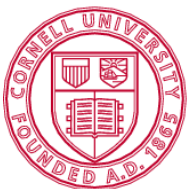


The Reuleaux Collection of Kinematic Mechanisms at Cornell University

An ASME Mechanical Engineering Heritage Collection housed in
Cornell's Duffield Atrium and Upson Hall in Ithaca, New York



Cornell University
College of Engineering



MECHANICAL ENGINEERING HERITAGE COLLECTION

REULEAUX COLLECTION OF KINEMATIC MECHANISMS AT CORNELL UNIVERSITY
1882

FRANZ REULEAUX (1829-1905) ESTABLISHED THE STUDY OF THE KINEMATICS OF MACHINES. HIS THEORIES HELPED STANDARDIZE MACHINE DESIGN IN THE LATE 19TH CENTURY. THE REULEAUX COLLECTION OF KINEMATIC MECHANISMS AT CORNELL UNIVERSITY WAS ACQUIRED BY ANDREW DICKSON WHITE AS PART OF HIS REFORM OF ENGINEERING EDUCATION. THESE IRON AND BRASS MODELS, REPRESENTING THE FUNDAMENTAL BUILDING BLOCKS OF BASIC MACHINERY, NOW CONSTITUTE THE LARGEST SUCH COLLECTION IN THE WORLD. MANY OF THE 230 ITEMS ARE STILL USED TODAY TO TEACH PRINCIPLES OF MACHINES AND ROBOTICS.



AMERICAN SOCIETY OF MECHANICAL ENGINEERS - 2004

Credits:

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Map, page 14: Cornell University

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A Historic Cornell Collection housed in the University's new Duffield Atrium



In November 2003, the American Society of Mechanical Engineers designated the Reuleaux Collection of Kinematic Mechanisms at Cornell University a **Mechanical Engineering Heritage Collection**. The ASME bronze plaque honoring the Collection was unveiled in December 2004. This dedication was symbolic not only for the Collection and the Sibley School of Mechanical and Aerospace Engineering, but also for ASME and Cornell, in light of the intertwined histories of the University and the Society. Robert Thurston, who pioneered new curricula in mechanical engineering at both the Stevens Institute of Technology and Cornell, was the first president of ASME and three other Cornell faculty members were early presidents of the Society. The Reuleaux models have been on display for over 120 years and in October 2004 were installed in beautiful, museum-quality cases as part of the new Duffield-Baum Atrium next to Upson Hall.

On view is the world's largest collection of 19th-century kinematic mechanisms. The models were created by the great German engineer, Franz Reuleaux (1829-1905) of the Berlin Technical University. Reuleaux was in fact one of the first honorary members of ASME along with Eiffel and Siemens. The 230 Reuleaux models were purchased in 1882 by Cornell's first president, Andrew Dickson White. The funds were donated by Hiram Sibley, a friend of Ezra Cornell and benefactor of Cornell University's Sibley College of Mechanical Engineering and the Mechanic Arts. Sibley College was the original home of the present School of Mechanical and Aerospace Engineering and the School of Electrical and Computer Engineering.

There are six special exhibits of the Reuleaux models in Duffield's Baum Atrium:

- ❖ History of Cornell Engineering
- ❖ The Evolution of Machines: from The Renaissance to Reuleaux
- ❖ Engines and Pumps
- ❖ Kinematics, Mathematics and Calculating Devices
- ❖ Clocks and Escapements
- ❖ Modern Applications of Kinematics

Kinematics is the study of geometry of motion. Reuleaux designed the models in the Cornell collection as teaching aids for the kinematic design and invention of machines. The mechanisms in the collection represent the fundamental components of complex machines and were conceived as elements of a basic "language of invention." Today the models are used in the teaching of machine design and synthesis, robotics, dynamics, architectural drawing and mathematics.

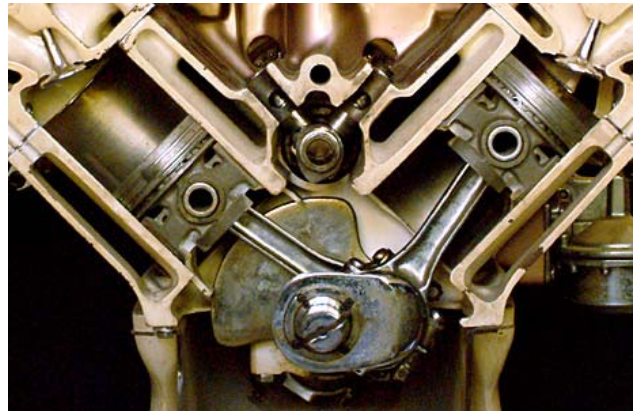


Top, left to right:
Peaucellier straight-line mechanism
Intermittent mechanism
Slider crank mechanism

Bottom left:
Mathematical curves generated by rolling cones

Bottom right:
Cochrane chamber crank pump mechanism

The brass and iron models of the Reuleaux Collection illustrate the motions of linkages, pumps, engines, clock escapements, belt drives, clutches and gear transmissions and many other basic machine elements. These mechanisms are used today in modern vehicle engines, robotics, biomedical prostheses, space satellites, and micro-machines. The Collection also contains a cutaway model of a 1960 V8 Chevrolet engine as well as several cutaway automobile transmissions that illustrate some of the practical applications of the basic Reuleaux mechanisms.

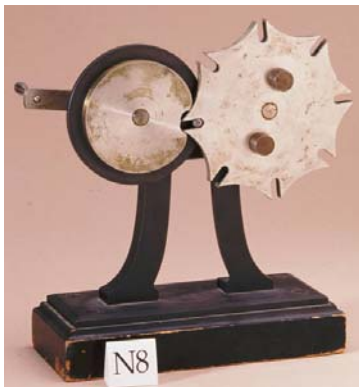


Cutaway of GM V8 engine in the Cornell Collection



"Reuleaux triangle"

Many of the models demonstrate mathematical theorems and geometric curves related to mechanisms and machines, such as cycloid curves of rolling bodies, epicycloid motions of gear mechanisms, the so-called Reuleaux triangle and curves of constant width, and exact curve-tracing linkages such as straight-line and ellipse-drawing mechanisms.



Left: Geneva Mechanism
Right: Cylinder Clock Escapement



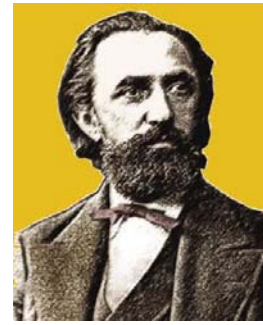
There are also "digital motion" models that convert continuous motion into discrete counting events such as the Geneva mechanism (used in watches and movie projectors), ratchets, clocks, and various time-counting mechanisms once used in tower clocks. The Collection contains a number of "funny"

gear wheel mechanisms, including elliptical and square wheel gears as well as many differential, hypoid and bevel gear pairs.

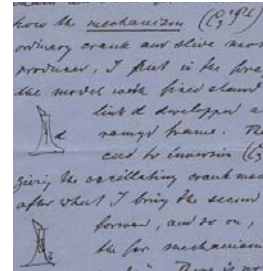
History of the Collection

Cornell University was founded in 1865 as a Land Grant University pursuant to the Morrill Act of Congress to encourage the teaching of “mechanic arts” and agriculture. The teaching of “mechanic arts” for the University’s first fifteen years was based on the workshop model. Around 1880 Cornell President Andrew Dickson White initiated discussions about the future of engineering education. White had likely met both Franz Reuleaux and Robert Thurston at the Philadelphia Centennial Exhibition as both White and Reuleaux were on the judging panel for educational models. White was also US ambassador in Berlin around this time and likely visited the Royal Technical Institute where Reuleaux had his large collection of 800 kinematic models. There is an 1882 letter in the Cornell archives to White from Reuleaux confirming the pending delivery of the models from Berlin to Ithaca. In 1885 White hired Thurston from the Stevens Institute of Technology to establish a College of Mechanical Engineering based on an engineering science model (See Calvert, 1967).

Robert Thurston was an expert on steam engines and was ASME’s first president. In a letter to White from Thurston in 1885, Thurston noted Cornell’s acquisition of the Reuleaux models. Thurston had earlier written about the models in his report to the US State Department on the Vienna Exhibition of 1873 and had also visited Berlin and noted Reuleaux’s fine model collection there. An article by Thurston on the new science- and mathematics-based engineering curriculum so impressed Franz Reuleaux that he translated it into German.



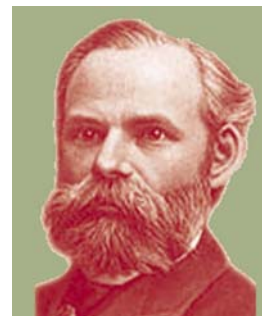
Franz Reuleaux
(1829-1905)



1882 letter from Reuleaux to White regarding the impending shipment of kinematic models to Ithaca.



Andrew Dickson White
(1832-1918)



Robert Henry Thurston
(1839-1903)



An 1885 issue of *Scientific American* featured Cornell's Sibley College of Mechanical Engineering on its cover. This detail shows the Reuleaux Collection housed in Sibley Hall.

The models were purchased for Cornell University with an \$8,000 gift from Hiram Sibley (an associate of Ezra Cornell and an early investor in Morse's telegraph company). A Museum of Mechanisms and Machines was established that was featured on the cover of *Scientific American* in 1885. This museum acquired other instrument and machine artifacts, including the Steven Vail and Samuel Morse telegraph receiver that was used to send the first telegraph message in the US from Baltimore to Washington in 1844. After World War II, Cornell's College of Engineering was moved to a new campus and the Collection was installed in a public hallway of Upson Hall in oak cabinets. In the fall of 2004, the Collection was reinstalled in the new Duffield-Baum Engineering Atrium in museum quality cabinets with professional graphics and descriptions. Over 200 models and artifacts relating to mechanisms and the history of machines are on public display.



Displays in Cornell's Upson Hall and Duffield-Baum Atrium, 2004.



Today the Collection contains around 300 artifacts relating to machine mechanisms, mechanical instruments, slide rules and mechanical calculators. In addition to the 230 Reuleaux models, there are three 19th-century working steam engine models, a gas engine model, 18 models from the Illinois Gear Co., circa 1950, as well as 17 kinematic models dating from around 1860-85 that were based on the designs of Reuleaux and other 19th-century engineers and built by the German model maker J. Schroeder of Darmstadt. There is also an 1895 Swiss-made "Millionaire Calculator," the first to perform direct multiplication. The School also has six cutaway full-scale engines and transmissions from General Motors dating from around 1960. The College of Engineering owns historic machines built by Robert Thurston, as well, including a model steam engine, his patented "autographic testing machine," and his viscosity-measuring instrument.

A digital library of kinematics and the history and theory of machines: KMODDL

A companion to the artifact Collection in the Engineering Atrium is the Kinematic Models for Design Digital Library (KMODDL), an open access online resource developed by Cornell University Library in collaboration with Cornell



**KINEMATIC MODELS
FOR DESIGN
DIGITAL LIBRARY**

faculty in Mechanical Engineering and Mathematics. KMODDL (<http://kmoddl.library.cornell.edu>) is a pedagogical space designed for use by teachers and researchers, as well as students at a range of educational levels, and other learners, young and adult. Cornell's Reuleaux Collection is at the core of KMODDL and interactive video enables the visitor to experience many of the models in motion. KMODDL offers a spectrum of textual and multimedia materials for teaching, research, and learning about kinematics and the history and theory of machines.

KMODDL incorporates:

- ❖ still and interactive moving images of kinematic mechanisms, with systematic descriptions, beginning with Cornell's Reuleaux collection
- ❖ tutorials that employ the models and simulations in the classroom at the undergraduate, high school, and middle school levels
- ❖ computer simulations of mathematical relationships associated with the mechanisms' movements
- ❖ key historical and contemporary texts related to the history and theory of machines and mechanisms
- ❖ stereolithography files for “printing” working physical replicas.

Use of the KMODDL website by educators can help stimulate student interest in the history of machines and technology, provide design projects for engineering and technology students, and provide middle school, high school, and college mathematics teachers with geometry and algebra applications. The collection is also of interest for art and architecture curricula as a resource for student drawing and kinetic art design projects.



KMODDL has been developed with funding from the National Science Foundation (NSF) as part of the National Science Digital Library (<http://nsdl.org>) program. A 2004-2006 grant from the Institute for Museum

and Library Services is enabling the project to expand its mechanism collection in collaboration with the Museum of Science (MOS) in Boston and to test the potential of rapid prototyping (“3D printing”) technology for sharing artifact collections.

Ratchet mechanism.

Left: original Reuleaux model from the Cornell Collection.

Right: “Printed” model from stereolithographic file.



ASME and Cornell University

ASME was founded in 1880 and Cornell University played a significant role in its early history. January 18, 2005, marks the 125th anniversary of the call to a meeting by Professor John E. Sweet, who taught at Cornell University from 1872 to 1879, that was to precipitate the establishment of ASME.

“Dear Sir:

It having been suggested by several prominent engineers that a national association of mechanical engineers would be desirable, and a meeting for the purpose for taking steps to organize such a society being in order, your presence is hereby requested at the office of the American Machinist, 96 Fulton Street, New York, the sixteenth day of February, 1880, at 1 o’clock sharp, at which time the necessary steps for organizing such an association will be made.

Very truly yours

(signed) John E. Sweet”

On April 7, 1880 a formal meeting was held at Stevens Institute of Technology to approve bylaws and a charter. At this meeting, Robert H. Thurston, then professor of Mechanical Engineering at Stevens Institute of Technology, was elected the *first president* of the American Society of Mechanical Engineers. He served for two terms, 1880-81 and 1881-82, before coming to Cornell to assume the post of the first director of the Sibley College at Cornell University in 1885. Years later, Reuleaux wrote to Sweet’s company in Syracuse, New York, praising Sweet’s design for a measuring instrument.

Both White and Thurston had met and corresponded with Franz Reuleaux, whose models White had purchased in 1882. Thurston transformed Cornell’s curriculum from a shop-based model to an engineering science model of mechanical engineering beginning in 1885. By 1900, President Schurman of Cornell would claim that in a national survey, Cornell’s Sibley College of Mechanical Engineering was ranked number one, and that at ASME meetings Cornell graduates presented 47 percent of the papers.



Gear-tooth profiles

Four Cornellians have served as Presidents of ASME and one as Vice President:

Robert H. Thurston: Founder 1880; President 1880-82 [Left Stevens for Cornell]

John E. Sweet: Founder 1880, Manager, 1882, President 1884

William F. Durand; Vice Pres. 1912, President 1925 [Left Cornell for Stanford]

Dexter Kimball: Manager 1920-21, President 1922.

Edwin N. Trump (*Cornell Class of 1879*): Vice President 1905-07

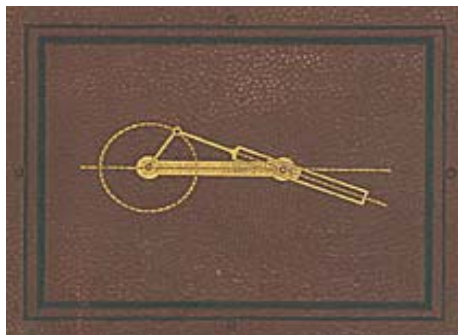
Also John S. Coon, student and instructor at Cornell (1874-78), was a founding ASME member and went on to be the head of Mechanical Engineering at Georgia Tech in 1888.

There is a bas-relief bronze sculpture of Robert Thurston in ASME Headquarters in New York, and a copy in Cornell's Thurston Hall. This sculpture was done by one of America's premier sculptors, Herman A. MacNeil, who also created the beloved standing bronze sculpture of Ezra Cornell in Ithaca. MacNeil was hired by Thurston to teach Industrial Art.

Who Was Franz Reuleaux?

Machine mechanisms are largely hidden in modern technology. Yet mechanisms remain important components in many technologies, including aircraft, automobile suspensions, robotic manipulators, satellites, consumer electronics and biomechanic prostheses.

Central to the design of these devices is the kinematics of machines. Franz Reuleaux (1829-1905), one of its principal theorists, is often called the "father of modern kinematics."



Detail from the cover of Reuleaux's *Kinematics of Machinery*.

Many of our ideas about kinematics of mechanisms and multi-body systems originate in this period and stem from Reuleaux's two major books, *The Kinematics of Machinery* (1875-76), and *The Constructor* (1861-93), a machine design book that went through four editions in four languages. He was also the first to attempt to place invention, kinematic synthesis, and design of the machine as a whole on a mathematical and scientific basis.

In addition to technical papers, Reuleaux wrote reports on the major World Exhibitions, commentaries on technical and industrial progress around the world, as well as German translations of Robert Thurston's *The Animal as a Machine* and of Longfellow's *Hiawatha*.

Reuleaux's Early Life and Career

Reuleaux's father and grandfather were machine builders with roots in Liege, Belgium, in the 18th century. Around the beginning of the 19th century, his family moved their business about 40 kilometers west of Liege to Eschweiler, a village near the German city of Aachen. Reuleaux received his technical training at the Polytechnic University of Karlsruhe (1850-52), where he studied with a major machine theorist, Professor Ferdinand Redtenbacher (1809-1869), who is sometimes called the father of mechanical engineering in Germany. The program at Karlsruhe was influenced by the French *École Polytechnique*. In 1856, at the age of 27, Reuleaux received an invitation to become a professor of mechanical engineering at the Swiss Federal Institute in Zurich and after eight years took a position in Berlin.

In Berlin Reuleaux developed a mechanical engineering program at the *Königliche Gewerbeinstitut* or Royal Industrial Institute in Berlin in 1864, serving as its Director from 1868 to 1879. The *Gewerbeinstitut*, renamed *Gewerbeakademie* in 1866, merged with the architecture-based *Bauakademie* in 1879 to become the *Königliche Technische Hochschule zu Berlin*



Double universal joint

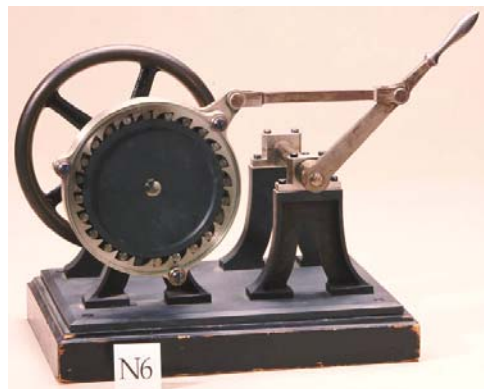
(Charlottenburg). By the time Reuleaux was elected Rector of this new institution during 1890/91, it was one of the major technical universities in the world with more than 3,000 students and 300 professors. He worked in this role advocating new educational programs in Germany. He also received the title of Royal Privy Councilor in the government. Reuleaux was a member of the Imperial Patent Office for eight years.

Reuleaux was not a major inventor in the mold of James Watt, nor was he an entrepreneur in the style of the Siemens brothers. He was not a pure scientist as we imagine Maxwell or Einstein to have been. He personified a new figure in the industrial age, the *engineer-scientist*: professor, kinematics theorist, head of a university, industrial consultant and confidant to capitalists, government expert

and technical ambassador to the emerging global industrial world – someone like Theodore von Karman a century later. Unlike James Watt, who was an instrument maker and craftsman, Reuleaux and his fellow engineer-scientists were trained in science and mathematics, philosophy and literature, as well as in “mechanical arts,” influenced in part by the French “Polytechnique” tradition with its strong mathematics and mechanics base. Unlike the craftsman-engineer who believed in trial-and-error, hands-on education, the engineer-scientist believed that machines could be created and designed using scientific principles guided by rigorous mathematics.

Reuleaux’s life spanned the period of enormous growth in travel spurred by the development of powerful steam engines that carried people across oceans and continents by steamship and railroad. He traveled to World Exhibitions in London (1862), Paris (1867), Vienna (1873), Philadelphia (1876), Sidney (1879), Melbourne (1881), and Chicago (1893), often as German ambassador to these fairs. He regularly communicated with colleagues in North America and many of the founders of ASME.

Aside from his scholarly contributions, Reuleaux was a player in the political world of the machine age. In Philadelphia he wrote letters that were published in Berlin newspapers and appeared as a book, *Briefe aus Philadelphia* (1877), on how “cheap and shoddy” (*billig und schlecht*) German manufactures were compared to English and American produced goods. In this book he proposed an economic design principle; when faced with competition, one should raise the quality, not lower the price. Later this principle became a hallmark of German manufacturing. Reuleaux was active in revamping the German patent system. He was also a consultant to the development of the Otto-Langen internal combustion engine (c. 1867), as well as to the industrialists Mannesmann (c. 1889) who had developed seamless pipe manufacturing. At the Chicago Columbian Exposition (1893) Reuleaux created another controversy in Germany by praising American precision manufacturing methods.

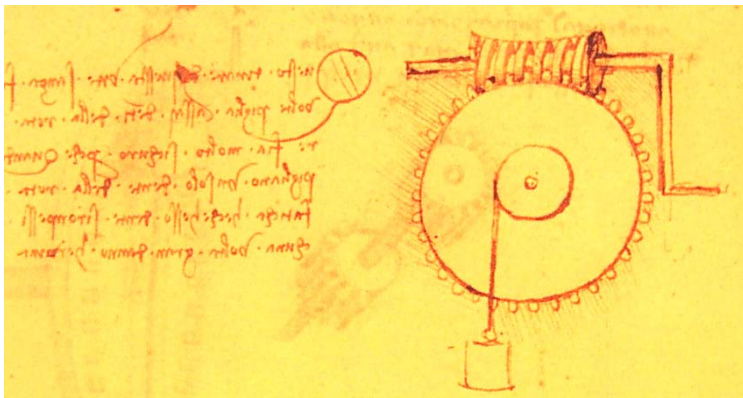


Reuleaux model N6: Langen clutch used in the 1867 Otto Langen engine.

Reuleaux believed there were scientific principles behind invention and the creation of new machines, or what we call *synthesis* today. He attempted to posit principles of design theory, a subject that has come into vogue a century later. This belief in the primacy of scientific principles in the theory and design of machines became the hallmark of his worldwide reputation, particularly in the subject of machine kinematics.

Reuleaux's Theory of Machines

Historically, there have been many attempts to classify machines according to the tasks or type of motion they produce. Some attribute the deconstruction or 'dissection' of machines into basic machine elements to Leonardo da Vinci, who often mentioned this in his manuscripts *elementi macchinari*, and Leonardo was thought by some to have attempted to describe the first collection of machine elements in 1493 in his Codex Madrid I, a work that was unfortunately lost until 1966.

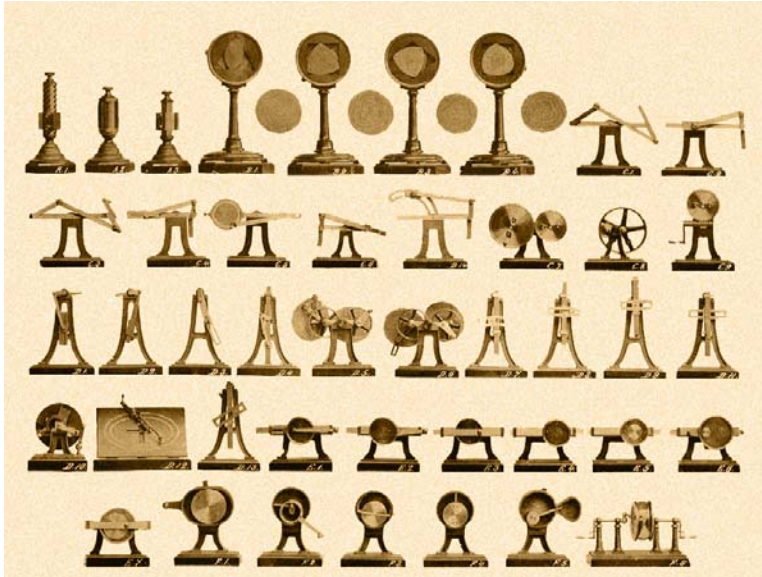


The "endless screw" mechanism was featured in Leonardo da Vinci's drawings in his Codex Madrid.



Reuleaux's version of the "endless screw."

More than three centuries later, Reuleaux, using topological concepts, conceived of machine elements as a *kinematic chain* or network of pairs of connected parts, where the motion of each part is constrained by the neighboring parts in the chain (*kinematic pairs*). This led him to represent a chain of parts in a machine by a set of symbols. Reuleaux believed that each mechanism, then, had a unique symbolic representation. From the idea that symbols could represent a machine mechanism, Reuleaux believed he had discovered the key to rational principles of invention and synthesis, a *language of invention*.



A page from Voigt's catalog of Reuleaux mechanisms

In addition to his kinematic theories, Reuleaux also created a museum of 800 models of mechanisms that he hoped would codify machine elements. He authorized copies of his models to be built by the workshop of a Gustav Voigt and his sons. By 1900, 350 models were on sale.

The Berlin collection was lost in World War II, as were many other European collections of teaching models. At the present time, Cornell has the largest set of these 19th-century Reuleaux models. Reuleaux was an advocate of aesthetics in machine design. This is evident in the graceful designs of the Voigt-Reuleaux models. Also he had inscribed on the parts of each of the models numbers and letters corresponding to figures in his book, *Kinematics of Machinery*, indicating that he envisioned the use of the models with his text as a method of teaching the kinematics of motion in machines. Reuleaux's books are available online at <http://kmoddl.library.cornell.edu/>.

Reuleaux decried the growth of specialization in mechanical engineering. *"The endless isolation of efforts must be detrimental to the whole,"* he wrote in *Kinematics of Machinery*. In reading the tributes to Reuleaux's work in his time, many contemporaries hailed his theories as genius, which is difficult for most of us to understand a century and a quarter later, when machines are taken for granted.



Circular guide slider-crank mechanism

For more information about Reuleaux and his mechanisms, see Francis C. Moon (2003) "Franz Reuleaux: Contributions to 19th Century Kinematics."

Readings about Reuleaux, Cornell and ASME

- Bishop, M. (1962) *A History of Cornell*, Cornell University Press: Ithaca, NY.
- Calvert, M.A. (1967) *The Mechanical Engineer in America 1830-1910: Professional Cultures in Conflict*, [See Chapter 5, School versus Shop; Cornell's Sibley College], The Johns Hopkins Press: Baltimore.
- Durand, W.F. (1929) *Robert Henry Thurston: A Biography*, ASME: New York.
- Hutton, F.M. (1915) *A History of the American Society of Mechanical Engineers from 1880-1915*, ASME: New York.
- Moon, F.C. (2003) "Franz Reuleaux: Contributions to 19th Century Kinematics" *Applied Mechanics Reviews*, Vol 56, No. 2, March 2003, pp 261-285. Publ. ASME: New York.
- Walker, K., et al. (2003) "Building a Digital Library of Kinematics," *RLG DigiNews* Vol. 7, No. 4, 15 August 2003, <http://www.rlg.org/preserv/diginews/diginews7-4.html#feature1>.

Where is the Cornell Reuleaux Collection Located?

The Collection is located on the Cornell University Campus in Ithaca, New York, on the Engineering Quadrangle, in the Dwight C. Baum Atrium in Duffield Hall, and in Upson Hall, the home of the Sibley School of Mechanical and Aerospace Engineering.



For information about visiting the Reuleaux Collection, inquire with the Sibley School of Mechanical and Aerospace Engineering, Upson Hall, Cornell University, Ithaca, NY 14853; telephone (607)-255-3623; online at <http://www.mae.cornell.edu/>.

The History and Heritage Program of ASME

The History and Heritage Landmarks Program of ASME (the American Society of Mechanical Engineers) began in 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee initially composed of mechanical engineers, historians of technology and the curator (now emeritus) of mechanical engineering at the Smithsonian Institution, Washington, D.C. The History and Heritage Committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements of particular significance. This Committee is part of ASME's Council on Public Affairs and Board on Public Information. For further information, please contact Public Information at ASME, Three Park Avenue, New York, NY 10016-5990, 1-212-591-7740.

Designation

Since the History and Heritage Program began in 1971, 231 landmarks have been designated as historic mechanical engineering landmarks, heritage collections or heritage sites. Each represents a progressive step in the evolution of mechanical engineering and its significance to society in general. Site designations note an event or development of clear historic importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The Landmarks Program illuminates our technological heritage and encourages the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

The 120,000-member ASME is a worldwide engineering society focused on technical, educational and research issues. ASME conducts one of the world's largest publishing operations, holds some 30 technical conferences and 200 professional development courses each year, and sets many industrial and manufacturing standards.

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