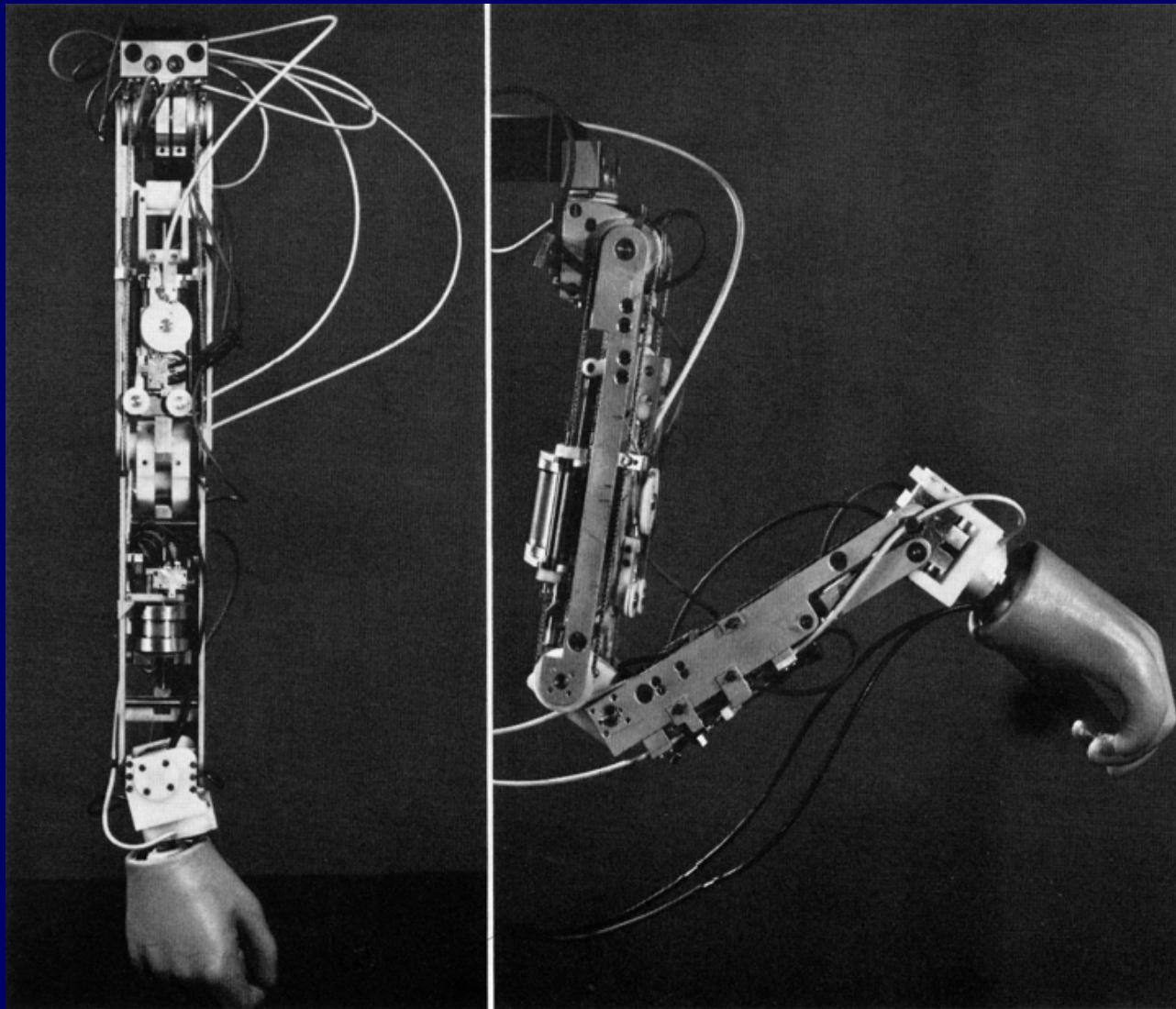


nmsi  
[www.nmsl.ac.uk](http://www.nmsl.ac.uk)

Steeper, 1963

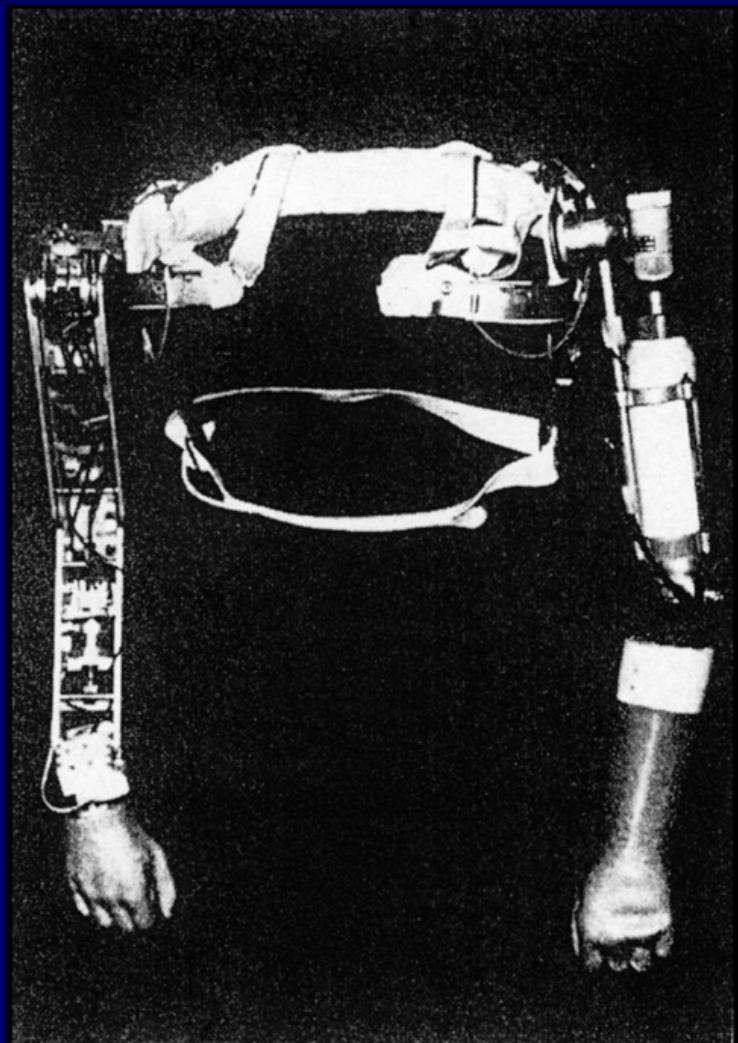
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**TU**Delft

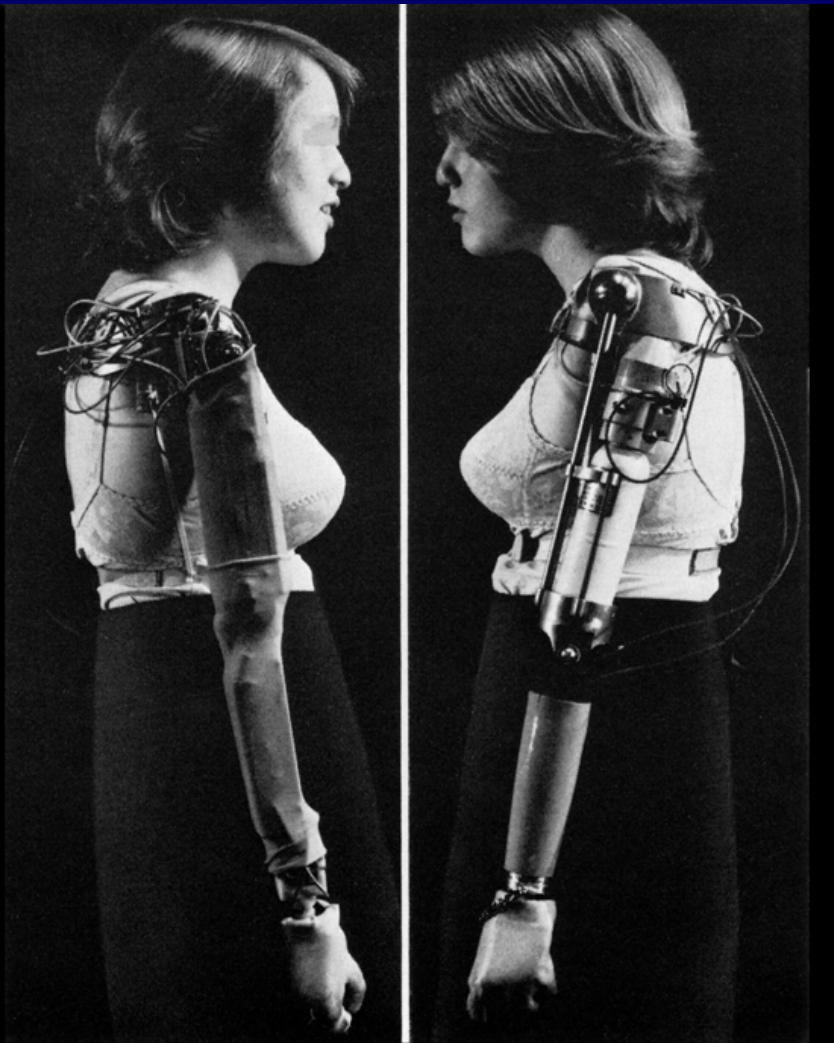


Baumgartner, 1977

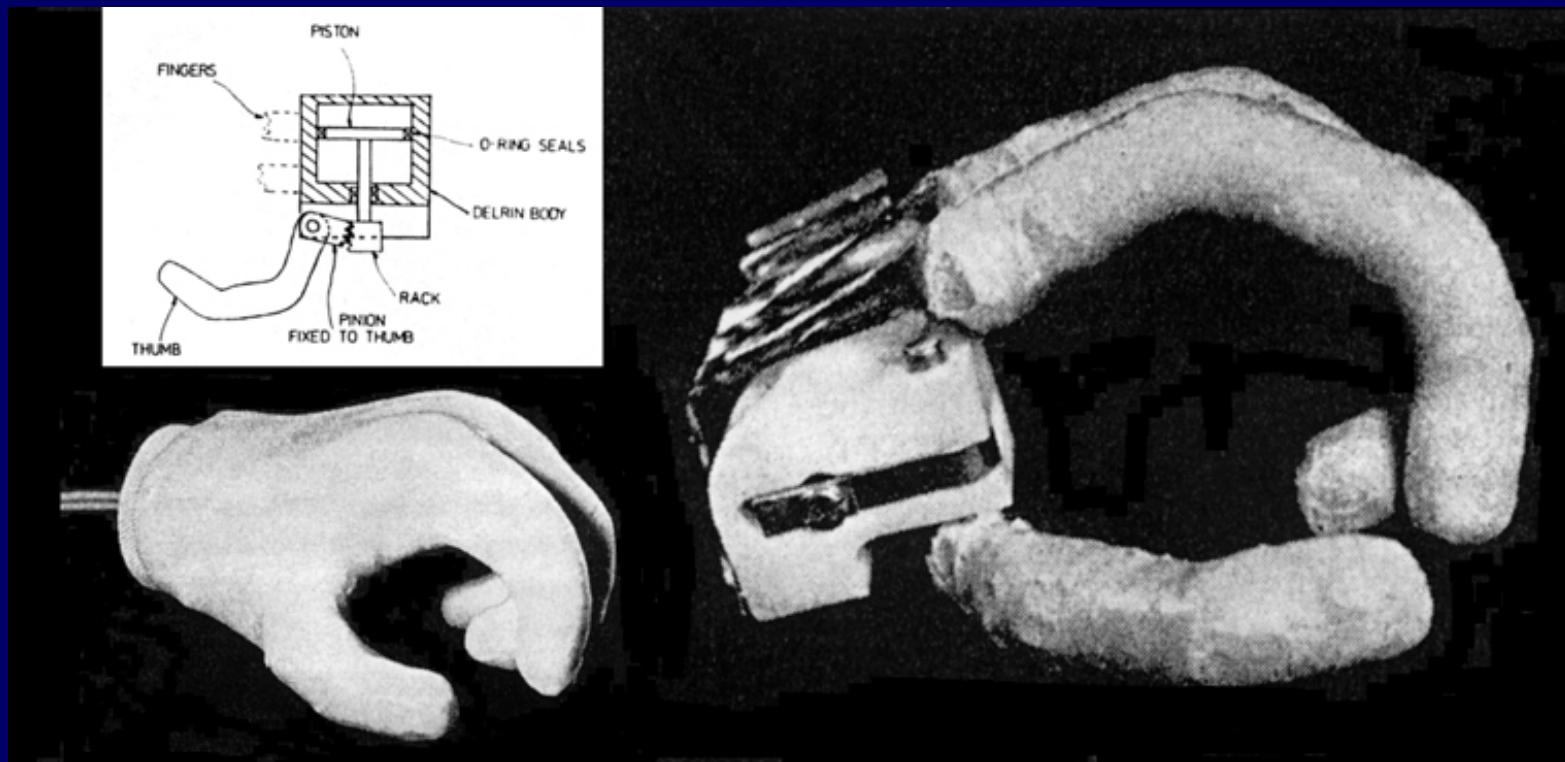
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Baumgartner, 1977

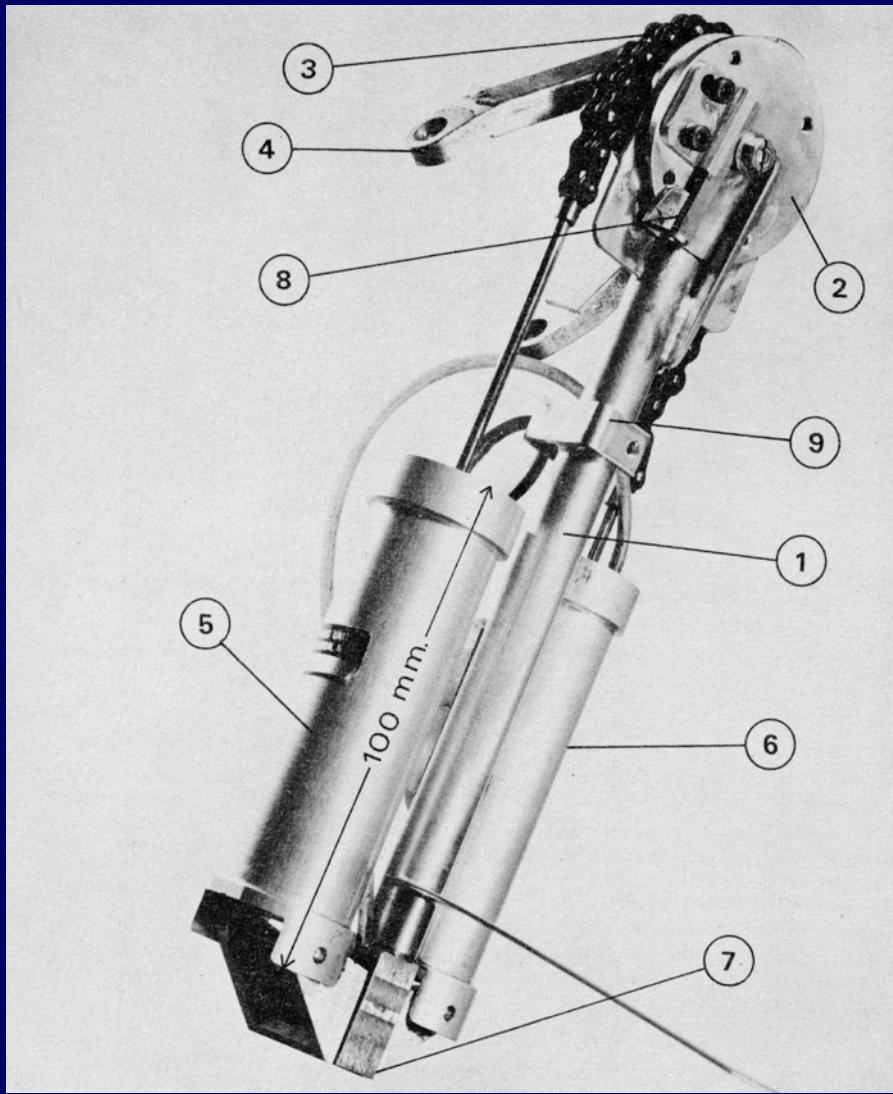


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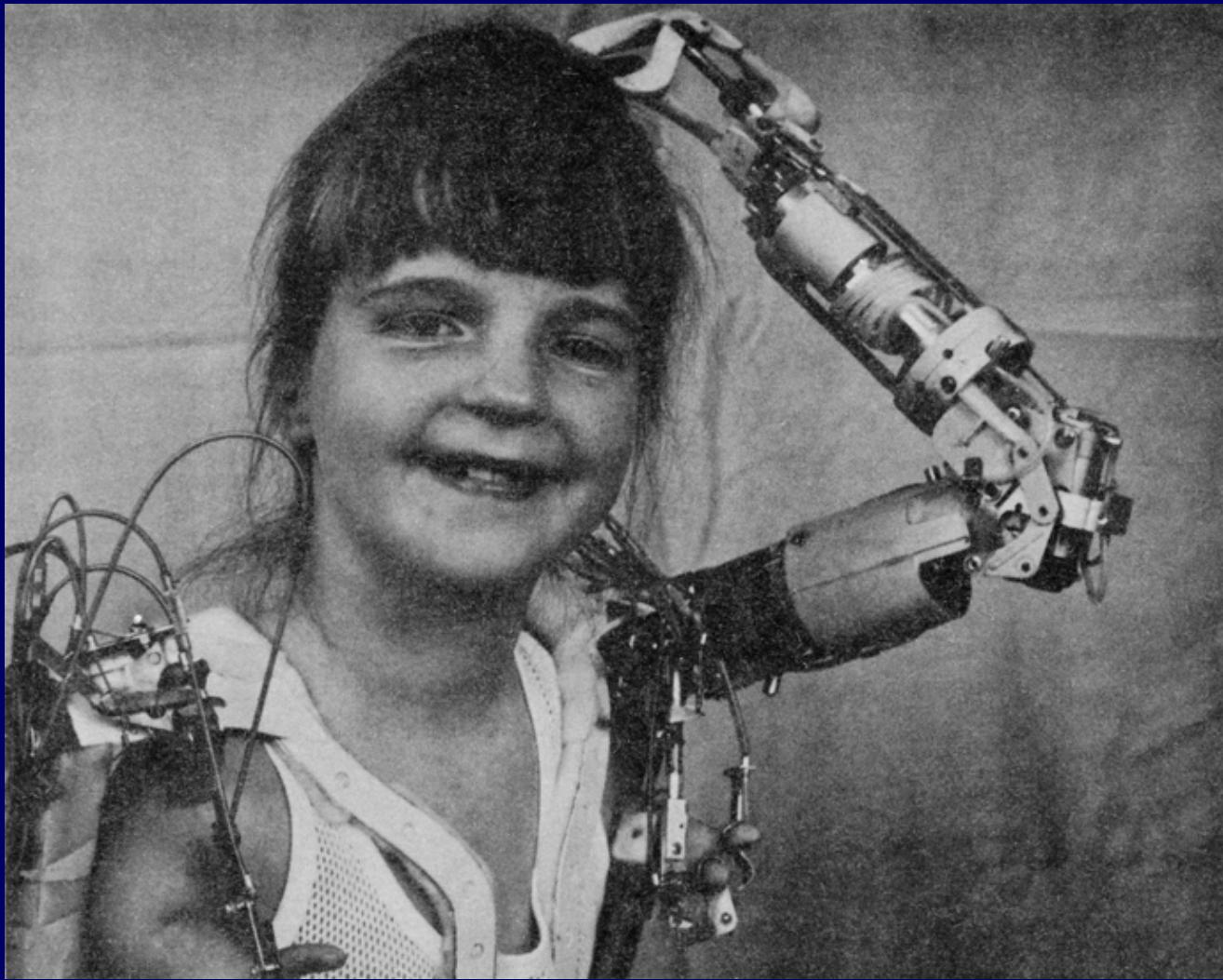
Kenworthy, 1974

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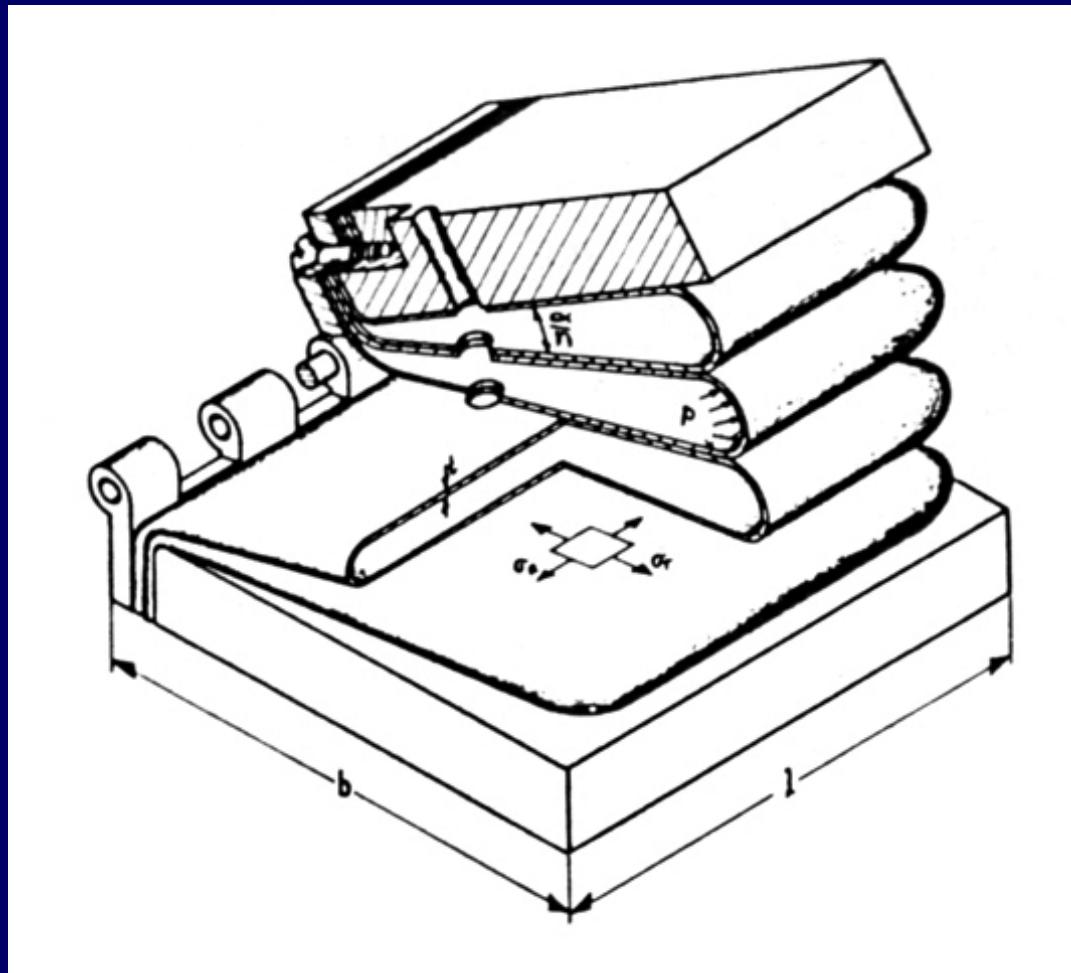
McWilliam et.al., 1970

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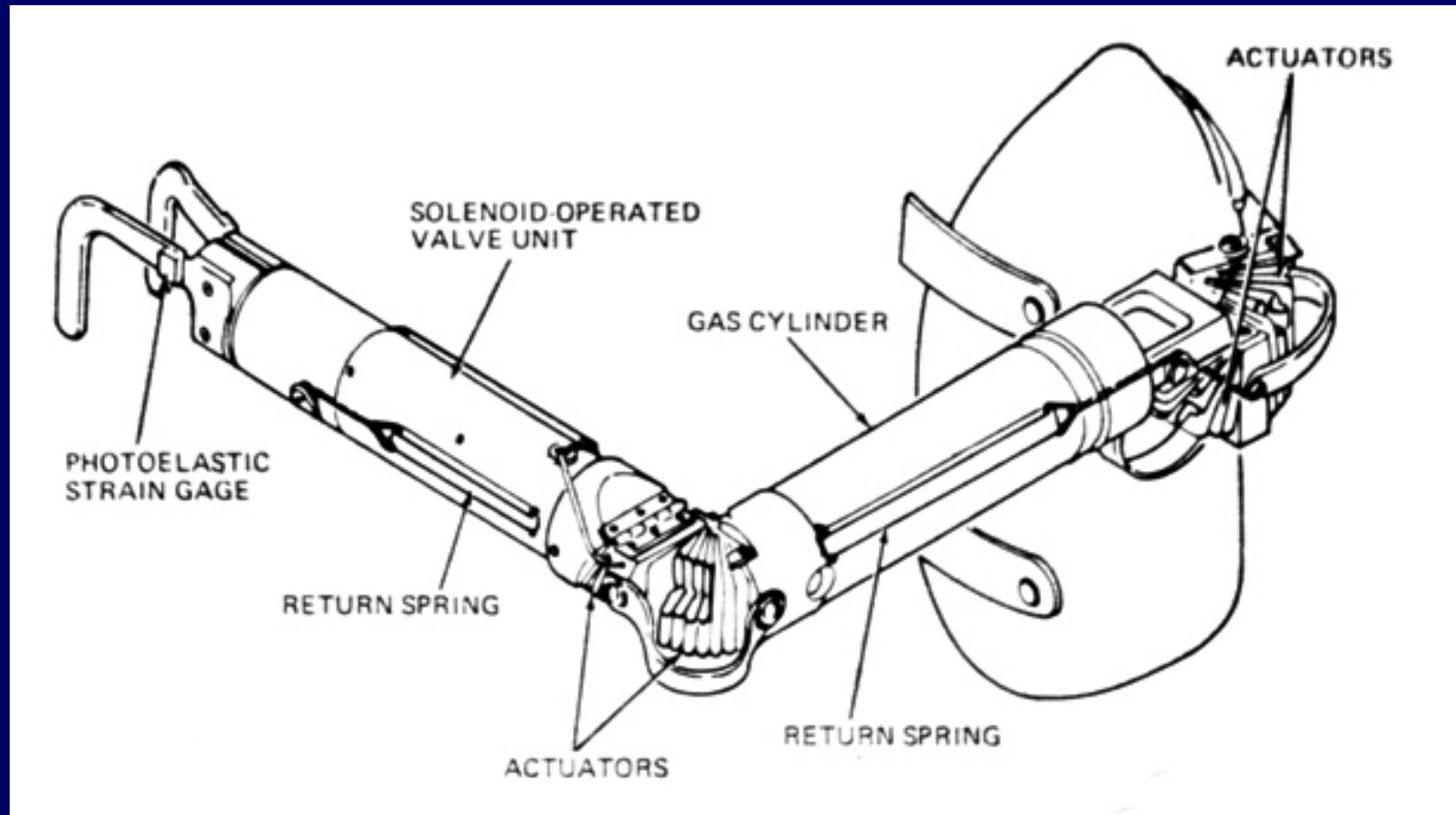
McWilliam et.al., 1970

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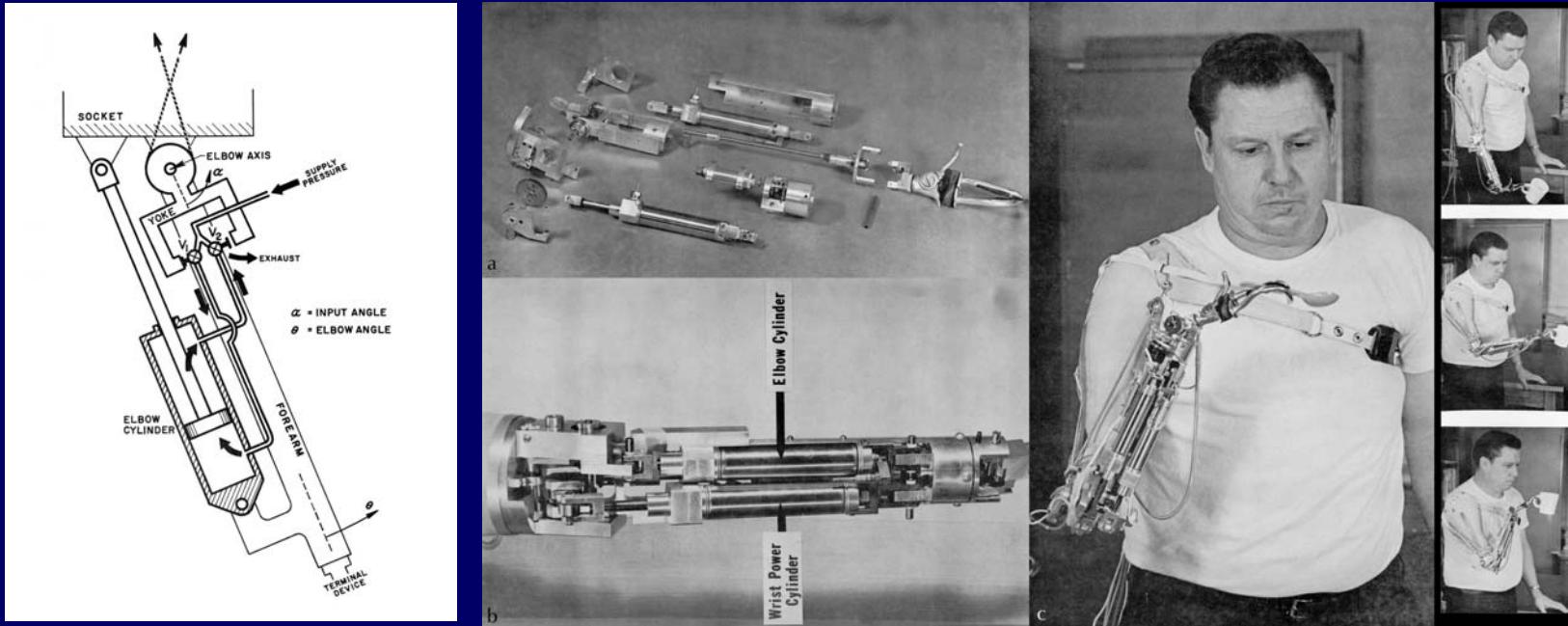
Boussø, 1969

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Boussø, 1969

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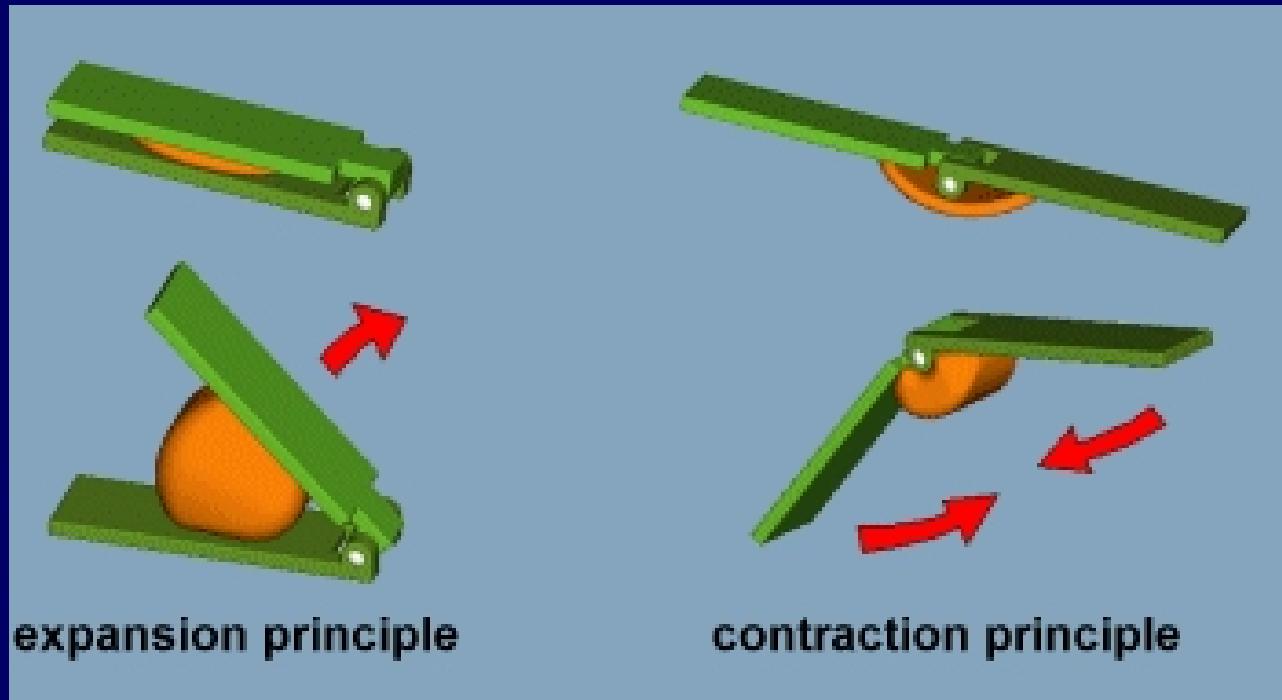


L.E. Carlson, 1971

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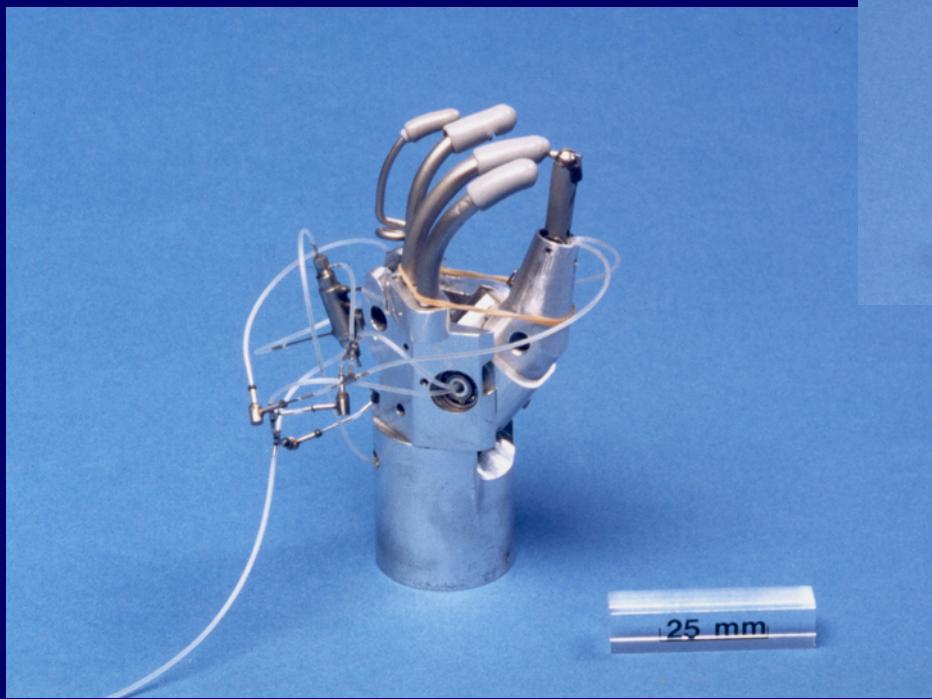




Schultz et.al., 2001

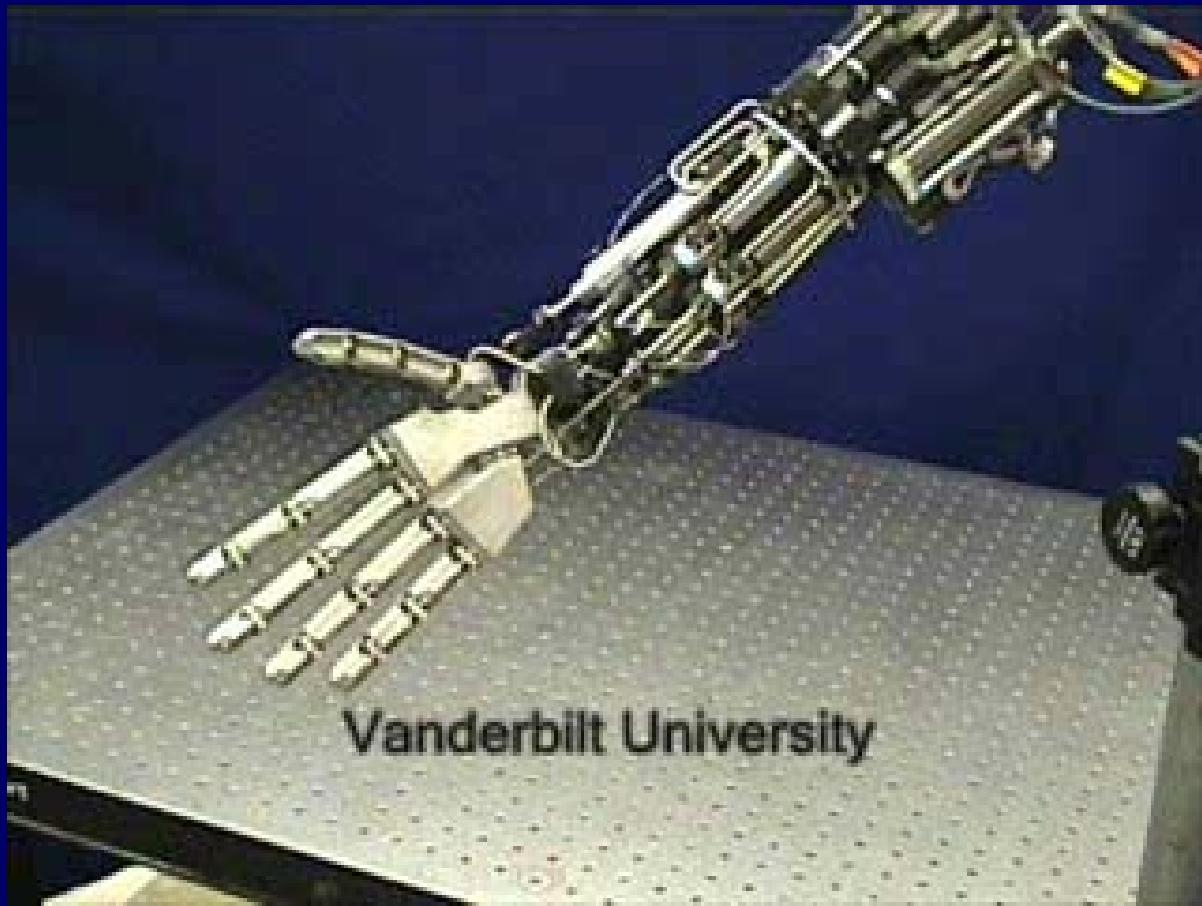
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Vanderbilt University

Vanderbilt University, USA

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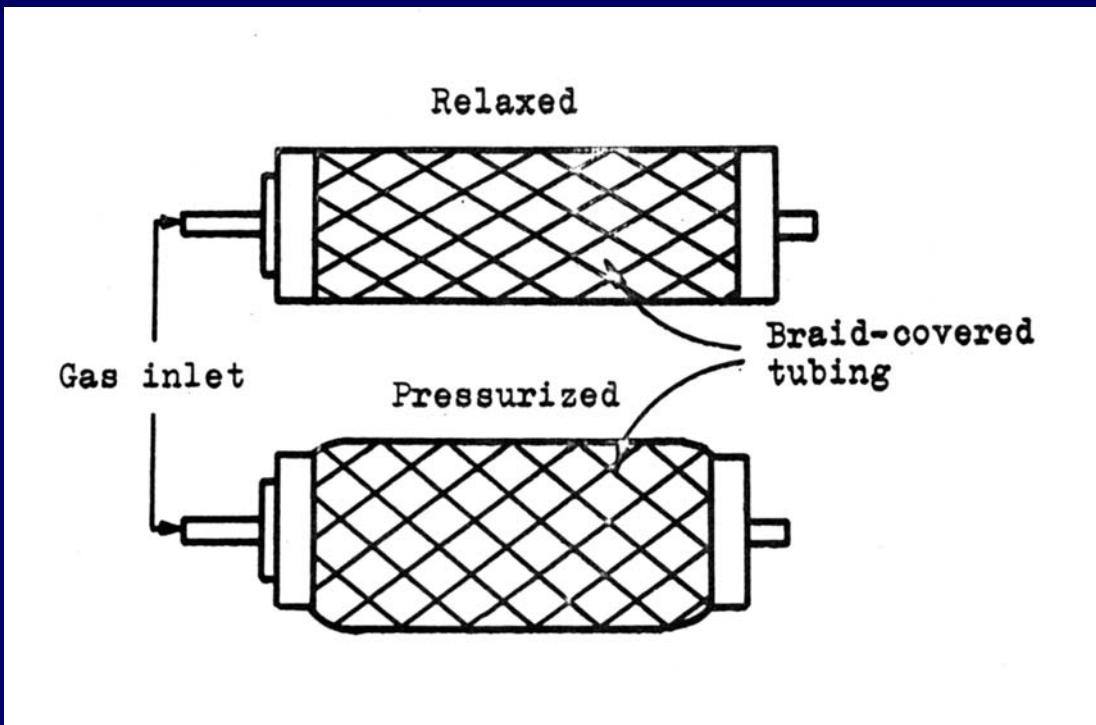
 **TU**Delft



Foto: Alex Ridder

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# McKIBBEN-MUSCLE

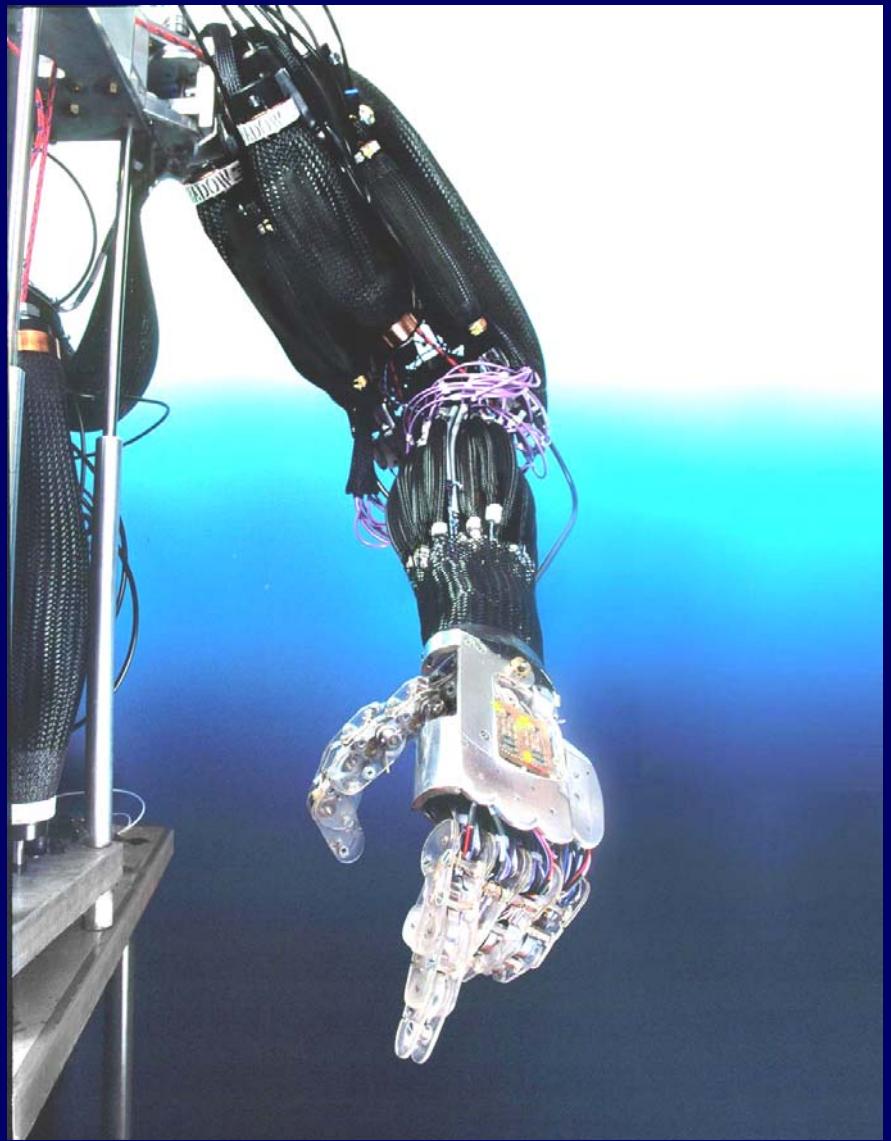
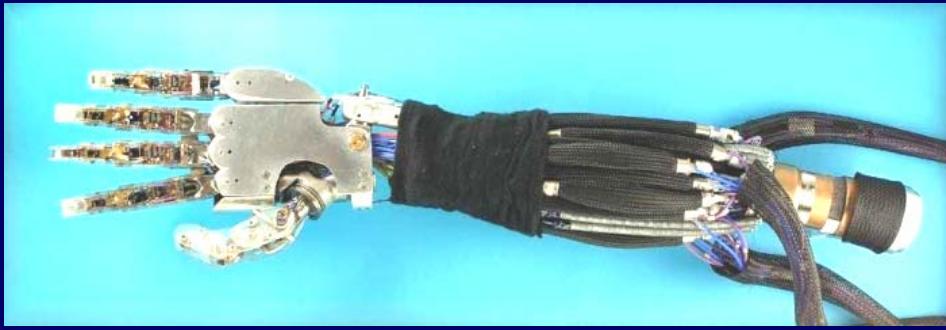




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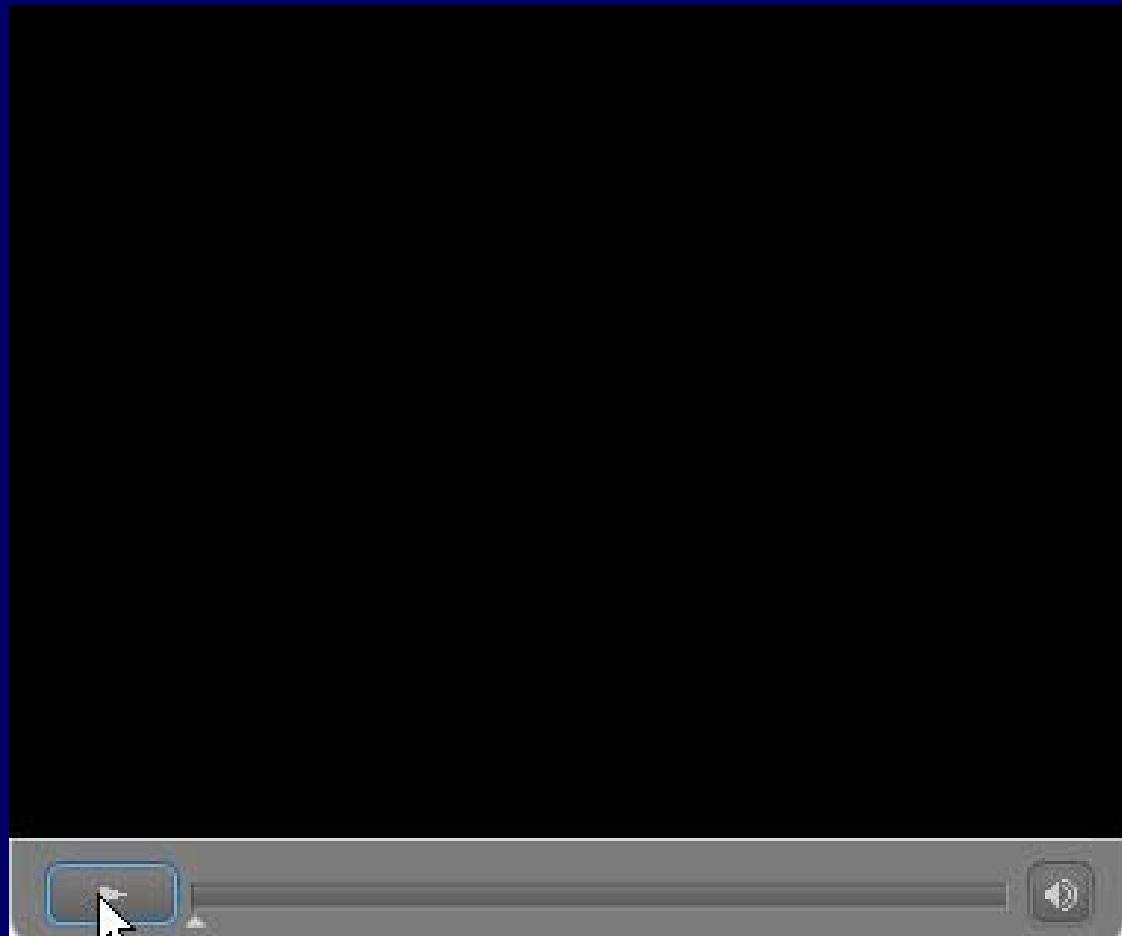
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Shadow, UK

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DBL, Netherlands

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# Pneumatic passive-based biped

Martijn Wisse  
Jan van Frankenhuyzen  
2004

Delft Biorobotics Laboratory





Vanderbilt University, USA

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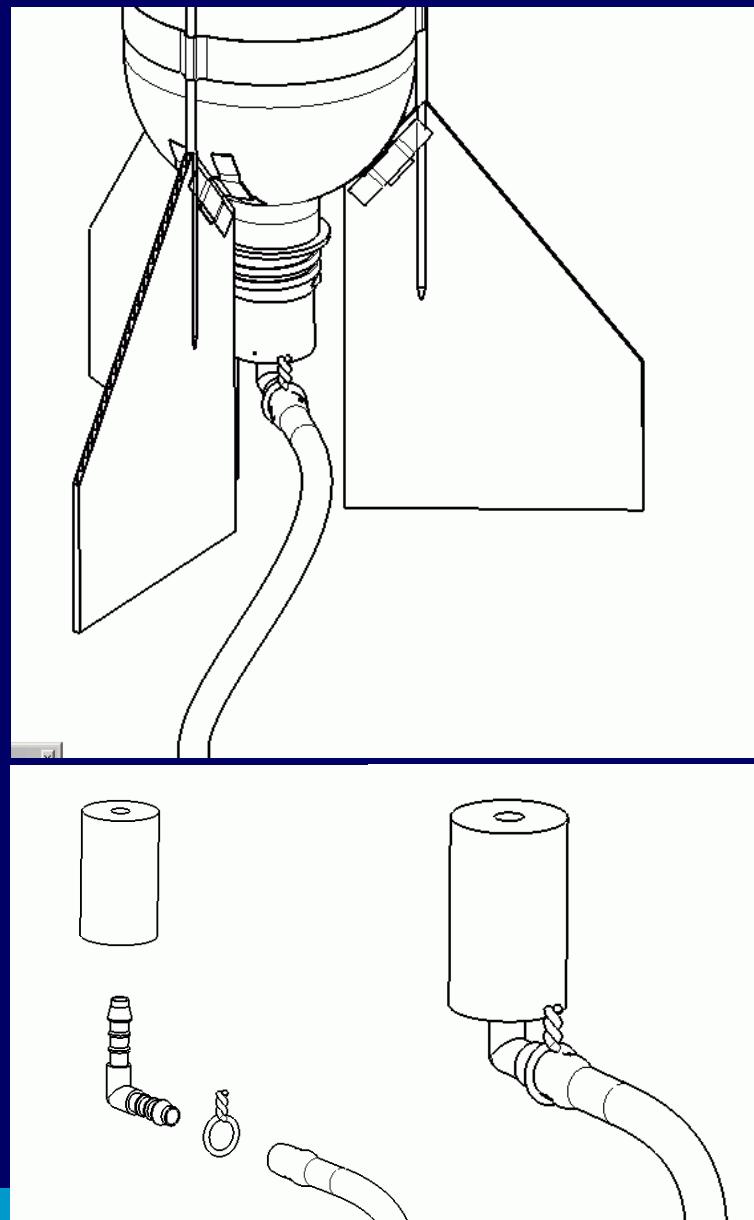


[www.festo.com](http://www.festo.com)

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[www.geocities.com/yoramretter](http://www.geocities.com/yoramretter)



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# Water Rocket Car

by Zippy





[home.people.net.au/~aircommand/](http://home.people.net.au/~aircommand/)

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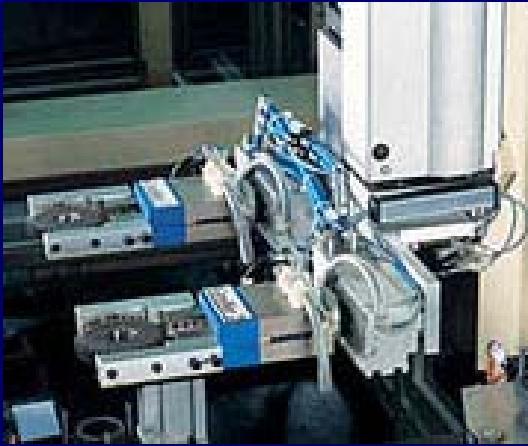




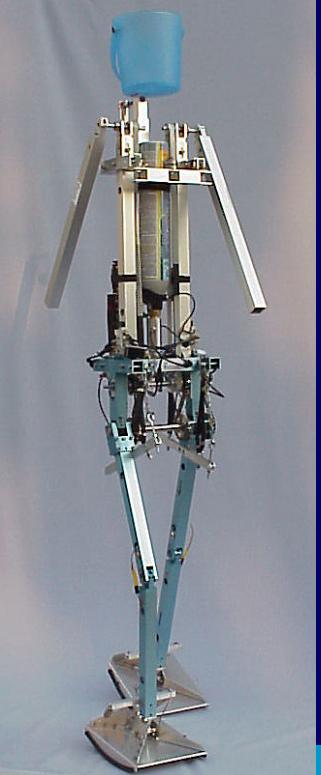
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