

# Open Technology and the Early Airplane Industry

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**Abstract.** It took a century from the first fixed-wing airplane design about 1800 before a piloted airplane flew a controlled flight. An industry began quickly after that point. Participants in the slow and painfully uncertain development of the first airplanes often followed what we call here *open technology practices*. Like scientists or open-source programmers, they generally shared information without cost or burden as they tried to make progress. They produced thousands of publications, joined into clubs, exchanged letters and visited one another. Many also filed patents but did not apparently earn license fees. Thus the first airplanes were built on the basis of knowledge that was mainly in the public domain. By 1908 an infant industry was beginning, with on the order of 25 new firms a year. This paper illustrates (in a preliminary way, in this draft) that the new entrepreneurs, investors, and designers were a different set of people from the earlier experimenters. The transition may be analogous to those of other new-technology industries.

## Introduction

For thirty years before functioning airplanes appeared, there was serious discussion about how to design them. Over time, basic design ideas became established on how to make a fixed-wing, heavier-than-air powered glider that could carry a person on a controlled flight. Hundreds of experimenters, theorists, and other authors contributed to the relevant literature. New participants found there were journals, books, and clubs available to them, and they were never short of curious visitors. The open literature and the culture of curiosity and sharing contributed to technical progress, as experimenters

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were able to work from previous designs. This paper explores how the sharing of information among the early experimenters, hobbyists, and scientists led to the invention and subsequently the industry. This case exemplifies the recurrent phenomenon of *open-source innovation*, in which technological progress depends largely on information that is not secret and not proprietary.

Experimenters communicated actively and linked up across borders. By the mid-1890s, the active participants were aware of many other experimenters and their writings refer to work by others more often than before. Influential experimenters of that time were familiar with this literature and they imitated prior designs. Many distinct “firsts” followed, including controlled powered glider flights by the Wright brothers in December 1903 and by Alberto Santo-Dumont in 1906. Major public exhibitions occurred in 1908 and scores of startup companies began in short order.

A staggering amount of original documentation and historical research is available on the developers of early airplane technology and their precursors. *A Bibliography of Aeronautics* (Brockett, 1910) lists more than 13,000 publications related to aircraft before 1909, principally from France, Britain, Germany, and the U.S. In these same countries, hundreds of patents were filed for aircraft in the nineteenth century, and hundreds of airplane-manufacturing establishments started before the First World War. From various sources we have beginning databases of this information.

One useful frame of reference is to envision the information that was available to the early twentieth-century inventors of working airplanes. The Wright brothers, for example, read key works by Otto Lilienthal, Samuel Langley, and Octave Chanute. Chanute’s 1894 survey book on the developing field of aerial navigation, called *Progress in Flying Machines*, defined the field for many. We can trace some of the knowledge that was available to the Wrights and their contemporaries, where it came from, and the networks of innovators who produced it.

This sharing of information by aircraft experimenters has several parallels to open source software development. These attributes characterize open source innovation:

- Contributors were autonomous and geographically dispersed, with diverse objectives and projects;
- Contributors were drawn to the activity because of the appeal and potential of the technology, not because of connections or similarities to the other participants;
- Contributors routinely shared inventions and discoveries openly without explicit exchanges or payoffs;
- Some contributors found formal intellectual property institutions detrimental to inventive progress.
- Organizers, writers, and evangelists had roles beyond technical experimentation. They ran clubs, journals, contests, and other events. They introduced people to one another and encouraged them.

Similar dynamics have occurred in other cases. Creative experimenters and hobbyists have advanced other technologies, in the computers, software, and online fields for example, to the point that entrepreneurs could start businesses on the basis of open new technology. The open-source innovation dynamic sometimes outperforms the research and development mode in which the researchers are hierarchically authorized, funded, equipped, and motivated by explicit rewards. Open-source innovation seems to matter most in fields where technological uncertainty is greatest. There is no established general economic model of open-source innovation, but data on the gradual invention of the airplane helps provide microfoundations for such a model.

## **Open technology practices**

The idea of open technology practices is meant to characterize the individual behavior of people who are trying to achieve technical progress but not particularly to take ownership of the advances. We see these kinds of behavior on open source software projects, in universities and other scientific institutions drawing from a history of "open science", and from computer and software user groups (Haigh, 2007) and analogous societies for other historic technologies. The motivations can include the career advantages of publicly establishing one's competence and capability through public review and publication. (David, 1998; David, 2000; Levy, 2001). In the open source software situation a variety of specialized tools support the activity such as public source code control systems.

These practices tend to support development of technologies across dispersed locations, a culture of helping the community, and an open exchange of ideas (BLS, 2008).

- The participants allow their designs and source materials to be discoverable and open to inspection. They do not create barriers to new participants, who are therefore able to participate.
- The participants are the users of the product. The project is organized and designed by people who want the product and who can do the work. Individuals choose what to build, and "buy in".
- Source materials and resulting products evolve iteratively. With success, an expanded range of users find the design or source material to be of interest, or useful.
- Participants find some collaboration to be useful and share work and information across organizations or hierarchies, not only within them. A community or interest group evolves organically; these are sometimes now called communities of practice. The work team is not chosen entirely in advance, nor is it chosen exogenously, but rather emerges and evolves over time. Participants encourage one another, partly because it must be encouraged for it to continue; there is no extrinsic reward.
- Participants work separately on small portions of a project; projects are modular.
- Participants usually start only small projects.

- Successes and standards emerge, rather than being authorized hierarchically. Open technology practices facilitate emergent or opportunistic progress because a number of people develop a view of what works for them. It may well not be possible to foresee the relevant dimensions of success and failure under conditions of great technological uncertainty; planning may not work, and a formal requirements specification is not likely to be helpful. Some discoveries are serendipitous.
- Participants may often duplicate one another's work; decentralized development can result in failure of coordination, lack of knowledge, or lack of trust.

These are abstractly phrased with the thought that a microeconomic model could mimic them without including details of the technology. They are meant to apply to open source software, the design of early microcomputers, and to early aeronautics. These practices would not work for technologies that require central planning because (for example) the subunits depend too tightly on one another: dispersed workers following their own imaginations and applying open source practices would not likely be able to succeed in making a cathedral, a rocket ship, or an atom bomb.

## Nineteenth-century aeronautical developments

Modern airplane designs are traceable back to George Cayley's visions of fixed-winged aircraft around 1800.<sup>2</sup> The fixed-wing idea is an important departure from the more natural and recognizable mechanisms of birds and balloons. Aircraft with flapping wings ("ornithopters"), though intuitively appealing, were flimsy, underpowered and difficult to construct.<sup>3</sup> Balloons could not be made to move quickly or in directionally controlled ways. It turned out to be more practical in engineering terms for fixed wings to provide lift while speed was provided in some other way -- from a human, an engine and propellers, or, in a model, wound-up rubber bands. Separating the speed-generating system from the lift-generating system turned out to be an essential design idea.

Ballooning clubs promoted discussions on aerial *navigation*, which often meant a focus on fixed-wing, heavier-than-air designs, and new clubs with this orientation appeared. At least a dozen such societies were founded in the nineteenth century. Important ones included the Aeronautical Society of Great Britain, the Société Française de Navigation Aérienne, and the Aéro Club de France, with up to 400 members by 1865.<sup>4</sup> The societies or clubs were linked to regular journals of which the most important to aerial navigation were *L'Aéronaute* and *L'Aérophile*. A research assistant and I have

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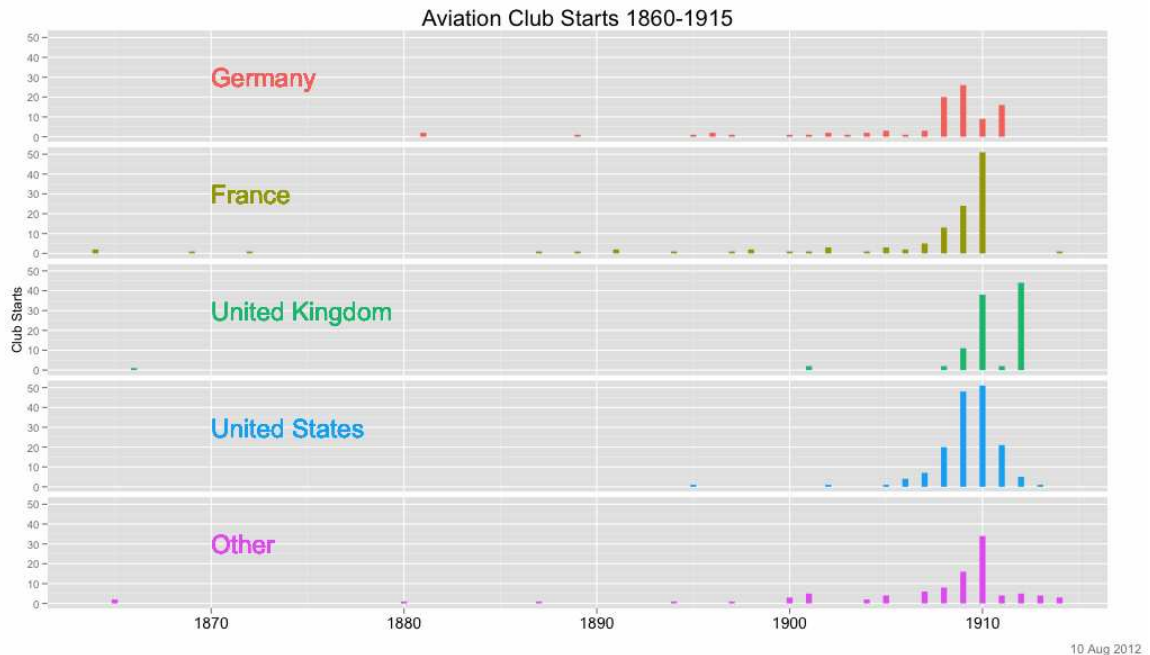
<sup>2</sup> Gibbs-Smith, 1962. Cayley's attention was drawn to aircraft by the recent success of balloons and the first helicopter designs.

<sup>3</sup> Cayley used flapping wings for propulsion but not for lift. Several experimenters were convinced by evidence that flapping wings could not be as efficient as fixed ones. This is confirmed by later aerodynamic science. Other metaphors existed, such as rockets and helicopters, but these were not central to the fixed-wing discussion. The line of thought that turned out to work proceeded from kites, to gliders, to powered gliders.

<sup>4</sup> Marck, 2009, p.37.

collected information on many of these clubs. There were dozens of them even by the 1890s and the number explodes after feasible airplanes have flown.

**Chart 1. Count of newly starting aeronautics-related clubs, from eclectic sources**



Key innovators in this period include Alphonse Penaud, Louis Mouillard, Lawrence Hargrave, Samuel Langley, Otto Lilienthal, and Octave Chanute. These were self-motivated men, coming from a variety of backgrounds and locations. They did not have a joint plan. They did not have the same vision of what they were trying to make, although some aspects of the basic design was similar.

Hargrave’s thinking offers a useful example of the thinking behind open technology practices. After an effort to patent an aircraft design, Hargrave decided to publish results from all his experiments and patent nothing. He wrote that there would be plenty of credit and money in the field once the key achievement of making a flying machine was achieved, and until then it was expensive and unhelpful to place stakes around intellectual property. He took an open-science kind of view: “Workers must root out the idea that by keeping the results of their labors to themselves a fortune will be assured to them. Patent fees are so much wasted money. The flying machine of the future will not be born fully fledged . . . Like everything else it must be evolved gradually. The first difficulty is to get a thing that will fly at all. When this is made, a full description should be published as an aid to others. Excellence of design and workmanship will always defy competition.”<sup>5</sup>

<sup>5</sup> Quoted from Chanute, 1894, p. 218.

These experimenters and others had various motives, but mainly they were strongly drawn to flying, itself. From their writings we know they hoped to participate in making a great invention, and some of them imagined getting prestige and fame (though their actual experience was that most people did not believe that what they were doing was practical or feasible). Some also wanted to change the world; one recurring idea was that quick easy travel across borders easier would increase contact and comfort with foreigners and help bring peace. In an economic model, their progress toward these internal or altruistic goals can be represented by utility functions. Some had an interest in selling a product eventually but except perhaps for Lilienthal they did not have a clearly-defined plan or profit incentive.

Their economic and social environments provided enough support to allow some of these experimenters to publish, travel, and work creatively, although the aerial navigation activity was not widely respected. There was no general agreement that the activity was likely to succeed in a predictable way. In economic language, they faced *technological uncertainty*. Understanding this environment in a model can help characterize how creative individual actions, over decades, lead to the appearance of new industries. An important dynamic discussed in the next section is that they got in touch with one another, building an informational network through correspondence, visits, clubs, and journals.

When technological development is so often justified by future revenue streams, why would individuals develop technology on their own, at their own expense, without having a plausible plan to sell it? As with the open source software developers surveyed by Lakhani and Wolf (2005), there were a variety of motivations. Some experimenters found the project inherently absorbing and challenging. Some looked forward to being able to fly themselves. These are sometimes called *intrinsic* motivations. Some experimenters anticipated receiving honors, prestige, career benefits, credit for having made something useful, and perhaps somehow wealth from their own success at addressing the problem of flight. These are *extrinsic* motivations. Some experimenters anticipated that flight would improve the human condition or their nation's security, which are *altruistic* motivations. Several thought that since airplanes would increase human contact across borders, they would help bring about peace.

Specifically regarding extrinsic motivations, Otto Lilienthal invented the modern hang glider, and sold a few in kits from his steam engine firm. Samuel Langley had research funding from the Smithsonian and from the War Department which was interested in using aircraft for reconnaissance. Many experimenters patented their inventions, though until the Wrights demonstrated the feasibility of flight aircraft patents brought no substantial revenue. In the airplane case, the prospects for extrinsic rewards were not great for most of the experimenters. Progress took decades, and several experimenters died in crashes. None became rich from aircraft until after 1903. They were not rewarded as professional engineers for their quixotic attempts to fly, and many left the activity even after some success, in order to do something more rewarding. The experience of experimenters did not suggest that they would expect extrinsic rewards to outweigh costs.

Aircraft experimenters referred directly to their intrinsic or altruistic motives:

- “A desire takes possession of man. He longs to soar upward and to glide, free as the bird . . . ” (Otto Lilienthal, 1889).
- “The glory of a great discovery or an invention which is destined to benefit humanity [seemed] . . . dazzling. . . . Otto and I were amongst those [whom] enthusiasm seized at an early age.” (Gustav Lilienthal, 1912, introduction).
- “The writer's object in preparing these articles was [to ascertain] whether men might reasonably hope eventually to fly through the air . . . and to save effort on the part of experimenters . . . .” (Chanute, 1894).
- “I am an enthusiast . . . as to the construction of a flying machine. I wish to avail myself of all that is already known and then if possible add my mite to help on the future worker who will attain final success” (from Wilbur Wright's 1899 letter to the Smithsonian Institution requesting information).
- “Our experiments have been conducted entirely at our own expense. At the beginning we had no thought of recovering what we were expending, which was not great . . . .” (Orville Wright, 1953, p. 87).
- “[I offer] experimental demonstration that we already possess in the steam-engine as now constructed . . . the requisite power to urge a system of rigid planes through the air at a great velocity, making them not only self-sustaining, but capable of carrying other than their own weight. . . . [My experiments required] a great amount of previous trial and failure, which has not been obtruded on the reader, except to point out sources of wasted effort which future investigators may thus be spared . . . .” (Samuel Langley, 1891, on pp. 5-6 of 1902 edition)

The experimenters who devoted their time to the subject seem rational if they had intrinsic motivations. If they were motivated only by a long shot possibility of getting rich, their behavior seems poorly informed, or irrational, because it was time-consuming, dangerous, and unlikely to pay off financially sufficiently well to repay their expenses.

In a world of millions, perhaps a few hundred tried to contribute specifically to making heavier-than-air, fixed-wing aircraft. Early aeronautical experimenters were unusual, self-selected by their distinctive interest in the project of flight and their belief that they could contribute to it. They had an interest in the end goal. This helps explain why they would share their findings and innovations in clubs and journals and networks.

## **Octave Chanute and the open information network**

After becoming independently wealthy from railroad work, Octave Chanute became a writer and experimented with flying machines. He wrote a series of articles about the efforts toward flight and combined them into a book with the optimistic title *Progress in Flying Machines* (1894). It had an important effect by surveying and organizing a dispersed literature. By contrast, the earlier works of Langley and Lilienthal, for example, are insightful and detailed, but they are one-way broadcasts about particular sets

of experiments, with very few citations to others. By taking a global perspective, Chanute served as a kind of technology information broker or moderator, identifying key persons and technologies and evaluating them. He would put aircraft builders in touch with one another, either via his book or through personal correspondence. He was infused with the idea that by communicating and cooperating, experimenters around the world would make success possible. Chanute’s speeches and writings were “noteworthy for fostering a spirit of cooperation and encouraging a free exchange of ideas among the world’s leading aeronautical experimenters.”<sup>6</sup>

*Progress in Flying Machines* cited 190 experimenters from around the world. The frequency with which the book referred to various persons, a kind of citation count, provides a proxy measure of their significance and contribution according to Chanute’s vision of the network of airplane creators. Table 1 ranks the men Chanute cited or quoted most often, according to the number of pages on which they appeared.

**Table 1. Most-cited authors and experimenters in Octave Chanute, *Progress in Flying Machines* (1894)**

Experimenter / group	Pages referring to, or quoting, that person	Location (background)
Hiram Maxim	33	Britain (US)
Otto Lilienthal	31	Germany
Alphonse Penaud	22	France
Louis Mouillard	21	Algeria, Egypt (Fr)
Lawrence Hargrave	19	Australia (Br)
Thomas Moy	19	Britain
Jean-Marie Le Bris	17	France
Samuel Langley	16	US
Francis Wenham	15	Britain
H. F. Phillips	14	Britain

These “citation counts” have the advantage for analysis that they come from a book finished before the Wrights or other twentieth-century airplane builders had even begun experimentation. The list was not selected or ordered on the basis of later successes. The people on it were, however, significant by other criteria, and connected to personal networks of information.

Chanute visited and corresponded with many of the key experimenters cited in his book and in later years. The letters were gracious and personal in style, and almost always referred to experiments, experimenters, or related technical subjects. Simone

<sup>6</sup> Stoff, 1997, p. iv. Similar technology moderators, with similar ideologies, appear in other cases of collective invention. They organize networks of creative technologists which supports later entrepreneurship. Examples include Joel Lean, the steam engine builder who ran a newsletter in the early nineteenth century in Cornwall (Nuvolari, 2004); Alexander Holley, a consultant, frequent author and journal editor at the time that Bessemer steel plants were being built in the U.S.; Lee Felsenstein, who moderated the Homebrew Computer Club from which Apple and a dozen other Silicon Valley startups spun out in the 1970s; Tim Berners-Lee, who invented the World Wide Web and made its standards public; Richard Stallman, who founded and organized the GNU free software efforts; Linus Torvalds, who founded and organized the development of Linux; other open source software projects also had charismatic founders who encouraged openness and did not seize chances to keep the technology secret and extract maximum profit. For more details on these comparisons, see Meyer (2003).



Short, who is writing a biography of Chanute, has located 29 letters between Chanute and Lawrence Hargrave, 26 between him and Francis Wenham, and 12 to or from the Lilienthals.<sup>7</sup> Thanks to Short's and others' work, 175 letters between Chanute and Mouillard are online.<sup>8</sup> Once the Wrights contacted him, Chanute maintained a strong relationship with them too, sending at least 230 letters to them and receiving at least 177 from them, which have been published by McFarland;<sup>9</sup> Short has identified another 50 unpublished items of their correspondence.

Other bibliographies were published around the same time, and there was a general upturn in the size of the common pool of information and the number of publications. The environment had changed. While Lilienthal (1889) and Langley (1891) cited almost no one else, successful experimenters in the mid-1890s were clearly aware of a broad range of past experiments. It is convenient to mark 1894 as the beginning of a global search for a better technology informed by a connected technical literature; what may be described as a pool of aeronautical knowledge.

Some of the correspondence of the Lilienthal brothers also survives. Schwipps (1985) has collected this correspondence which was sometimes aided by brother Gustav who knew English and who traveled more. They too corresponded with dozens of other experimenters.

In a preliminary collection of the indexes from 15 published books with histories of aviation, across languages and countries, I find they cite the Wrights, Chanute, Lilienthal, Louis Blériot, Langley, and Glenn Curtiss most frequently.<sup>10</sup> Blériot and Curtiss were later pilots, not nineteenth century experimenters.

The Smithsonian Institution in Washington D.C., had been an early participant and publisher of works on aeronautics, and when experimenter Samuel Langley became the Smithsonian's director he brought his collection of publications there. As a result, the Smithsonian developed a large library on aeronautics and an associated bibliography, which systematically included references to works that were not in its own collection. Smithsonian librarian, Paul Brockett, published a series of books of aeronautical bibliography. The first, *Bibliography of Aeronautics* (1910) lists more than 13,000 publications related to aeronautics before 1910, including many which were not held at the Smithsonian.

This bibliography has been scanned and put online at archive.org by Cornell University and the University of Michigan. After cleaning up the electronically scanned text, we have for most of these publications a title, author(s), year of publication, a journal of publication, the language of the text, and country of publication. The cleaned

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<sup>7</sup> Personal communications with Simine Short.

<sup>8</sup> "The Chanute-Mouillard Correspondence," from 1890 through 1897, translated from French into English, at <http://invention.psychology.msstate.edu/i/Chanute/library/Chanute-Mouillard/Chanute-Mouillard.html>.

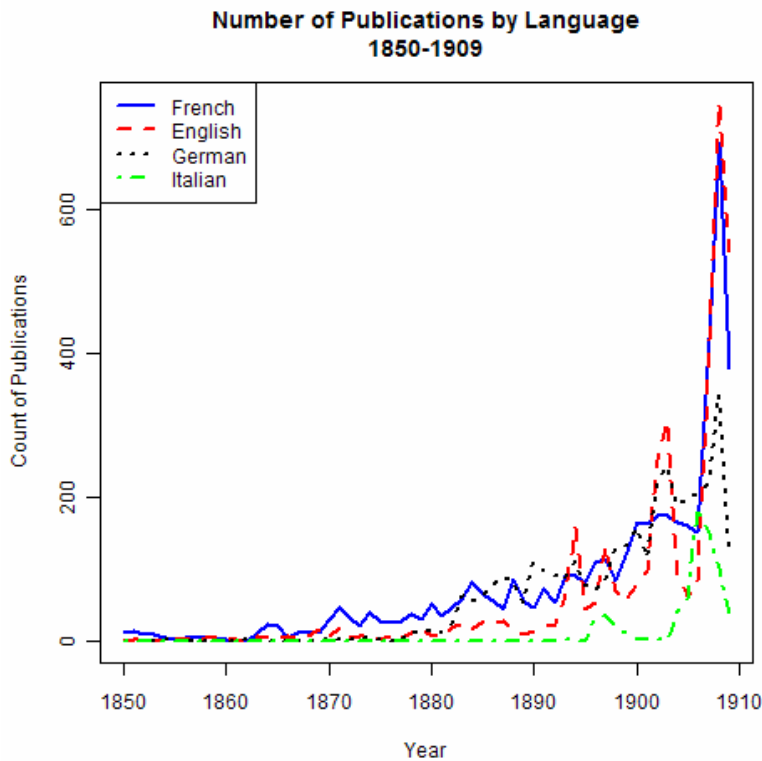
<sup>9</sup> McFarland (1953). Reference for Short?

<sup>10</sup> Meyer, "A Pre-History of the Airplane", presented at Columbia University. I excluded references to events after 1909.

text is available at <https://econterms.net/pbmeyer/wiki/images/b/bd/Brockt9n.txt>. It is bit over 2 megabytes. It has been converted to a database to track the evolution of this technical literature.

There were hundreds of publications per year on aeronautics, broadly described, before 1890 (Chart 2). The most common languages in this literature were French, English, and German. Over time, a growing fraction of the articles in this selected sample were about kites or gliders, not balloons. Ballooning had been invented in France, and articles about ballooning were disproportionately likely to be in French. The decline in 1909 is an artifact because only half that year is included. The second half was included in a later bibliography book which goes to 1916 but has not been organized into a database yet.

**Chart 2. Count of publications per year in 1910 *Bibliography of Aeronautics***



The meaning of “aeronautics” changed somewhat over time. I have classified many of these publications by subject in Table 2 so that we can see approximately what it meant to the classifiers for this bibliography. Counts are approximate, and based usually only on the title of the entry, with good translations from French and German but not yet from other languages.

**Table 2. Key subjects or concepts in aeronautical literature**

<b>Terms and concepts</b>	<b>Related entries in Brockett's <i>Bibliography</i> (of about 13,600)</b>
<b>Balloon</b> , aerostat, dirigible, Zeppelin, voyage, ascent	2100
<b>Navigation</b> (control, steerable)	623
<b>Clubs/societies</b>	600
<b>Kites, gliders</b> (gliding, soaring)	550
<b>Scientific</b> (research, theory, meteorology, atmosphere, experiment, measurement, duration, altitude, temperature, weight)	475
<b>Military/warfare</b> (army)	400
<b>Motor</b> (engine, propulsion, propellers)	380
<b>Bird</b> (animal, fish, insect)	270
<b>Wing</b>	180

Many articles were descriptions of balloons or voyages in them, and starting in the 1890s there are more and more articles about dirigibles which are balloons with exoskeletons. These contribute little directly to the development of aeronautics and the airplane; despite many efforts, balloons could not be made satisfyingly fast and maneuverable enough to reach the goals of speed and control which were inspired by the flight of birds. The subject of navigation was discussed with respect to balloons, to fixed-wing craft, and to birds, insects, and animals. Balloons were occasionally useful in military affairs and it was expected that fixed-wing craft could be too. Relatively little of the literature followed what would turn out to be key lines of advance: designing better fixed wings and propellers, and learning to glide in the air without power.

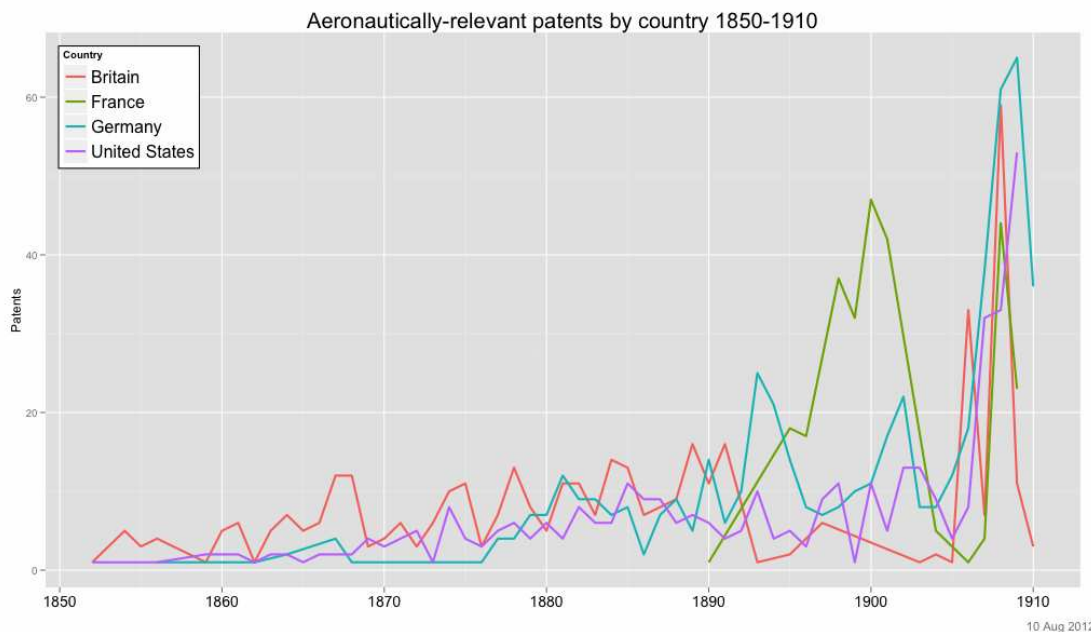
## **Patents in the aerial navigation field**

Patents are publications which make claims of intellectual property. I have gathered an eclectic list of about 1400 aeronautics-related patents up to 1915 from France, Britain, Germany and the U.S. These had different examination criteria but were in general similar patent systems. Nineteenth-century aeronautical patents seemed to have been thought of simply as publications and I am not aware of any fixed-wing aircraft patent through 1905 which earned any license revenue, and I have seen no discussion of

any attempt to get license revenue from them. Patentees did sometimes apply for patents simultaneously in multiple countries.

From eclectic sources I've gathered information on about 1500 patents which have been judged, in some previous collection, as relevant to aeronautics.<sup>11</sup> Chart 3 shows that the data are patchy (though improving) but are generally increasing over time in each country. Several of these patentees, and occasionally the patents themselves, were referred to in Chanute's book and in the literature of the 1900s. Some valuable advances were patented, but it is not clear that the patent system itself contributed to the advances. In the descriptive literature of the time, or afterward, I see no discussion of patents as intellectual property, of licensing, or of infringement. I believe that under great technological uncertainty a patent does not mean the same thing as it does in a world of R&D oriented toward product development and sale.

**Chart 3. Count of aeronautics-related patents per year; from several sources**



This casual environment changed after the Wrights filed their wing-warping patent in March 1903, which was granted finally in 1906. Their patent was interpreted broadly by the U.S. courts and they enforced it vigorously. Yearly patent counts related to aeronautics rose immediately from 1907, because the basic technological uncertainty had

<sup>11</sup> There are several collections from which to draw a sample. Researchers Simine Short, Gary Bradshaw, and colleagues have compiled a list of early U.S. patents related to aircraft. (The list is available at <http://invention.psychology.msstate.edu/PatentDatabase.html>.) The publications *L'Aerophile* periodically published lists of relevant French patents. The Otto Lilienthal Museum has listed German patents by early aircraft experimenters online at [http://www.lilienthal-museum.de/olma/pat\\_ar.htm](http://www.lilienthal-museum.de/olma/pat_ar.htm). Brewer and Alexander (1893) collected and gave abridged descriptions of 250 British patents, with the intent "be of benefit" to "those interested in the subject of aeronautics". They expressed hope that "failures will not deter inventors from still striving to master the great problem of aerial navigation." Neilson (1910) collected and summarize more British patents and comments on them. Kelly (2006) and the *Aeronautical Journal* refer to other relevant British ones. There is more to be gathered and standardized and this is underway.

been resolved. Specialists then knew that airplanes could work and believed there would be a market for inventions.

## **The Wright brothers and their inventions, 1900-1906<sup>12</sup>**

Wilbur and Orville Wright enter the story in 1899 when, inspired partly by Lilienthal, Wilbur took a specific interest in the possibilities of winged aircraft. He wrote to the Smithsonian Institution for information and was rewarded with a reply that contained substantial reading material and advice on the prior literature that he should study. The Wrights followed these leads and wrote also to Chanute for information. They continued a long correspondence with Chanute for years afterward, and these exchanges of letters have been studied by many historians to describe what happened technologically.

The Wrights began their research with kites and gliders designed in imitation of Chanute's design of 1896.<sup>13</sup> They studied the behavior of this kite at length. Sticking with the same basic design, they made a series of larger, heavier, stronger kites and gliders which a pilot could ride. These were inexpensive until 1903, when they felt sure of success and added an engine (and filed their first patent). The wings were like Lilienthal's and Chanute's, made of canvas stretched over a wooden frame. Their aircraft were not designed to be intrinsically stable, but rather to depend on frequent adjustments of the wingtips by the pilot; in this way their aircraft were like bicycles, which they knew well. Progress (like Lilienthal's) required experience in the air, and the development of a skill of piloting this kind of aircraft. The Wrights were proficient toolsmiths, and measured more precisely what they intended to measure than other experimenters did. Among their key technological achievements was the development of a small but precise wind tunnel which made better wings and propellers possible.

Until 1903, the Wrights had participated in the open, collective inventive process in ways similar to those who had advanced the field previously. They frequently discussed technical issues and previous work with Chanute, hosted visitors to their experimental flights, helped others to test their wings and aircraft, and took advice (Crouch, p. 249 and p. 253). Wilbur gave a public speech to engineers, at Chanute's invitation, and published two papers in European journals in 1901.<sup>14</sup> The published papers of the Wright brothers refer often to Chanute, Lilienthal, and Langley.<sup>15</sup> They refer much less often to other individuals, although they were familiar with previous work.

## **Transition from open technology dynamics to industrial competition**

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<sup>12</sup> This section draws from Jakab (1990) and Crouch (2002).

<sup>13</sup> Wilbur's first letter to Chanute in 1900 said so: "[T]he apparatus I intend to employ . . . is very similar to the 'double-deck' machine with which the experiments of yourself and Mr. Herring were conducted in 1896-7."

<sup>14</sup> Anderson (2004, pp. 110-111) argues that one of these was an important contribution to the field of aeronautics.

<sup>15</sup> Jakab and Young (2000).

Within the context of this unorthodox activity of aeronautics, imitations were rife: the most successful and influential designers copied from others and this was considered normal. Cayley's design started the field; many experimenters copied Penaud's design; Chanute's 1896 gliders depended on many predecessors including the work of Penaud, Hargrave, and Lilienthal; the Wrights explicitly copied Chanute's design. Moreover, before the Wrights achieved their success, Ferdinand Ferber had already imitated the same design, based on Chanute's enthusiastic descriptions and pictures. Ferber's work was central to the later successes of European aviation.<sup>16</sup> Copying in early aeronautics was fuzzy and imprecise, not precise and bit-for-bit as it is in software. Imitators usually worked from verbal or photographic descriptions, and learned more details by personal collaborations. Patents existed only in the background.

Successes came from the open literature but there were also many attempts at secrecy. After 1901, Langley prepared for a large scale experiment and became more secretive.<sup>17</sup> The Wrights did too starting in 1902. Crouch (p. 296) infers that this was because they foresaw success:

The brothers had been among the most open members of the community prior to this time. The essentials of their system had been freely shared with Chanute and others. Their camp at Kitty Hawk had been thrown open to those men who they had every reason to believe were their closest rivals in the search for a flying machine. This pattern changed after fall 1902.

The major factor leading to this change was the realization that they had invented the airplane. Before 1902 the Wrights had viewed themselves as contributors to a body of knowledge upon which eventual success would be based. The breakthroughs accomplished during the winter of 1901 and [successful demonstrations] in 1902 had changed their attitude.

Chanute had criticized others (such as Clément Ader) who kept designs secret before, and he had conflicts with Langley and with the Wrights. Analogous conflicts occur today between open source programmers, some of whom take the view that computer code must be freely available, and others who for various reasons would allow it to be owned and licensed.

In 1906, the Wrights received their key patent and Alberto Santos-Dumont flew a powered glider in Europe. The Wrights contacted the military in various countries in attempts to make long-term large contracts, and they founded a company to manufacture airplanes. By the time they started manufacturing, however, other companies were also making airplanes and they were in competition both over patents and in an infant market for airplanes.

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<sup>16</sup> Gibbs-Smith (1966), pp. 54-60.

<sup>17</sup> Langley felt pressure not to conduct his experiments too publicly to protect the Smithsonian Institution's reputation from being tied to any exotic failures. He could not keep his experiments entirely secret since they used a giant houseboat with a hangar on the Potomac river near Washington, D.C.

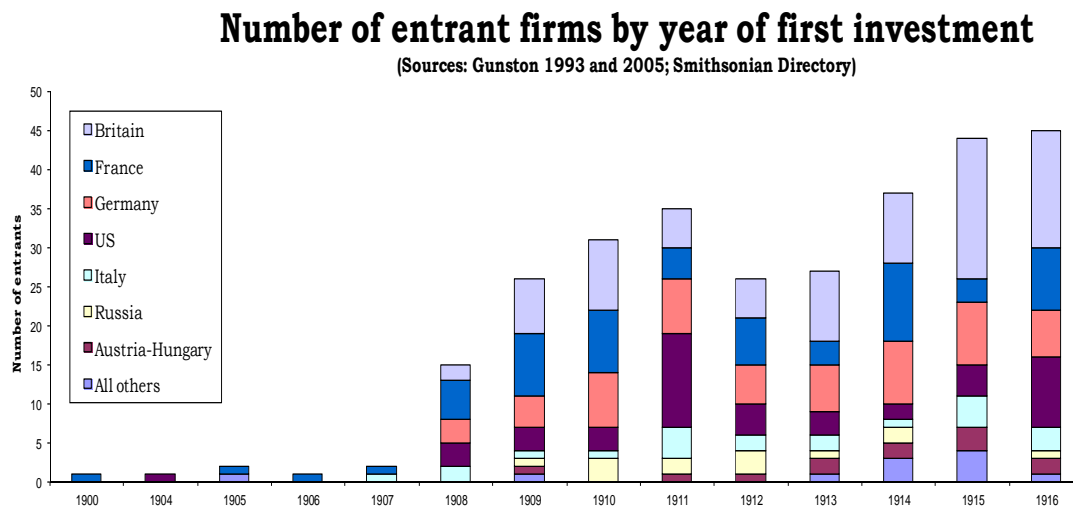
## 1907-1910: new dynamics and the rise of a new industry

In 1907, the annual number of aeronautical patents filed increased sharply in the U.S. and German data, and continued to rise thereafter. The annual number of publications also rose sharply.

In 1908 there were large public demonstrations of airplanes for the first time. It quickly became clear to newspaper readers in all the industrial countries that such flying machines were possible; many thousands witnessed their flights in 1908-9. For many members of the public, the next years must have been a time when their mindset or beliefs changed, from thinking that fixed-wing aircraft was improbable and useless, to thinking that it was a feasible activity and industry. In the language of Hannan et al. (1995), the new industry was perceived suddenly as legitimate.

In 1908, a burst of airplane-making firms appear across the industrialized countries. Fewer than a dozen were founded in 1907, but in 1908 there were more than thirty, and close to sixty a year after that. Differences across countries seem relatively small; the timing of the initial burst and subsequent flow looks similar in Britain, France, Germany, and the U.S., and several companies appeared in Austria-Hungary, Russia, and elsewhere. A spectrum of related privately provided services also arose: exhibition companies, flying schools, makers of engines, propellers, other parts, and of models, consultants, and service firms offering maintenance and repair.

**Chart 4. Count of new entering firms per year making airplanes**



Few of the founders of these new firms were experimenters in the period before 1900. The list of hundreds of nineteenth-century experimenters, authors, theorists, and patentees overlaps little with the list of founders, designers, and funders of the new companies in 1908 and afterward. Most strikingly, it seems that not one of the major contributors to the information stream in the 1890s was a central figure in the infant

industry of 1910. The Wright brothers in the U.S. and the Voisin brothers in France appear to be the earliest founders of significant airplane companies, and these were relatively new young experimenters. Many founders had manufacturing experience and financial resources.

This sharp turn in the history of technology and industry seems to result from the combination of great technological uncertainty and open-technology/tinkering behavior before the transition, and the need for capital-intensive manufacturing after the transition. This rapid takeoff of the industry, unmoored from the original inventors, suggests that much of the key knowledge was widely available. There were great patent battles after 1906 in the US (and after 1910 in Europe) and industrial competition, but the key knowledge necessary to fly was not in fact licensed from one place or closely tied to any particular patent.

Many of the new firms spun off from existing firms in another line of business and from other new aircraft firms, or licensed the technologies of the earliest firms. This is analogous to findings in early automobile companies about the same time. In a study of automobile startups in the U.S. at this time, Klepper (2009) defines *spinoffs* as a firm whose principal founder(s) came from another related firm, and defines a *diversifying* firm as one that has another line of business before it branches into the new field. Spinoffs by this definition made Detroit into a center of automobile production. Future research will evaluate the degree to which the new aircraft companies were spinoffs or diversifying firms.

Rapid growth followed. Chadeau (1987, p. 435) estimates that there were 57 airplanes and 95 airplane motors produced in France in 1909; 316 and 1050 in 1912; 796 and 2355 in 1914; and even faster growth in the first World War. Industry growth in the U.S. started more slowly. The first private sale of an airplane in the U.S. and the Wrights' first contract with the U.S. military both occurred in 1909 (Head, 2008). Most of the demand in both countries (and elsewhere) came from the military, and there were also private buyers and revenues from ticket sales for exhibition. In these years there was not yet significant revenue from passenger service, mail delivery, or freight.

## **Modeling the open technology period and the new industry**

To an extent, then, the invention of the first airplanes was based largely on open-source information and networks of enthusiasts. How can we model a period of open hobbyist tinkerers and the transition into a new industry? It is not like hierarchically authorized *R&D*, and it is not like a *race*, although there are occasional elements of competition. The phenomenon overlaps with *open science* (David, 1998), but it is not funded or evaluated by high officials and produces technology as well as scientific findings. It overlaps, too, with *skunkworks* but these are inventive efforts inside of organizations not between them. Like *collective invention* (Allen, 1983), it is not the main profit center for its agents, but unlike collective invention specified there the agents are not firms and the information is not produced as a side effect of a productive activity. As in *user innovation* (von Hippel, 2006 and a succeeding literature, the agents are self-



motivated, but they are chasing a dream not an alteration of a useful product not producing a useful product. Here a key element is that designs are shared and can be learned from and copied. The transition to create a new invention and industry is an essential new element, in the minds of the participants as well as the economic outcome.

The characterization of open technology practices is intended to help understand this. When there is great technological uncertainty – e.g., when it is not clear that an airplane can ever be functional and useful – the participants will be selected to be those interested in the problem for some reason, not on exploiting the solution systematically because this is not a realistic predictable outcome.<sup>18</sup> They follow open technology practices because these are more likely to lead to progress than alternatives. Some run institutions like clubs and journals which specifically support open technology practices.

If there is a sufficient breakthrough in functionality, for whatever reason – improving engines, better wings, better propellers, better control systems, or all these together – and a market appears, the participants in the activity expand sharply to include people who are different in type and style, and who have different objectives.

Both these phases can be modeled in principle, and the open technology behaviors and their end could thus be microeconomically mimicked, or “explained”.

## Conclusions

The legal definition of open-source software does not apply to the pre-history of the airplane, when information was either freely shared or published and patented. However, the mode of technological advance in flying machines in the nineteenth century has other similarities with open-source software:

- Experimenters are autonomous (not subject to a hierarchy or cult) and from around the world.
- Many of the experimenters have intrinsic or altruistic motives. They are drawn to their topic – pulled by desire, not pushed.
- The experimenters regularly share technological information.
- Within the network, experimenters specialize in improving specific aspects of the technology.
- At least one (Chanute) specializes in communicating – collecting information from other experimenters and authors, and inviting new people into the network.
- Some experimenters (such as Hargrave and Santos-Dumont) avoid intellectual property institutions which would delay progress.
- The Wrights used publicly known knowledge and technology. The patent system was not relevant to advances in the field until 1903.

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<sup>18</sup> On technological uncertainty, see Tushman and Anderson (1986), Dosi (1988), and Rosenberg (1996).

Such open processes supported industry among steam engine makers in the early decades of the nineteenth century (Nuvolari, 2004) and during the invention of the personal computer (Levy, 2001). In the British Industrial Revolution, progress in science and technology was supported by a relatively free press and the flowering of many scientific and technical societies with hundreds of thousands of members (Inkster, 1991, 71-9; Mokyr, 1990; Mokyr, 1993, 34; Mokyr, 2009).

In the airplane case there were several phases of development. Dispersed experimenters had the basic design idea from about 1800. By 1870, there were institutions, such as clubs and journals, that treated this vision as a recognizable and legitimate topic of discussion. Around 1895, there appeared unified global surveys of the field and design platforms which could be copied – a kind of information platform for future developers – and all the relevant experimenters know of it. Powered glider flights occurred around 1905. Startup companies appeared in recognizable numbers on both sides of the Atlantic in 1908 and quickly industrial dynamics appeared, including patent litigation, substantial capital investment in manufacturing and revenues.

The particular goal of this draft paper, not fully reached yet, was to show that there is a list of open technology practices ; that the key participants in the advances in nineteenth-century aeronautics followed them ; and that the founders, investors, and designers of the new industry tended not to. We see that Chanute and Hargrave, for example, followed open source practices, and that the Wrights did until their great invention then they ceased to. The work continues.

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