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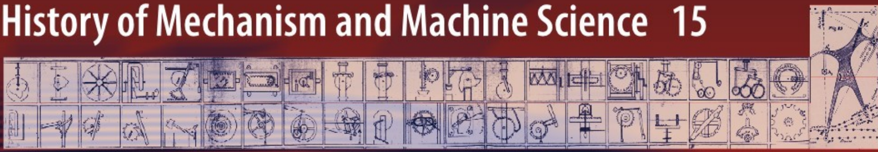

Teun Koetsier
Marco Ceccarelli *Editors*

Explorations in the History of Machines and Mechanisms

Proceedings of HMM2012

Springer

Explorations in the History of Machines and Mechanisms

HISTORY OF MECHANISM AND MACHINE SCIENCE

Volume 15

Series Editor

MARCO CECCARELLI

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This book series aims to establish a well defined forum for Monographs and Proceedings on the History of Mechanism and Machine Science (MMS). The series publishes works that give an overview of the historical developments, from the earliest times up to and including the recent past, of MMS in all its technical aspects.

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Preface

The organization of an international symposium on the History of Machines and Mechanisms (HMM) every four years is the main activity of the Permanent Commission (PC) for the History of Mechanism and Machine Science of IFToMM, the International Federation for the Promotion of Mechanism and Machine Science. The first two symposia, HMM2000 and HMM2004 were held at the University of Cassino in Cassino, Italy in the years 2000 and 2004. The third symposium, HMM2008, was held at the National Cheng Kung University in Tainan, Taiwan in 2008. The present volume contains the proceedings of HMM2012, the 4th International Symposium on the History of Machines and Mechanisms that was held at VU University in Amsterdam, The Netherlands, from May 7 until May 11, 2012.

The mission of IFToMM is to promote research and development in the field of machines and mechanisms by theoretical and experimental methods, along with their practical applications. The aim of the international symposia on HMM is to maintain an international forum for the exploration of the history of machines and mechanism. Although the emphasis is on the history of technical systems and their applications, the scope of the symposia is wide. Relevant topics are also the history of theories and design methods, biographies, the history of the institutions involved, the relations with other disciplines, the history of engineering education and the social and cultural aspects of machines.

History is not only full of exciting and entertaining stories. Historical investigations put our own present day activities in a wider perspective. They help us define who we are. Moreover history remains a source of ideas.

This book is meant for researchers, graduate students, engineers and all others with an interest in the history of machines and mechanisms. We believe that it can inspire and motivate them.

After the review process 40 papers by authors representing 20 different countries were accepted for publication in the proceedings of HMM2012. One glance at the table of contents is enough to see that we succeeded in bringing together an interesting group of people with a stimulating variation in subjects. We are very satisfied with this result and we thank the authors for their valuable contributions and for the efforts in submitting the final versions of the papers in time.

We would like to express our sincere gratitude to the members of the scientific committee: Gerard Alberts (The Netherlands), Hanfried Kerle (Germany), Alexander Golovin (Russia) , Carlos Lopez-Cajùn (Mexico), Jammi S. Rao (India), Lu Zhen (P. R. China), Hong Sen Yan (Taiwan), Thomas Chondros (Greece; Chair of IFToMM's PC for History), Baichun Zhang (P. R. China). Moreover, we would also like to thank the colleagues who helped us in the review process: Jean Pierre Merlet, I-Ming Chen, Emilio Bautista, Juan Ignacio Cuadrado, Teresa Zielinska, Klaus Mauersberger, Agamenon Oliveira, Erwin Lovasz, Ton Klein Breteler, Burkhard Corves, Stephanos Paipetis, Just Herder, Vera Chinenova, John Gal, Pier Gabriele Molari, Junichi Takeno, Juan A. Carretero, Manfred Husty.

We also thank the sponsors of the symposium: IFToMM, the European Society for the History of Science, the Institute for History and Social Aspects of Science of VU University and the Department of Mathematics of the Faculty of Sciences of VU University. Moreover we are very grateful for the support we received from many friends and colleagues at the Faculty of Sciences: Saskia van Es, Cees van Gent, Dick Hoogendoorn, Hubertus Irth, Ger Koole, Frans van Lunteren, Ronald Meester, Andre Ran, Dirkje Schinkelshoek, Maryke Titawano. Without their support we would not have been able to organize HMM2012.

May 2012 Teun Koetsier
Amsterdam Marco Ceccarelli

Introduction

Teun Koetsier

Erewhon

In 1859 a young Englishman, Samuel Butler (1835-1902), immigrated to New Zealand. New Zealand was not an industrialized country, but England was. Shortly after 1800 Britain had become the first industrialized nation in the world. Machine based industry had replaced agriculture as the most important economic activity. The Industrial Revolution had begun in the textile industry, but soon moved to other areas of industry. Steam engines had been introduced. The iron industry grew and with it the coal industry. By 1850 most of England's areas were connected by railroads and in coastal and river transportation steamships had taken over. Butler had witnessed it. In New Zealand in 1863 he wrote a letter with the title "Darwin among the machines". He wrote:

> *"Day by day, however, the machines are gaining ground upon us; day by day we are becoming more subservient to them; more men are daily bound down as slaves to tend them, more men are daily devoting the energies of their whole lives to the development of mechanical life. The upshot is simply a question of time, but that the time will come when the machines will hold the real supremacy over the world and its inhabitants is what no person of a truly philosophic mind can for a moment question. Our opinion is that war to the death should be instantly proclaimed against them. Every machine of every sort should be destroyed by the well-wisher of his species."* (See [7])

Butler's memories of Britain together with his impressions of New Zealand stimulated his fantasy. In 1874 he anonymously published the novel called *Erewhon*. The word 'Erewhon' is an anagram of 'nowhere'. Erewhon is a country, somewhere hidden behind the mountains in New Zealand, where the inhabitants used to use machines but not anymore. The machines have all been destroyed together with all books on mechanics and all engineer's workshops in a war, the war between the machinists and the anti-machinists. The anti-machinists got the victory. After his arrival in Erewhon the protagonist of the novel learns about all this in the City of the Colleges of Unreason. Some machines survived the war, because of the intervention of the professors of inconsistency and evasion. These machines are studied in Erewhon in the way we study long forgotten religious practices.

In this fascinating novel machines are compared to a new life form that is evolving rapidly and threatens to become superior to man. It is argued that there are no good reasons to suppose that they cannot have consciousness. They have started to do things that are very similar to eating and talking. Moreover, they can reproduce. Of course, their reproduction is different from the way mankind reproduces itself. However, in nature there are many kinds of reproduction. The author of the *Book of the Machines* foresaw that the machines would enslave man in the distant future. In Erewhon this had not happened, but a war had been necessary to prevent it.

Butler's book nicely illustrates how the industrial revolutions were perceived in the 19th century. They were seen as revolutions in which machines became omnipresent in society. *Erewhon* is the first novel in which this technological development is taken as a central theme. The book is satirical, but also critical of the ubiquity of machines. Many similar stories would follow. In 1909 Edward Morgan Forster published a story in *The Oxford and Cambridge Review* called "The Machine Stops". In 1920 the Russian novelist Yevgeny Zamyatin wrote the novel *We*. In 1921 Karel Čapek wrote the play *R. U. R. (Rossum's Universal Robots)*. In 1926 Fritz Lang made the film *Metropolis*. Aldous Huxley's *Brave New World* (1932) and George Orwell's *1984* from 1949 were written in a similar vein. For an extensive list see [6]. Although many of such novels and movies reflect a romantic longing for a distant past that is usually idealized and often does not have much in common with the real past, they are great works of art that draw our attention to negative aspects and possible dangers of technological progress.

The Escape from the Malthusian Trap

Of course, there is an entirely different way to look at the industrial revolutions. Instead of emphasizing possible downsides of the proliferation of machines one can also stress their positive effects. The *First Industrial Revolution* took place in the 18th century. In a sense it was the most striking development in the entire history of mankind. Economists sometimes say: The industrial revolutions made it possible for mankind to escape from the *Malthusian trap*. They mean this. Before the Industrial Revolution technology progressed – many examples of useful inventions can be given easily – but the standard of living of the average individual did not really change. Increases in the production of food were always followed by growth of the population leaving the average income per capita unchanged. Mankind was trapped. Yet the industrial revolutions changed it all. Mechanization in combination with the use of fossil fuels made such an increase of production possible that growth of the population could no longer neutralize it. Mankind had escaped from the trap.

Moreover, the First Industrial Revolution, dominated by textile machines, steam engines, iron, coal and the introduction of the factory system, was only the beginning. In the middle of the 19th century it was followed by a new wave of innovations: the *Second Industrial Revolution*. In this revolution railroads, steamships, steel, rubber and farm machines played the central role. The application of the steam engine to transportation had an enormous impact. Steam ships had been limited to coastal shipping because of the impossibility to bunker enough coal. The invention of much more efficient compound engines changed all this. Moreover in the iron industry finally one succeeded in producing steel cheaply. Some other industries emerged in addition to the railroads. The telegraph was invented by Samuel Morse and others. The electric dynamo made it possible to produce electricity. The transformer made long-distance transportation of electricity possible. Electricity could be used in industry. Charles Goodyear invented the process of vulcanization, which made rubber less sensitive to changes in temperature. It no longer became brittle in cold weather and sticky in hot weather. The petroleum industry got started and the chemical industry grew. Agriculture changed, because of new machines and fertilizers. In the industrializing nations production per capita rocketed.

With the First Industrial Revolution mankind seems to have entered an entirely new phase in its history. In the industrialized countries recurring waves of technological innovations pushed up production higher and higher. At the beginning of the 20th century the *Third Industrial Revolution* took place. It involved automobiles, airplanes, electricity, radio, petroleum, movies. The economy and daily life were transformed by the automobile and by the use of electricity. This is the phase in which science began to play an important role in technology. The impact on the way wars were fought was also dramatic. The cavalry was replaced by tanks and aircraft began to play a role. The automobile industry and the aircraft industry received an immense stimulus. In 1938 the United States 3.600 airplanes were built. This number had become 96.000 in 1944 ([5], p. 199). The next wave came in the second half of the 20th century when the *Fourth Industrial Revolution* took place: television, computers, plastics, the Internet and many of us wonder what the next industrial revolution will be like. Although Japan played an important role during the Fourth Industrial Revolution all four of them took place in the Western World. It is probable that in the *Fifth Industrial Revolution* Asian nations will dominate.

The escape from the Malthusian trap has considerably improved the lives of most people in the industrialized nations. And although as for the distribution of wealth worldwide there is much to be desired, technological progress is basically a good thing. This is fortunate because it happens to be an inevitable development. It is something we cannot escape from. It is the human way and if technology creates problems, we can only hope for good government and the development of more technology to solve them.

Machines, the Science of Machines and IFTOMM

In everyday language a machine is an artifact that can be used to assist us in the execution of a specific task. This is a very broad definition. It covers simple tools like a hammer or a can opener, but also an airplane and a computer are machines in this sense. The definition may even be too broad. Is a frying pan a machine, are knitting needles machines? According to the Dictionary [1] of IFToMM , the *International Federation for the Promotion of Mechanism and Machine Science*, a machine is a technical system "built to transform energy or matter or to transfer and transform movement and force in accordance with certain control information" (Translated from the German: "zum Umformen von Energie oder Stoff oder zum Weiterleiten und Umformen von Bewegung und Kraft gemäß zugeführten Steuerinformationen"). IFToMM's definition refers to traditional machines, the machines that dominated during the first two industrial revolutions and continued to play a central role during the revolutions that followed. In IFToMM mechanisms are "constrained system of bodies designed to convert motions of, and forces on, one or several bodies into motions of, and forces on, the remaining bodies". Often, mechanisms are parts of machines. It is not unusual that in a big machine many different mechanisms can be distinguished.

Although attempts to understand and design machines and mechanisms on a scientific basis go back to antiquity, scientific mechanical engineering as an established discipline of great practical importance must be associated with the Third Industrial Revolution. Scientific mechanical engineering was born when mechanical engineers discovered the value of a scientific approach. This started on the continent in Europe with sophisticated and often graphical methods that were used in the design of mechanisms. It took some time before these methods spread to the US. Once they had established themselves there, after World War II they were replaced with the introduction of electronic computers in the 1960s by analytical methods. This led to extremely fertile research programs in mechanism and machine science.

One might have the impression that only during the first and the second industrial revolutions machines played a central role. That impression is wrong. Many machines have become less visible. They have become smaller and less noisy. They have also become more autonomous, needing less people to control them. Moreover, we got very much used to them. Yet, in industry, in construction works, in transportation, in agriculture, in the army, in hospitals and at home, machines are everywhere. Although one does not immediately associate the new technologies in the second half of the 20th century with them, machines and mechanisms continued to play a central role in our interaction with nature. Machines were and are one of the pillars of modern scientific technology and they are, moreover, from an intellectual and engineering point of view challenging. So it is not strange that the Fourth Industrial Revolution was accompanied by considerable interest in the theory of machines and mechanisms. The birth of IFToMM as part of the Fourth Industrial Revolution wasn't accidental.

In 1969 engineers from behind the Iron Curtain, the Western World and some crucial non-aligned countries, got together and founded IFToMM. This is remarkable. IFToMM was founded in the middle of the Cold War. In the 1970s, I had the pleasure of meeting a vice president of a major American aircraft industry. This gentleman by the name of Barton Evans told me he had worked for the CIA in the 1950s and 1960s contacting American scientists who were going to be or had been in touch with colleagues from communist countries. He proudly showed me his copy of *Who is Who in CIA*, a booklet prepared in 1966 and published in 1969 by the Department of Disinformation in Czechoslovakia in order to make life for the CIA harder ([2] and [3]). The name of my CIA agent was in the booklet. Although Evans had not been involved he was sure that the foundation of IFToMM had been surrounded by considerable CIA and KGB interest and briefing and debriefing from all sides. Right from the start IFToMM was in every respect an international organization. The USSR, Bulgaria, the German Democratic Republic, Hungary, Poland and Rumania represented Eastern Europe. The West was represented by the USA, Australia, the German Federal Republic, Italy and the United Kingdom. India and Yugoslavia were the non-aligned countries. On the other hand, big parts of the World were not represented. Right now IFToMM has 48 member organizations. The Ibero-American community is represented and so is Asia. The organization has grown but, inevitably, it has also changed its focus. In the 1960s, for example, classical kinematics of mechanisms remained a core discipline. In the past 50 years fast computing, sophisticated software and new applications have changed the theory of machines and mechanisms. Mechanical engineering has always been a multidisciplinary activity, but the number of disciplines involved has only grown. Kinematics, dynamics and gearing are classical subjects but the computer has changed them. We now have, for example, computational kinematics, multibody-dynamics and tribology. Really new subjects are robotics, mechatronics and micromachines.

IFTOMM'S Permanent Commission for History

The history of Mechanism and Machine Science is part of the history of science and technology. The word *technology* was coined by the German Johann Beckmann (1739-1811). He used it for a description and classification of all the existing crafts and methods of manufacture. The 1971 edition of *Webster's Third International Dictionary* says that technology is "The science of the application of knowledge to practical purposes". Definitions and distinctions are useful. However, it is difficult to draw a sharp border line between practical problems and non-practical problems. Basically a practical problem is a problem that requires some action outside of the study or the laboratory. In this context it makes sense to distinguish *knowledge-how* from *knowledge-that*. *Knowledge-how* is related to functionality; it concerns what should be done to reach some goal. We know how to get somewhere, how to do something, sometimes without even knowing why the method works. *That is knowledge-how*. Technology is or concerns always *knowledge-how*. *Knowledge-that* is related to truth; we know that something is the case, nothing more, nothing less. It may be completely useless. Pure science is *knowledge-that*. It is the multidisciplinary character of Mechanism and Machine Science in combination with the fact that it encompasses both knowledge-that and knowledge-how, which has led to a situation in which the history of machines and mechanisms and the scientific theories related to them is not often studied in its own right. Obviously historians of science are interested in the history of machines, but usually only in so far as it concerns mathematics, physics or one of the other sciences. On the other hand, historians of technology tend to concentrate on what machines can do and discuss their economic, social and cultural impact. Although such work is very valuable, the focus is usually not on machines and mechanisms in its own right. That is where IFToMM's Permanent Commission (PC) for History is filling a gap. The commission was established in 1973 because of the strong support from the first IFToMM President, the impressive Ivan I. Artobolevskii from Russia. In the PC for History almost all nations participating in IFToMM are represented. In the course of time the PC has been chaired by Jack Phillips (Australia), Elisabeth Filemon (Hungary), Teun Koetsier (The Netherlands), Marco Ceccarelli (Italy), Hong Sen-Yan (Taiwan) and Hanfried Kerle (Germany). The present chair is Thomas Chondros (Greece).

Originally the PC primarily dealt with the institutional history of IFToMM but in the course of time it broadened its scope. Now, the activities of the commission cover all aspects of the history of machines and mechanisms and the theories dealing with them. I think this is a very good thing. Given the central role of machines and mechanisms in the development of technology their history indeed deserves special attention.

This Volume

The 38 chapters of this volume nicely illustrate the activities of IFToMM's PC for History. Most of the authors are engineers and not professional historians. Modern professional historians of science and technology put great emphasis upon understanding the actual historical development, while many of the authors in this volume deal with what is sometimes called "heritage": they look at the past as modern engineers. What happened in the past from an engineering point of view? is for them the central question. That in itself leads to very interesting results. It leads, for example, to the possibility of a modern analysis of an ancient machine or the application of modern design methodology to answer the question what kind of machine could have been built in the past.

It is interesting to view the contributions in this book against the background of the big history of mankind. In his extremely well written *Why the West Rules – For Now* [4] Stanford historian Ian Morris describes the history of mankind as a race between the East and the West. After the last Ice Age the so-called "Hilly Flanks" in an arc shaped area covering parts of Iran, Turkey, Syria and Israel was in an extremely favorable position. By 10.000 BC the possibility of the domestication of plants and animals had been discovered there. The cereals that would develop into wheat and barley grew there abundantly and the climate was suitable for agriculture. The West, defined broadly by Morris, took the lead. The East followed two thousand years later. In both the East and the West social development took place along similar lines. In the course of time big agricultural empires developed. A major step forward was the transition from kingdoms that functioned on the basis of relations between the members of the elite to so-called high-end states in which taxes were raised and professional bureaucrats and soldiers represented the state. In this respect the Roman Empire in the West can be compare to the empire of Qin Chi Huang Ti, the emperor whose grave in Xi'an is protected by the well known army of terracotta warriors. Rome started as a city in Italy and became a superpower in the 2nd century BC. Qin was a small Chinese state, but it conquered its last enemy in 221 BC. At the time the West went ahead as for social development. However, in the last centuries of its existence the Roman Empire entered a period of decline which created an opportunity for the East. Things were different in the East. In the 6th century the East took over the West. When Marco Polo visited China in the 13th century everything about China amazed him: in many respects he faced a superior civilization. This supremacy would last until the 18th century when in the West the First Industrial Revolution started. The West bounced back and in the 19th century it took over most of the world.

Yet, as we know, in the 20th century things started changing. The West still rules. For how long, however? Morris argues that in order to understand social development in the past and in the future geography is a crucial factor. The domestication of plants can only be discovered if the geographical circumstances are favorable. Morris explains the fact that the Industrial Revolution took place in the West and not in the East also in terms of geography: the West was favorably positioned in order to discover America, which had in many different ways an enormous impact, Together with other geographic factors like the availability of coal in England this led to the First Industrial Revolution.

The present volume on the history of machines and mechanisms consists of six sections. In Section I the emphasis is on the role of institutions. Section II is devoted to primarily biographical contributions. The Sections III, IV and V are on mechanical systems. Section VI is devoted to papers on concepts and theories. If we consider the book against the background of Morris' big history, most of the 38 chapters in this book are understandably clearly directly related to developments in the West. They concern the industrialized nations in the 19th and 20th centuries. There are, for example, contributions on the history of MMS in German, Russia, Spain, France Italy, Romania, Mexico, Serbia and England. Yet several contributions refer to the wider context. Kuo Hung-Hsiao and Hong Sen-Yan apply a modern design methodology to an ancient Chinese cross bow. Section II starts with a paper by Nam Moon-Hyon that nicely illustrates the technological potential of the East in the 15th century. He discusses the Korean Chief Royal Engineer Jang Yeong-sil, who designed a complex water clock.

Several chapters in the book are devoted to Greek and Roman culture. In section III Finlay McCourt studies mechanisms of movement in Heron of Alexandria's work. In this same section Junich Takeno and Yoshihiko Takeno attempt to unravel the mystery of the defense chain that once protected Constantinople. Section IV starts with a paper by Michael Wright on the Antikythera mechanism, an unbelievably complex planetarium from the second century BC. In the last section Giuseppe Boscarino compares the epistemological status of concepts in Aristotle and Archimedes. Such papers demonstrate unique aspects of Western culture. The East never developed anything comparable to Greek mathematics and astronomy. This is a significant point. Could the first industrial revolution have taken place in the East? Morris argues that in the 11th and 12th centuries such a revolution was brewing in Kaifeng, at the time a very big and prosperous city. Momentous changes took place there, in the textile industry, in coal and in iron works. Yet, the development didn't continue. In the 15th century huge Chinese Treasure Fleets explored the Indian Ocean, but they did not cross the Pacific; geographically China was positioned less favorably with respect to the Americas than Europe. At certain moments China consciously rejected Western culture. In section I Michela Cigola describes the role of the Jesuits in the spreading of mechanical knowledge from Europe to China in the 16th and 17th centuries. That is the period in which the East was still superior. In some respects Jesuit astronomical knowledge was clearly superior to Chinese astronomical knowledge, but the Chinese emperor felt he did not need Western science.

One of the crucial elements in Western culture that did not have its Chinese counterpart is the clockwork model of nature. Western philosophers like Descartes realized that it was not necessary to consider nature as a living organism. One could view it as a machine and understand its functioning from this extremely fertile point of view. Several chapters in this book are on the Western tradition of automata and clocks. The clockwork model of nature was a crucial element in the Scientific Revolution in the West and is clearly linked to the development of mathematics during and after the Renaissance. Western culture had at the time one great asset that the East did not have: the Greek scientific heritage. The question why the Industrial Revolution did take place in the West and not in China is not a simple one. Geographic factors were certainly important – Morris is right there - but it seems highly probable that essential elements in the Western cultural tradition, that go back to the Greeks and include a theoretic interest in machines, also played a role. At this point the work of Margaret Jacob must be mentioned. See [8]. She did show how the Scientific Revolution, which was influenced decisively by Greek culture, had in its turn a cultural impact that in a subtle way contributed to the First Industrial Revolution.

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Section I

History of Institutions

A Social Network Model for Innovation in Early Aviation History

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Abstract. Using data from many historical studies of early aviation, we present evidence that early advances in aviation were the result of an evolving social network with more than eighty nodes and over three hundred links. The node-link distribution is shown to be similar to a scale-free, power law behavior, characteristic of modern social networks such as the World-Wide-Web. This study suggests that technical innovation and invention in the late nineteenth and early twentieth centuries flourished through complex social networks commonly assumed to be unique to the twenty-first century.

1 Introduction

Historians of science and technology have long made a narrative case for the evolution model for scientific and technical innovation. As early as 1929, the historian Abbott Usher wrote; "The more serious recent literature (c.1929) on the theory of invention recognizes the necessity of presenting invention as a cumulative synthesis of a relatively large number of individual items." More recently the aviation historian Anderson (1993) has presented narrative evidence that there were many developments in the science and technology of flying machines before the Wright brothers advances (1899-1904) and it would have been only a matter of one or two years before someone else would have created a controllable flying machine. Our goal in this paper has been to assess the role of social networks in invention and innovation in technology as well seek similarities between late 19th century historical networks and modern day social networks. This example is also a test case for exploiting the techniques of complex network theory for relatively small network node sets. (Barabasi 2003, Newman 2003, Watts 2003).

In this study we have culled a number of classic histories of aviation beginning with Chanute (1893), Gibbs-Smith (1954), Crouch (1981) and Anderson (2004), and have created an influence matrix establishing links between approximately eighty nodes spanning the period 1810, the time of George Cayley's writings on flying machines to 1910 the year of the great international aviation meet in Belmont Park in New York City.

For the reader not familiar with the history of aviation, there were a dozen major players in the evolution of flight technology, ten of whom are listed here;

T. Koetsier, M. Ceccarelli (Eds.): Explorations in the His. of Machines & Mech., HMMS 15, pp. 3–19.
springerlink.com

George Cayley: {1809-1850} Early writings on the topology of aircraft;
Gottlieb Daimler; {1875-1900} Developed Otto's four-cycle engine into a lightweight engine for flight.
Otto Lilienthal; {1898-1896} Experimented with monoplane and biplane gliders;
Samuel Langley: {1898-1903} Measured lift and drag and built powered models;
Octave Chanute; {1898-1906} Published review of the world's research as well as built classic biplane glider;
Orville and Wilbur Wright; {1899-1910} Built and flew the first controllable human carrying aircraft;
Alberto Santos-Dumont; {1900-1906} Built flyable aircraft in Europe;
Gabriel Voisin; {1903-1910} Designed and built aircraft for many aviators;
Louis Bleriot; {1905-1910} First to fly the English Channel;
Glenn Curtiss: {1904-1910] Developed lightweight engines and fast planes as well as built the first seaplanes.

These principals were linked by a historical network of more than seventy other individuals and institutions.

2 A Social Network of Early Aviation

'H*istorical innovation networks'* consist of a set of persons [inventors, scientists, artisans], organizations [e.g. universities, Royal Societies] and social events such as international expositions, each of which is called a *node*. This collection of nodes has inter-nodal connections called *links* (or edges). Links between person-nodes are created by friendship, letter exchange, writings, books, and financial interest, to mention a few. Links between person-nodes and organizations involve membership, professorial appointments, education of students etc. Connections between event nodes and person-nodes are created by attendance or by proceedings etc.

Each link is either directional or bidirectional. For example links between nodes in different generations are unidirectional. Thus Lilienthal could influence the Wright brothers but they did not influence Lilienthal because he died in 1896 three years before the brothers became interested in flight (1899). In social network theory, nodes can have attributes called *fitness,* which measures the importance of the node or link. For example the Wright brothers would be a high fitness node as would be Lilienthal. Unlike social networks such as the World Wide Web, or *Facebook*, a history network spans generations linking person-nodes living in one generation with dead person-nodes in an earlier generation. In a history network, nodes can be connected across generations. Historical Innovation/Invention Networks [HIN] also evolve as new nodes are added and new links are created between new players. In HIN, there can be *sub-networks* that can focus on a specific component; e.g. in aviation one can focus on lightweight engine evolution, or the wing design as well as the underlying aerodynamic theory development.

The difference between a pure narrative history and a history network theory, is that in the latter, the historian is obliged to determine if there are links between all of the nodes in the network. Thus if a new node (player) is mentioned, it's links to all the other nodes must be established. The analysis in this paper uses an influence matrix (Figure1), a network graph (Figure 2) and an event-node timeline graph (Figure 3b).

An overall picture of early aviation network is shown in Figure 2. For print legibility, only about 60% of the nodes are shown and about 50% of the links. Even at this level one can see a significant complexity in this network. Not shown here is the directedness of the links nor the fitness or weighted value of the nodes and links. Lists of person nodes, association nodes and university nodes are given in Appendices I, II, III respectively.

Node	Cayley	Lilienthal	Chanute	Wrights	Bleriot	#Links
Cayley	X	1	1	0	0	2
Lilienthal	0	X	1	1	1	3
Chanute	0	1	X	1	1	3
Wrights	0	0	1	X	1	2
Bleriot	0	0	0	1	X	1

Fig. 1. Sub-matrix of Influence Links; Rows are the source nodes and columns are the dependent nodes. The "link" column sums the number of influence links for a given source node.

The data in Figures 2 was obtained from an influence matrix M[NS, NT] where NS are the source nodes of the influence and NT are the terminus nodes of the directed influence links. Thus Cayley is an NS link for Chanute, while Chanute is a source node for the Wright brothers. The matrix M is 80 x 80 nodes and the entries are not weighted and contain only zeroes and ones. [See Figure 1.] In general node-pairs that were contemporary were assigned both outgoing and incoming links; it was assumed that each influenced the other. Earlier generation nodes connecting later nodes were assumed to have only outgoing links. A more detailed HIN would include weighted, as well as directed links. One could also scale the importance of the nodes with respect to the advance of the technology, however we did not attempt to assign a node scale in this study. An example of a sub-influence matrix is shown in figure 1.

The top of the graph in Figure 2 dates from 1810 with George Cayley as a node. The lower middle section around 1890 has Otto Lilienthal and Octave Chanute as major nodes and the lower part of the graph dating from 1900 to 1910 has nodes for Orville and Wilbur Wright in the US and Gabriel Voisin and Louis Bleriot from France. The reader can find a list of short biographies of most of these nodes in Longyard (1994).

Also shown in this graph are a few institutional nodes such as the Aeronautical Society of Great Britain [later the Royal Aeronautical Society] founded in 1866, the Technische Hochschule Berlin, where Lilienthal attended, Cornell University in upstate NY where a number of secondary but essential nodes where associated, and the Smithsonian Institution, where Langley was Director and from whom the Wright brothers obtained their early information. [See e.g. Mackersey, 2003.]

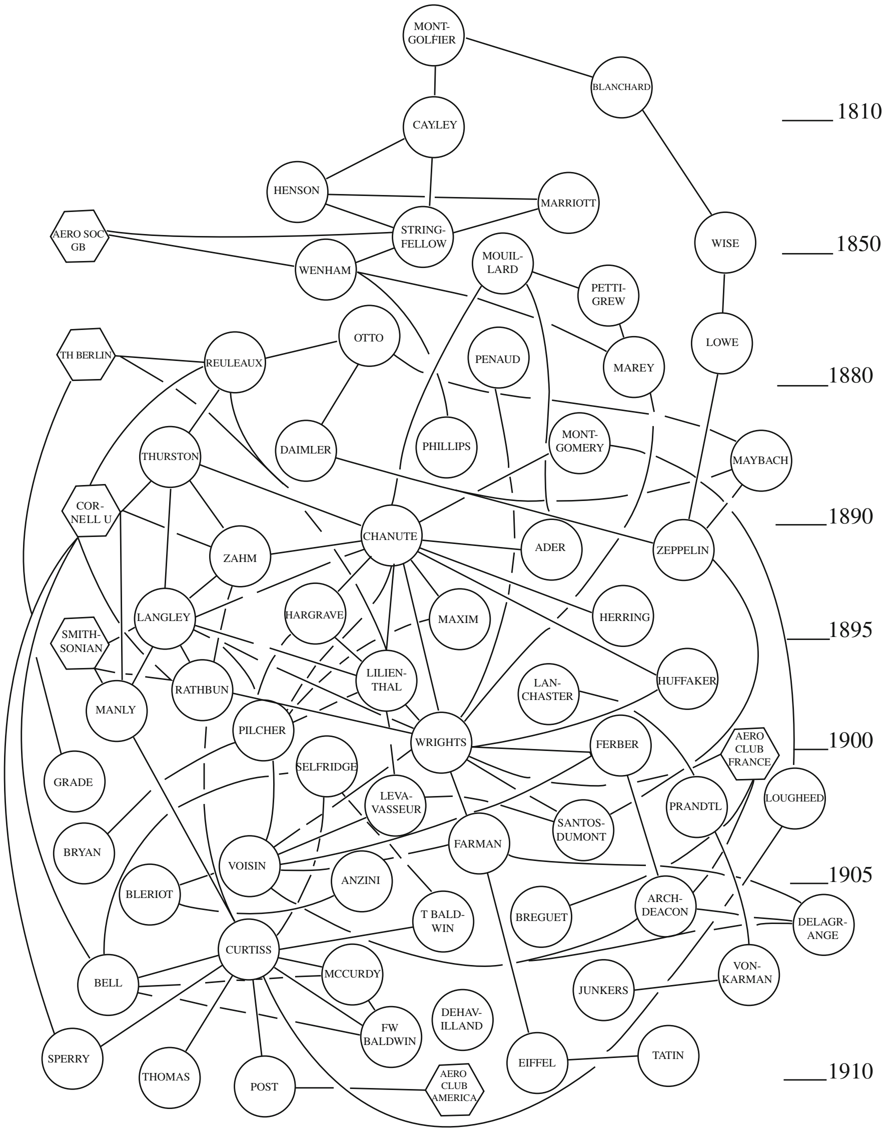

Fig. 2. Partial aviation network of innovator nodes and selected links, including four institutional nodes, for the period 1810-1910. Directional nature of the links is not shown. Most ballooning innovation nodes are not included.

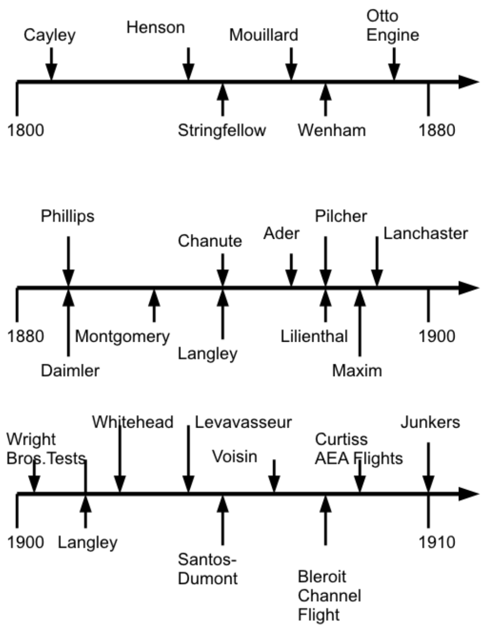

Fig. 3. a. Selected aviation events timeline, 1800-1910, showing increasing density with time.

This network includes only a few ballooning nodes. A ‘lighter-than-air’ machine network would show similar complexity to that for ‘heavier-than-air’ machine development. However a number of ballooning nodes are included in the network of Figure 2. Cayley, it was written, was inspired by the ballooning exploits of the Montgolfier Brothers. Also, the American balloonist T. Lowe mentored Zeppelin. Zeppelin later employed a Daimler engine in his dirigible that led to lightweight engines for ‘heavier-than-air’ machines. Similarly, the American balloonist, Thomas Baldwin used a Curtiss motorcycle engine in his dirigible that brought Curtiss to the attention of Alexander Bell.

Another measure of the progress of heavier-than-air development is a plot of the growth of event nodes with time, shown in Figures 3a,b below. The addition of new nodes shows the beginnings of exponential growth several years before the seminal year of 1903 in which the Wright brothers demonstrated a controllable flying machine.

One commentator on the dual slope result of Figure 3b, suggested that the low slope growth reflects the “passion years” of aviation and the steeper slope the emergence of the “profit years” through air meet prizes and aircraft sales.

One can also associate with many of the nodes the creation of actual flying machines. A plot of the growth of engine-powered flying machines in the period 1900-1915 is shown in Figure 4 using data from Jane (1917) *All the World’s Flying Machines.* This illustrates the fact that, although the Wrights did not fly publicly until 1908 in Paris, the world’s knowledge base in aviation science and technology was ripe by the turn of the century enabling the creation of dozens of aircraft in a half dozen nations.

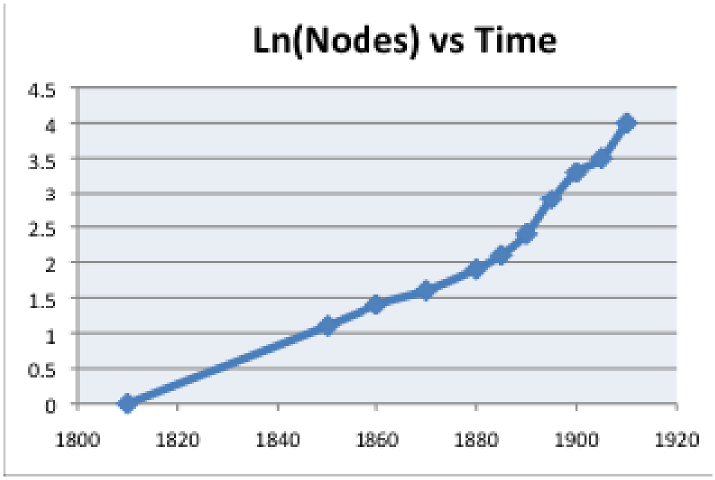

Fig. 3. b. The growth of aviation innovator nodes vs. time showing periods of different exponential growth.

Modern network analysts usually try to measure the degree of connectedness by plotting the distribution of nodes and links. [See e.g. Watts 2003, Barabasi 2003] Using a data base of 66 nodes and over 300 links, the distribution of number of nodes N(k) with 'k' links for our early aviation network is shown in Figure 5;

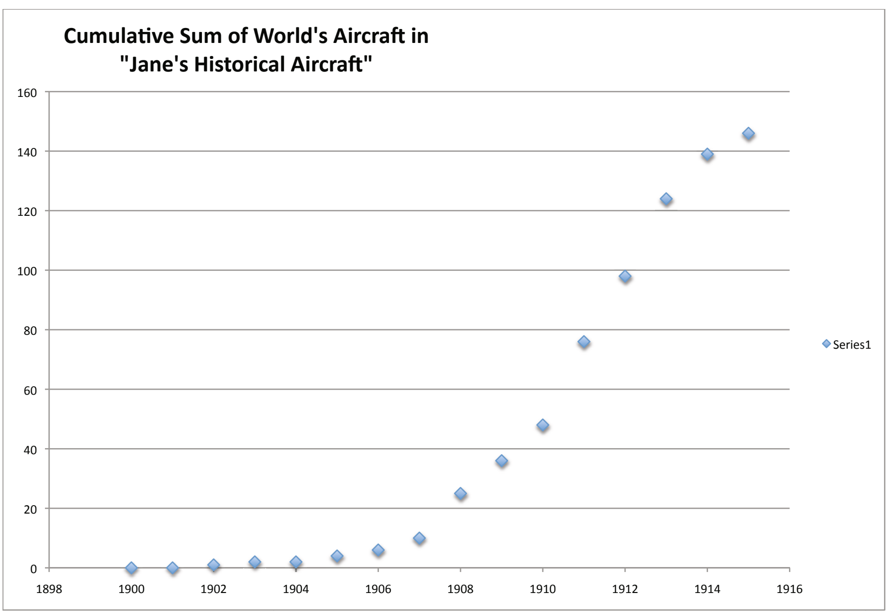

Fig. 4. Growth of flyable human carrying aircraft in the post Wright brothers era. From Jane (1917).

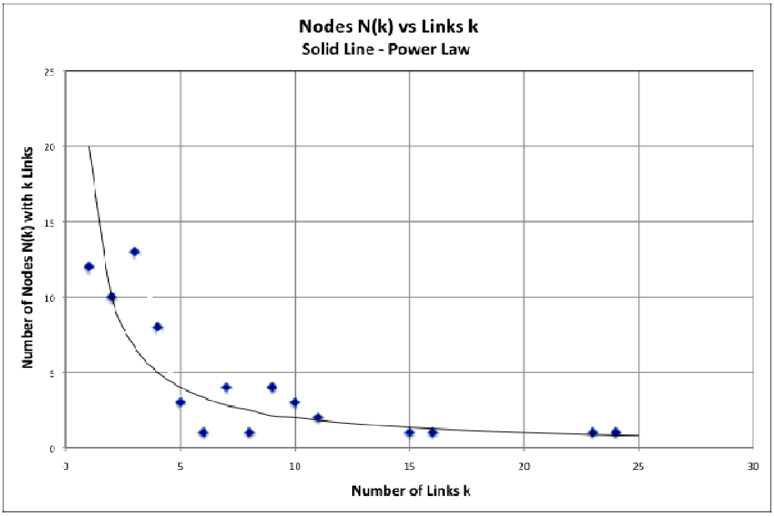

Fig. 5. Distribution of number of nodes N(k) with 'k' links for the aviation network in Figure 1. Solid Line; Power law fit N(k) = 20/k, for the data in Figure 5. Number of nodes = 66 and number of links = 320.

3 Discussion of Results

The nature of modern networks such as airports in the US or the World-Wide Web, has been characterized as scale-free networks [See e.g. Watts (2003), Barabasi (2003)] in which a small number of nodes have the majority of links and the majority of nodes have a small number of links. This behavior seems to be similar to the early aviation network of Figure 2. The two largest nodes are the Wright brothers and Octave Chanute with 24 and 23 links respectively. The Wrights influence is understandable. However, Chanute's role as one of the most important nodes in the aviation social network is largely ignored in popular histories except that of serious aviation historians. [At this writing the author could not find one biography written on Chanute] Chanute was a retired civil engineer who communicated with almost all the principals in early aviation, including hundreds of letters between him and the Wright brothers (MacFarland, 1953). Chanute also wrote definitive essays on flying machines in 1893, a decade before the Wright's successful flights.

A sub-network centered around Octave Chanute is shown in Figure 6. Here we include more detail but we omit links to other nodes outside Chanute's influence.

The Chanute sub-network in Figure 6 shows much greater detail but does not contain links outside Chanute's influence circle. The graph has a more 'star'-like shape. When this graph is sewn together with other sub-networks, such as the Wrights or the French aviators, the overall network has the complex qualities illustrated in Figure 2.

The two next largest nodes are Otto Lilienthal (1899) [who died in 1896 in a glider test] and Samuel Langley (1911) with 16 and 15 influence links respectively. Both innovators had published articles and books on flying machines that served to extend their influence. Although Langley's 1903 machine did not fly, he had performed careful experiments in the early 1890's and had succeeded in creating large unmanned engine-powered flying machines in the late 1890's that gave encouragement to the growing number of inventors and would-be aviators.

Further down the list in Appendix I are Lawrence Hargrave and Robert Thurston with 10 influence links. Although Hargrave worked in Australia, he belonged to a local scientific society and published more than a dozen papers on flying which he sent to others in Europe and North America including Robert Thurston of Cornell.

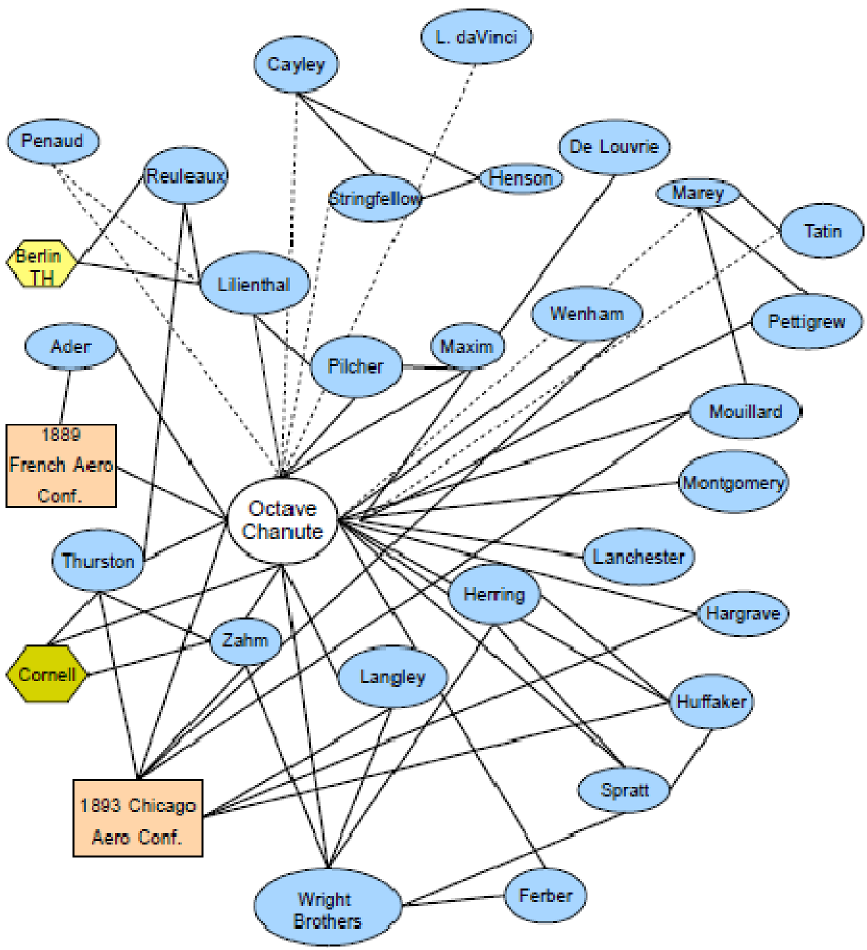

Fig. 6. The Octave Chanute sub-network spanning 1800-1905.

The Thurston node is an example of an enabling node – one that is not a principal contributor [he presented a paper on "materials of aeronautic engineering" at Chanute's 1893 Chicago Conference] but one that linked important players together. Thurston was an expert on the steam engine and thermodynamics and taught at the US Naval Academy and Stevens Tech before coming to Cornell in 1885. Thurston invited Octave Chanute to Cornell in 1890 to lecture on aerial navigation when Chanute was worried that he would be ridiculed for speculation about flying machines. Alfred Zahm (1911) was Thurston's student who attended these lectures and graduated from Cornell in 1892 and convinced Chanute to organize an international conference on aerial navigation in 1893 at the Columbian Exposition in Chicago. Around 1900, Thurston was asked by his friend Langley to recommend a Cornell engineer for the scale-up project of Langley's flying models and Charles Manly took the job. Thurston was a friend of Alexander Bell who was also a Cornell lecturer. Bell later organized the Aerial Experiment Association in 1907 out of which came Glenn Curtiss's 'June Bug' machine. (See e.g. Curtiss and Post, 1911, Hatch 1942) Thurston also had links to the Berlin nodes of Reuleaux and the engine nodes in Germany. Finally William Durand was a younger colleague of Thurston at Cornell who would later go to Stanford and start propeller research and head up the new National Advisory Committee on Aeronautics in 1914.

Association, Print Journals

In addition to individual human nodes, there were institutional nodes such as Cornell University and the Smithsonian Institution. Cornell was the site of Chanute's 1890 lectures on 'Aerial Navigation' that were subsequently published in Cornell's Sibley Journal of Engineering. Cornell's Charles Manly was the engineer and pilot for the Langley machine. Also Albert Francis Zahn, a Cornell grad of 1892, was instrumental in helping Chanute organize an international conference on aviation at the Columbian Exposition in Chicago in 1893. Elmer Sperry, who developed a gyro controller for later aircraft, also attended Cornell around this time. Lionel Marks another Cornell grad taught at MIT and wrote a textbook on aircraft engines.

There were other institutional nodes such as the Aeronautical Society of Great Britain founded in 1866 or the Aero Club de France and many of the Ivy Colleges had glider 'aero' clubs in the eastern US before WWI, including Cornell University. [NY Times, June 1, 1913] See Appendix II for a list of early aeronautical societies, as well as Figure 7. Some of these aeronautical associations were focused on ballooning as well as heavier that air flight. However as the list in Appendix II shows, there were hundreds of members in these aero clubs who helped spread the word that human flight was not only possible but was close to reality at the turn of the 20th century.

Other nodes, not shown but equally important, were journals such as *Scientific American*, the *American Engineer and Railroad Journal*, and *Means Aeronautical Journal* to mention a few in the United States and *L'Aerophile* in France. Another transient node class were international meetings such as one held in France in 1889 to which Chanute attended and the 1893 conference in Chicago that Zahm and Chanute

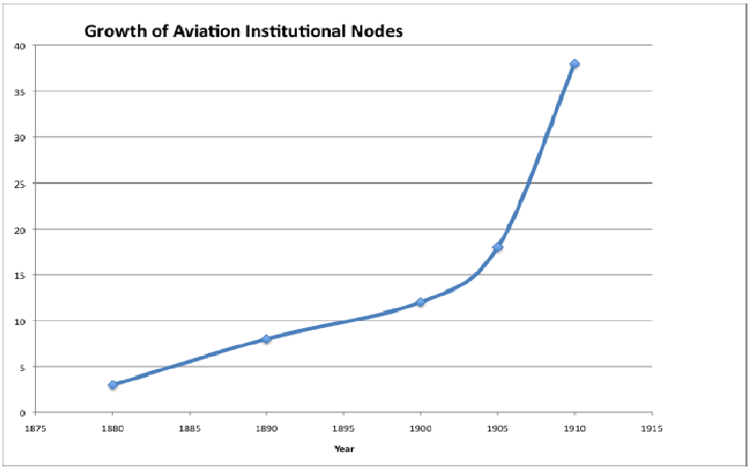

Fig. 7. Growth of Aviation Related Institutional Nodes [See e.g. Moebedeck 1906]

organized. [Third International Conference on Aerial Navigation] Chanute's linguistic ability in French and English also helped spread the news of US progress to Europe as well as interpret research from such obscure nodes as Louis-Pierre Mouillard in French controlled Cairo, Egypt.

The Gas Engine Sub-Network

Often forgotten in the history of flight is the development of the gasoline engine, which would certainly be labeled an *enabling technology* for heavier than air machines. A sub-network for gas-engine development would show similar complexity as in Figures 2, 6. Non-steam engines have origins in the work of the French Lenoir engine and the German Otto-Langen gas engine, both shown at the Paris Exposition in 1867. [Langen was a friend of Reuleaux in Berlin, who had connections to Cornell.] Otto set up a US subsidiary *The Otto Gas Engine Works* in Philadelphia in 1878 after exhibiting the engine at the 1876 Expo in Philadelphia. Daimler worked for Otto before setting up his own business with a subsidiary business in New York City. Later Daimler made a lightweight engine for Zeppelin.

By the time of the Wright brothers powered flight, the gas engine and the gasoline engine had entered the knowledge base of workshops all over the industrial world, making it difficult to trace the influence path from Otto to the Wrights. In *Scientific American* of 1900, one can find advertisements and articles about gasoline engines from Otto, Daimler, Charter, Webster, Olin and Olds, all in the United States to mention a few. In Buffalo there was the E.R. Thomas Co. making engines, automobiles and motorcycles. Curtiss bought engine castings from Thomas. The development of the internal combustion engine had reached beyond the 'tipping point' or avalanche stage of technology making it difficult to create an accurate influence network.