10 An Inventive Commons: Shared Sources of the Airplane and Its Industry

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I. Introduction

In 1809 a scientific journal published a paper describing a fixed-wing aircraft design that could carry a person. Author George Cayley bravely wrote in its first paragraph that by publishing his observations on the subject he might be "expediting the attainment of an object that will in time be found of great importance to mankind; so much so, that a new era in society will commence from the moment that aerial navigation is familiarly recognized."

That paper launched the phrase "aerial navigation," which was then used for over a century in an international discussion among experimenters and scientists about how to make an aircraft that could be piloted and controlled better than a balloon or projectile. Participants in this discussion published articles, created new journals, filed patents, formed clubs, and attended exhibitions and conferences. After a century, this line of thought and work led to the invention of the modern airplane.

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This chapter explores the ways in which documents, information, and networks associated with the century of aeronautical texts represented a *knowledge commons* space in the sense of Madison, Frischmann, & Strandburg (2010). Their work inherits from the discussions of natural resource commons by Ostrom (1990) and of the informational commons by Ostrom & Hess (2007).

This case study of commons management describes structures encouraging the creation and maintenance (also called "provision" or supply) of the common resources and of structures controlling or encouraging appropriate use of the common assets. In general the participants in the development of the airplane were self-motivated experimenters, interested in flight partly as a dream and partly as an intellectual challenge, so the fundamental source of provision of shared knowledge was intrinsic to each of them. Provision was subsidized by their own enthusiasm.

Key institutions enabled and supported their internally motivated pursuit of "aerial navigation." They created and used a pool of ideas, often codified in publicly available documents. For a natural resource such as a river, usage must be controlled; for a stream of information, which is inherently nonrivalous, that is not generally the case. As has been demonstrated by studies of "user innovation," usage may replenish or improve a shared resource of knowledge about a particular technology (von Hippel 2006). Such was the case with the common pool of knowledge about aerial navigation through 1905.

The *inventive commons* described here differs from most commons examples in certain critical ways. First, this commons was diffuse—neither the group of participants nor the common documents and ideas were clearly bounded or delineated. Second, there was not much enforcement of rules or norms, even within local groups. There were norms of behavior with respect to shared resources and various leaders and organizers encouraged "good" behavior, but we do not see formal rules across national boundaries or enforcement by agreed-on punishments. There were occasional instances of some kind of cheating; of a person who did not share; of a person who disliked or was angry with another; and perhaps many instances of shunning. Primarily, these arose in the later period of invention of aerial navigation when the stakes were higher because airplanes were real, there were real revenues and real military buyers, and the scope for a great reputation had expanded. Just as there was no strong paradigm for the scientific field of aeronautics or for the technical and industrial field of aviation, there was no strong social paradigm for the aeronautical commons.

The next sections lay out some of the history of the interactions by which these driven dreamers experimented, communicated, and slowly advanced the field of aeronautics toward modern airplane aviation. It is useful to think in four stages: an early stage in which individuals worked alone, a stage in which aeronautics became more unified as a field across the world, a stage of start-up industrialization and, finally, a stage when World War I military use drove the story. Knowledge was governed and managed differently in each of these stages as the issues faced by aeronautical science and practice changed.

II. Efforts toward "Aerial Navigation," 1809–1905: Overview

Modern airplanes can be traced conceptually back to George Cayley's early designs.[1] Cayley was an inventor, scientist, and public official. He conducted years of experiments, then published papers in 1809–1810 presenting original fixed-wing aircraft designs and discussing his experiments on them.[2] He stated that he expected an era of aerial navigation to come, which must have surprised readers. The rest of his text was empirical. The papers described his experiments on gliders, giving a dozen diagrams and reporting scores of measurements including comparisons to birds. Cayley referred implicitly to the work of predecessors who had published studies of ballistics and air pressure in scientific and engineering publications, including Isaac Newton, Giovanni Borelli, and Benjamin Robins; though Leonardo da Vinci's aeronautical designs were not known to him. Cayley's papers adopted an open science approach and were works of scientific engineering, not fantasy. By adopting this approach, Cayley set a pattern or precedent of treating the issue scientifically.

Cayley's scientific approach to aerial navigation garnered the attention of others partly because he had earned their respect in other scientific and technological endeavors. In the 1830s he was a founding member of the British Association for the Advancement of Science and became the first chairman of the Royal Polytechnic Institution, which taught practical science and technology. In the 1840s others finally started to use glider designs similar to his in their studies of flight. Cayley returned to experimentation periodically and launched gliders with a person on board in the 1850s.

Cayley seems to have reached out repeatedly for a network of colleagues with whom to develop aerial navigation. He published quickly and enthusiastically in response to publications on aviation and ballooning topics by others, analyzed technical topics with enthusiasm, and predicted a bright future for aerial navigation. He proposed government funding and a broad subscription to create an organization to focus on the topic. But for most of his life he was too far ahead of others to have valuable peer or network relations related to aircraft; indeed, his last works, which included many features of the modern airplane, were not even cited by others in the field, perhaps because they did not understand the issues (Gibbs-Smith 1962).

Cayley operated in an environment in which ballooning was recognized as a respectable leisure activity for the wealthy, as was the case throughout this period. Although there was not much technological overlap between balloons and the kites and gliders that eventually would lead to the airplane, balloon clubs were natural places for people interested in winged craft to find one another. In 1852 the first society that included

[1] This historical account is drawn from Meyer (2013) and many earlier works.

[2] Cayley (1809, 1810) in the *Journal of Natural Philosophy, Chemistry and the Arts*. They are analyzed in context by Gibbs-Smith (1962).

aerial navigation along with ballooning and meteorology in its mission, the Société Aérostatique et Météorologique de France, was established. Cayley lived long enough to republish some of his papers in translation in its brief-lived journal and to write a substantial original paper for that journal.[3] Thus, the networks and practices of aeronautics built on the social and institutional infrastructure of the balloonists.

During the century of these developments, a number of creative experimenters, including Alphonse Penaud, Louis Mouillard, Lawrence Hargrave, Samuel Langley, Otto Lilienthal, and Octave Chanute, tried to figure out how to control gliders in flight. These individuals came from a variety of backgrounds and locations and did not know one another prior to their experiments in this field. They published their studies in a scientific literature that was generally less formal than today's, and also in journals associated with ballooning.

To summarize some of their aeronautical contributions briefly: Penaud designed rubber-band-powered models and showed that an aircraft would be more stable if it had a tail that, like the main wings, brought lift. The tail helped the craft to maintain stability in the air. Mouillard studied birds and their flapping and soaring wings in detail. He tried to imagine and build wings that would match a human in the way that a bird's wings match its body. Hargrave ran many experiments, notably showing that box kites are more stable in gusty winds than flat kites are. Lilienthal experimented with wings and published detailed data about his experiments in a book in 1889. He then built gliders and flew them himself, leaping from a hill. These exploits drew crowds, and Lilienthal became a kind of celebrity. Langley published a book about a series of his scientific experiments investigating the lift experienced by flat wings with an airflow going past them. He went on to build a model aircraft that flew a substantial distance in the open air in the late 1890s. These were among the most important of hundreds of authors, experimenters, and theorists associated with aeronautics during this time.

III. Institutions Supporting an Aeronautical Commons

The technically focused and self-motivated individuals who worked on flight during the nineteenth century had to be willing to work alone, and often did. When possible they also joined into networks through clubs, societies, conversations, correspondence, exhibitions, conferences, and journals. Many of these activities were well documented, and my ongoing research involves building databases of them. Over time, these activities

[3] Gibbs-Smith (1962: 158–76). Cayley did not apparently feel a constraint against publishing original work on this subject in a French journal. Earlier in life he had suggested that aerial navigation was a suitable project for the British nation—its government or subscribers/investors in a particular project. It seems he cared about getting the project underway, not about who exactly would undertake it. He said aerial navigation would be good for spreading civilization generally and did not think there were any near-term military consequences.

changed what had been primarily an activity of individuals into a community activity supported by shared knowledge resources.

A. Clubs, Conferences, and Exhibitions

In the 1860s, societies oriented toward aeronautics appeared in London, Paris, and Berlin. Ballooning was popular in France. A dozen organizers of French ballooning societies, including photographer Gaspard-Félix Tournachon (known by the single pseudonym Nadar) and science fiction author Jules Verne, also took an active interest in heavier-than-air craft. Over time, clubs and societies associated with ballooning began to include more and more people interested in aerial navigation issues and in fixed-wing flying machines. Two especially relevant societies were the Aeronautical Society of Great Britain (founded in 1866) and the Aéro-Club de France (founded in 1898). Through their meetings, journals, and general legitimacy, these societies enabled experimenters to find one another and to build on one another's discoveries and designs. Available documents about the membership and activities of these societies suggest that interest in aerial navigation trended up over time, though there were periods of booming and flagging interest.

Conferences and exhibitions attracted curiosity and interest to the quest for flight. The number of meetings in which aeronautics played a significant part grew over time. There were at least four related conferences in the 1880s, six in the 1890s, then more than one a year after 1900.

B. Publications

There was no single central publication with all the latest in aeronautics globally. Then, as now, scientific publishing was partly a public good and partly a business. For example, Cayley's first key aerial navigation papers appeared in a relatively informal journal published by one man as a somewhat uncertain business enterprise. Papers in these journals were sometimes formally commented upon, but were not peer-reviewed in the modern sense.

There was a long-lasting public goods problem of collecting aeronautical findings and making them available. Without venues for collecting such findings, progress would have been considerably slower. By the 1880s, aeronautical societies in Paris, Berlin, and London published journals. These were central places to find hundreds of aeronautics articles, including accounts of voyages, celebrity balloonists, contests, and meetings and plans for future events. Many such articles were no more than two pages long. Aeronautics articles also appeared in general magazines, such as *Scientific American*, and occasionally in general scientific journals. A number were published as books or pamphlets. Many included diagrams or equations. Importantly, as discussed in the next subsection, several bibliographies appeared starting in the late 1880s to help those who wanted to survey the subject overall.

Figure 10.1 illustrates how the number of aeronautics-related articles, pamphlets, and books published annually grew over time.[4] (Please refer to "Figure 10.1 Count of Aeronautics-Related Publications Each Year. Source: Brockett's *Bibliography of Aeronautics* (1910)," located between pages 352 and 353.) This data comes from the books of aeronautical bibliography published by Smithsonian librarian Paul Brockett. The first volume of the *Bibliography of Aeronautics* in 1910 listed more than 13,000 publications related to aeronautics, including many that the Smithsonian did not itself hold.[5] Some of these publications were oriented toward the subject of ballooning; others to aerial navigation; others to meteorology and the ways birds and animals move. Throughout this period, journals started and disappeared. Paris-based *L'Aerophile*, founded in 1893, became the most central journal by 1900, according to historian Gibbs-Smith (1968: 75), and it is the publication with the most articles in the bibliography data.[6]

C. Information Intermediaries in the Late Nineteenth Century

The publications of Langley, Lilienthal, and others were insightful, detailed, one-way transmissions about particular sets of experiments, rarely citing the work of others. The establishment of a commons dynamic was given a large boost by the activities of Octave Chanute. Chanute had become wealthy as a civil engineer and railroad manager. He retired to write about and experiment with flying machines. In 1893, during the World's Fair in Chicago, he helped to organize a major conference and exhibition on flying machines. He published many articles reporting his work and summarized the state of the art in an 1894 book with the optimistic title *Progress in Flying Machines*. By surveying flying machine activity broadly, Chanute served as a kind of technology information broker or moderator, identifying key persons and technologies and incorporating their work into his summary and his own designs and experiments.

[4] Such growth over time in a data set can be an artifact of backward-looking ("retrospective") data, since respondents remember recent events more easily than previous ones, so counts of remembered events are naturally increasing over time. I do not think that is the main reason for the growth in the data here. The Smithsonian was collecting and indexing its library for a long time, and it drew information from long-lasting serials and bibliographies that explicitly referred to previous work, which they would also find and include. The growth pattern of publications is similar to that of patents, which do not have the retrospective problem since each accepted patent is recorded officially in the category at the time—we draw samples from the complete set of accepted patents. Based on all this, I believe earlier aeronautical publications are well represented and the growth pattern is not biased.

[5] Brockett's 1910 bibliography has been scanned and made available online at archive.org by Cornell University and the University of Michigan. I have cleaned up the electronically scanned text and made its entries into a database. For most of these articles, the bibliography includes the title, authors, years of publication, journal of publication, language of the text, and country of publication. This database can be used to track the evolution of this technical literature, but it is necessary to exclude many entries for which these data elements are not complete.

[6] *L'Aerophile*'s name means literally lover-of-the-air. Discussing a version of this paper, law professor Joseph Scott Miller characterized the name as telling because the overall history was a love story—an epic, multigenerational love story. These men indeed loved flight, and dreamed to make flight work. For most, their love was unrequited.

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. Penaud and the others listed above, whose work was later recognized as highly significant, are among those most often mentioned in the book. Chanute's description of the field in 1894 was broad and treated as definitive. Other bibliographies were published at around the same time. As a result, there was a general upturn in the size of the common pool of information and the number of publications about aerial navigation. The environment had changed. While Lilienthal's 1889 book and Langley's 1891 book cited almost no one else, successful experimenters in the mid-1890s could refer to a broad range of past experiments. Chanute's 1894 book is a convenient marker of the beginning of a unified global search for a better technology informed by a connected technical literature; a global pool of knowledge.

Chanute was a leader and moderator of the commons. He wrote repeatedly of his attempts to help others to behave as if they belonged to a community with a norm of reciprocal sharing. For example, an 1895 letter to Langley exhorted: "I propose to let you avail of whatever novelty and value there may be in my own models or ideas. I should expect in return a like frank access to your results."[7]

The Smithsonian Institution in Washington, D.C., was another important information intermediary during this period. It began collecting aeronautical studies in the 1880s, particularly after experimenter Samuel Langley became the Smithsonian's director in 1887 and brought his personal collection of publications there. The Smithsonian developed a large library of works on aeronautics and an associated bibliography. The Smithsonian library played a direct part in the history of the invention of the airplane when Wilbur Wright wrote them in 1899 to ask for any papers they had published on the subject and a list of other works. In reply, he received four pamphlets and a list of key books, which he obtained and used to begin his technical training in aeronautics.[8] The same library is the source for the publications data shown in Figure 10.1.

D. Aerial Navigation Patents

Thousands of ballooning and aerial navigation patents were taken out in the nineteenth century, particularly in France, Germany, Britain, and the United States. Colleagues and I have identified over 3000 relevant patents before 1910 so far, and thousands more were filed worldwide.[9] Perhaps surprisingly from a twenty-first-century perspective, patents

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[7] Chanute to Langley, 1895, quoted by Short (2011: 208).

[8] Anderson (2002: 85–87).

[9] A dozen eclectic sources may be used to identify particular patents as relevant to aeronautics. The patents themselves are visible online from the U.S. Patent and Trademark Office, espacenet.com, and Google-patents. The data set is expanding and improving over time. To get the data, please contact the author. The national patent

appear to have played a role similar to that of scientific publications in the early aviation commons, rather than a role as intellectual property.

Ballooning was a small business at this time, and presumably many of the patents associated with ballooning functioned as traditional intellectual property. Aeronautical patents seem to have played a different role. While the specific experimental tools, devices, and machines that experimenters built to embody these patents were not shared in a commons, the patent texts and diagrams became part of a commons zone. They were shared and discussed in ways that suggest that experimenters were expected to copy and make use of them in their own projects. While there were occasional discussions of selling rights to a flying-machine (aeronautical) patent—by Henson and colleagues in 1842–1843, and by Lilienthal for his hang gliders, I have not found any cases of actual licensing or claims of infringement before 1906, when the basic Wright airplane patent was granted.

Why, then, did these inventors patent? I have not found clear statements of their reasons, though perhaps many patenters hoped they might eventually have a chance to license their inventions. I speculate that most patenters also hoped both to receive credit for and to enable others to use their inventions. Patenting also was normal engineering practice, which perhaps needed no special motivation.

There is a great overlap between the population of experimenters who published articles and those who patented. However, a number of the most prolific patentees did not publish any articles that were noted in Brockett's *Bibliography* and were not mentioned by Chanute or by subsequent airplane makers.[10] Few of their patents contributed technology directly to the development of the first airplanes. It is not clear why these inventors chose to patent, but not to publish. Perhaps some of them did not have a better, more central or more convenient way to make their work known, though patenting required paying fees and I am not aware that publication would have been unavailable to them. In any event, although these patentees did not generally engage in the published discussion as far as we can tell, I believe it is sensible to say that their contributions were de facto part of the commons, since they shared their designs at least through the patents and are not known to have made property claims. This is a speculative interpretation, however, since it is not clear that the work of these nonpublishing patentees ever was adopted by others.

IV. Analysis of This Informational Commons

A. Goals, Objectives, and Dilemmas

Having now seen some key elements of the environment for studies of "aerial navigation" in the late nineteenth century, let us evaluate the period before the rise of the

systems were different from one another, but it is not difficult to combine the patent data into a single data set once it has been gathered.

[10] Meyer (2013: 124).

airplane industry—before 1908, that is—as a story of a commons. The basic goods and institutions—including experiments, publications, patents, clubs, and network interactions—were produced by the enthusiasm, resources, and ideas of the early experimenters themselves. These were self-motivated experimenters, interested in flight partly as a dream and partly as an intellectual challenge, so the fundamental source of provision was very much internal to them. During this period, participants who published designs or experimental results did not realistically expect to appropriate any financial rewards. Realistically, the best an experimenter could expect by way of payoffs from others was to be cited and respected and to contribute to the eventual achievement of the goal of controlled flight. Wilbur Wright's first letter on this subject, to the Smithsonian Institution in 1899, said that this was what he hoped for—to contribute a little to the future person who would achieve aerial navigation in a flying machine.

Users of a technological platform generally are better off if there are more users because of the positive network effects. A platform with more users has more developers, making it easier to use, providing add-ons, and enabling more people to train others to use it. This phenomenon has been studied in the contexts of user innovation (e.g., von Hippel 2006) and jambands, for example. Simcoe (2014) makes a similar point in the context of standards-setting organizations and other technological platforms, contrasting them explicitly with natural resource commons where there is a risk of overuse.[11] Indeed, while usage of a natural resource, such as a river, must be controlled, usage of a stream of information can replenish or improve the stream, as in this case of scientific experimentation.

Consistent with this observation, the institutions associated with the invention of aerial navigation were generally organized in such a way as to expand the use of the common expertise and designs. Expanding participation was interwoven with substantive progress. With successful experiments, there would be positive network effects from having many people engaged in the activity—more fun, more resources, more positive public perception, and positive feedback generating more progress toward the participants' technical goals. If instead the overall network did not produce valuable results, the enterprise would decline and perhaps collapse.[12] The following behaviors or situations represented threats to the aerial navigation enthusiasts' progress and their network:

- **Secrecy or inaccessibility**. If too many members kept their best findings secret, that would produce a failure-to-make-progress problem, because the others would

[11] This fundamental difference between natural-resource commons and informational commons is recognized in Ostrom & Hess (2007), Madison, Frischmann, & Strandburg (2010), Simcoe (2014), and Coriat (2013). Natural resources are subtractible, meanings use by A reduces what B can use, so institutions are designed to measure and constrain usage. Informational resources are generally nonrivalrous and have positive network effects so their commons seek more users.

[12] The same dynamics are faced by open source projects, many of which do not attract new participants beyond their founders. Similarly, technological standards need to accumulate a critical mass of users and developers. Simcoe (2014) discusses formal standards organizations in this context.

have too little to read, copy, and build upon. The problem would be extreme if the secret-holders were more successful than the commons participants; then the point of the commons would largely have evaporated. Accessibility was also a serious problem. Results were scattered throughout a wide variety of publications and written in different languages, making them difficult for interested parties to find and thus making it hard for the field to progress in a cumulative fashion.

- **Costly participation**. Difficulties and costs associated with accessing and learning from existing knowledge about aerial navigation would act as friction to slow down future contributions and associated progress.
- **Competition for one-of-a-kind opportunities.** One kind of "subtractibility" that did exist was that there were one-of-a-kind opportunities in this field, most notably the opportunity to make a working airplane for the first time. On a smaller scale, there were one-of-a-kind opportunities to make contributions that would help move the field toward that goal. In principle, competition for such opportunities could be a source of contention among the participants and a reason not to contribute to the commons. Many contributed anyway. Why? I think the central reasons was that most participants believed that they had little chance to reach that threshold and that only by working with other experts would they have any chance at all. Moreover, especially after bibliographies were compiled, publication provided a mechanism for documenting priority and establishing credit for contributions toward the shared goal.
- **Conflict or discouragement**. If members had unpleasant battles or broke into factions, participants would withdraw and the overall effort would again fail to make progress. Perhaps to avoid this problem, the phrasings in the texts of the era are often positive and encouraging—notably in Chanute's book *Progress in Flying Machines*.
- Dramatic technological **failure or humiliation**. All network efforts would be put at a disadvantage if flying machine efforts were put in a bad light, as dangerous or ridiculous. There was one event which seemed to have such an effect. The fatal crashes of glider-pilot Otto Lilienthal in 1896 and of his principal student, Percy Pilcher, in 1899 eliminated the men most likely to put a motor on a glider and fly a powered craft. They also put a damper on optimism about glider activity more broadly. Gibbs-Smith (1966: 54) writes that European aviation was "moribund" for six years after Lilienthal's death. The reaction is understandable. Lilienthal was an expert, hero, and celebrity. The crashes gave naysayers evidence of the difficulties and dangers of flight. As a result, progress slowed.[13]
- Dramatic technical **success**, too, would eventually represent a kind of threat to the network, since it would bring about competition and new economic forces

[13] As the databases on publications, patents, letters, and so forth improve, it may become possible to characterize that decline quantitatively.

and take away the motive of reaching for and contributing to that dramatic success. The participants do not seem to have written much about this possibility. They cared much more, I think, about making scientific and technical progress than about protecting the commons and its sharing norms.

B. Shared Resources

Published texts and patents were de facto shared resources. Published ideas were available for use in the search for functional flying machines, essentially without restriction, as long as they were able to locate and gain access to the texts. Relevant ideas were scattered among a variety of journals, books, and pamphlets, however. The lack of citations to one another's work in the publications of early experimenters suggests that the field evolved in a fairly disconnected manner in the early period. The bibliographies of aeronautical works that started appearing in the 1880s played an important role in turning a set of nominally public knowledge into a truly common pool of information. Chanute's 1894 survey book was particularly important in this regard. These published bibliographies constituted a layer of indexing and knowledge of the field on top of the underlying ideas, which provided interested experimenters with the *awareness* of, and the capacity to find, the spectrum of useful texts and people.

C. Community Membership, Openness, and Motivating Visions

A participant in the commons, here, was simply anyone who showed up at meetings or read, or especially published, articles containing new findings, discoveries, designs, or inventions. There were certainly hundreds, and perhaps thousands, of these self-selected participants. The community was global—participants were believers in natural laws, and that those laws would apply in Paris, London, or high in the air. They had an interest in those natural laws and debated exactly what they were.

There also seems to have been an inner core of participants who had been educated (or educated themselves) to be expert on natural science and acculturated to follow something like the norms of science (Merton 1973). Communications in the major French and British aviation societies had such a tone—that the participants were expert and high-minded and thought of society at large. In Chanute's letters and publications he also took this tone, as did those who wrote to him. I infer from reading these documents that certain leaders thought of themselves as an inner circle of wise experts and that others also thought of them that way. The desire to be part of, or gain access to, this inner circle of expert correspondents also would have motivated others to adhere to norms of sharing scientific and technical information and to make efforts to be seen as advancing the frontiers of scientific knowledge.[14]

[14] I am indebted to Katherine Strandburg for pointing this out.

Who did not participate? Though some of the aviation clubs had membership rules and certain club assets—such as equipment or access to landing fields—may have been available only to some members, I am not aware that those rules were used to exclude people with any regularity. We can, however, identify some aircraft designers who were doing relevant technical work but basically did not participate in the commons. Their stories illustrate some of the constraints on participation.

Clément Ader, a French engineer, oriented his attention to military purposes in the early 1890s, received funding from the military, and generally did not publish or widely share his aeronautical designs or findings. He appears not to have known of the best practices of others, either (Gibbs-Smith 1968). His story exemplifies the issue of secrecy mentioned above.

Chuhachi Ninomiya of Japan made elegant bird-like kites and model gliders and anticipated putting engines on them in the early 1890s, but does not appear to have known of the Western literature on the subject and never contributed to it. Richard Pearse of New Zealand, a poor farmer, knew something of the literature and made a powered but uncontrolled craft that flew in 1901–1903. He did not continue his experiments and did not become known to other aviation pioneers until much later. These stories illustrate the exclusive power of logistical issues such as geographical location, language, and education. Financial resources were another important constraint, given that aeronautical experimentation could be an expensive hobby. The communities and materials of aeronautical experimenters were thus open, but not universally accessible.

D. Governance of the Aviation Knowledge Commons

I have not found explicit rules about use and consumption of the flow of information in publications about aerial navigation in the nineteenth century. Rules or norms were implicit in behavior.

1. Leaders as Exemplars and Norm Entrepreneurs

Technological leaders of the network—such as Cayley, Chanute, Lilienthal, and many of the journal editors—encouraged norms of positivity, encouragement, and openness. Formation of the commons was powerfully influenced by particular characters such as these. Cayley was a published scientist, an inventor, and also a baronet and a politician. Chanute was a moderator, evangelist, and source of encouragement. By flying his hang gliders in front of crowds, Lilienthal brought a kind of charismatic celebrity and public legitimacy to the effort, and thus recruited new interested people to the subject. Langley was a recognized academic scientist who had bought in to the vision of aerial navigation. Generally these figures actively protected and nurtured the norms that would sustain and grow the commons.

Chanute was a central figure in encouraging norms of sharing and openness. Over and above the importance of his book in collecting the literature and putting aircraft builders in touch with one another, his many 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." (Stoff 1997: iv). Chanute believed that cooperation and free exchange would make success possible. Chanute also engaged in the cooperative free exchange he advocated. He visited and corresponded with many of the key experimenters. His letters exemplified gracious writing and an encouraging tone. He sent over two hundred letters to the Wright brothers alone.[15] Simine Short, author of a biography of Chanute (Short 2011) located hundreds more addressed to other experimenters. Chanute routinely credited others for their wisdom and accomplishments, which must have been rewarding for them. Chanute's open approach facilitated his substantive role as a kind of information broker. Because of his open interactions with other experimenters, Chanute was well connected and knew approximately what there was to know in this incipient field.[16]

These leaders exemplified appealing norms and laid down a kind of "soft law" of expectations. They did not rely on systems of control or power in which experimenters were actually ensured of recognition for their accomplishments or punished for failing to recognize the accomplishments of others.[17]

2. Norms about Patenting

There was certainly no general norm against patenting in the aviation community. Indeed, most of the productive aviation experimenters obtained patents. I have found no explicit statement as to why they did so, since these patents seem never to have been enforced. It seems likely these experimenters used patents as a means to document their achievements and ensure credit for priority in making an invention. It also seems likely that there was a good faith norm that one should not sue one's colleague in the search for aerial navigation. Experimenters saw themselves as members of an isolated minority and perhaps felt some fraternal bond. Even after 1906, when the Wrights began enforcing their patent with lawsuits, their opponents responded by attempting to undermine their suits, but did not sue the Wrights for infringing earlier patents. (I do not know whether

[15] Most were published in McFarland (1953).

[16] Technology moderators and organizers with this frame of mind have helped other new technologies along, including steam engines, iron blast furnaces, steel rolling mills, personal computers, the World Wide Web, and open source software. For details, see Meyer (2003).

[17] Modern scientific and technological communication more explicitly keeps score. For example, participants and others can track the number of postings someone made to an open source project, or to Wikipedia. In software development these are sometimes explicitly visible to and shared with potential employers or funders. This evidence has led to a line of economic argument that open source software developers might be justified in giving their code away because of the career benefits; but in early aeronautics career benefits were unlikely and formal incentives were weak. In this environment, the drive for intrinsically satisfying progress is a more relevant incentive.

such suits would have been viable given the patents in force at the time.) Another reason that there were no infringement suits before 1906 may have been that there was so little market value in the patents during that period.

At least two of the major experimenters, Lawrence Hargrave and Alberto Santos-Dumont, decided not to file for patents. In the early 1890s, Hargrave took the view that the technology was entirely uncertain and that it would be counterproductive to dispute ownership of designs until after airplanes worked, at which time there would be credit and money to spare. He wrote: "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."[18] Hargrave expressed faith that experts in aerial navigation would have a durable advantage in any commercial market because of complementary assets—their skills, knowledge, experience, and past designs. Hargrave seemed to think that these complementary assets were so valuable that there would be no need for intellectual property claims. In the event, his prediction did not seem to come true; the very few holders of key patents came out well and the founders of some new companies made money, but the past experience of the aeronautical developers did not bring them any long-lasting competitive advantage in the later market. Hargrave expressed a kind of idealism that many early technologists share. Such idealism helps progress along and certainly sustains sharing in a commons.[19]

Santos-Dumont also eschewed patenting. In the earlier period when he made dirigibles, "Santos-Dumont did not believe in patents. He made the blueprints of his airships freely available to anyone who wanted them. He saw the flying machine as a chariot of peace, bringing estranged cultures in contact with one another so that they could get to know one another as people, thereby reducing the potential for hostilities" (Hoffman 2003). In 1906, Santos-Dumont flew the first controlled powered airplane in Europe. A couple of years later he became involved in the commercial manufacture of airplanes, but continued to avoid patenting: "They urged him to patent *Demoiselle*. He refused. It was his gift to humanity, he said, and he would rather end up in the poorhouse than charge others for the privilege of copying his invention and taking to the skies." (Hoffman 2003: 4, 274.)

The antipatent norm advocated by these researchers did not take hold, however. Instead, patents were obtained, but generally not enforced, during this period.

18 As quoted in Chanute (1894: 218). Chanute expressed respect for this point of view, but he himself continued to apply for patents.

19 Analogous norms come up in the open-science context and in free or open source software context—that a scientist who creates a database or a software developer has an obligation to make the data or source code available because it is a norm of good practice, with likely good outcomes for people overall, and if everyone would do it, the world would be a better place.

3. The Direct Imitation Norm

Fairly direct copying, even of patented designs, played an important role in the development of the first successful airplanes. Well-known and respected figures in the community seem to have engaged in it and it appears to have been a community norm.

For example, having surveyed the state of the field in his well-known book, Chanute synthesized a glider from earlier examples in an 1896 design, built jointly with Augustus Herring and experimented with in 1896–1897. The glider incorporated Penaud's design of the fuselage and a tail which had lift to help the craft stay longitudinally stable. From Lilienthal, Chanute drew the critical idea that a person had to ride on, or pilot, the glider to learn control in the air. The new glider's wings were arched ("cambered") like bird's wings and like the wings of Lilienthal's glider. Drawing from Hargrave's box kite designs, Chanute made a biplane arrangement, with two wings connected by a rigid frame. Two wings would bring more lift than one. In order to keep the stacked wings light, he copied from his own bridge-building experience what he called a Pratt truss—an angled arrangement of wires to hold the wings parallel all along their length. Chanute then patented the resulting design.[20]

Eventually, Chanute was contacted by Wilbur Wright. Wilbur and his brother Orville had tackled a number of entrepreneurial and technical projects together and were running a bicycle making and repair shop in the late 1890s when Wilbur took an interest in flying machines. Among other things, Wilbur thought about why Lilienthal had crashed and what might be done to avoid future crashes. In 1899, Wilbur Wright wrote the Smithsonian Institution for advice about what to read on the subject and then wrote to Chanute directly. In his very first letter to Chanute, on May 13, 1900, Wilbur stated explicitly that he intended to build on the work of Lilienthal and would use a design like Chanute's own:

> Assuming then that Lilienthal was correct . . . [Wilbur explained what he will do differently] . . . . my object is to learn to what extent similar plans have been tested and found to be failures, and also to obtain such suggestions as your great knowledge and experience might enable you to give me. I make no secret of my plans for the reason that I believe no financial profit will accrue to the inventor of the first flying machine, and that only those who are willing to give as well as to receive suggestions can hope to link their names with the honor of its discovery. The problem is too great for one man alone and unaided to solve in secret. . . . . The 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.

[20] U.S. Patent no. 582,718 and British Patents nos. 13372, 13373, and 15221, all from 1897.

Chanute agreed quickly, replying back on May 17, 1900:

> I believe like yourself that no financial profit is to be expected from such investigations for a long while to come.

These phrasings give us some insight into the copying norms of the aviation commons at this time.

The Wrights made a series of aircraft similar to Chanute's, and Chanute and the Wrights exchanged hundreds of letters and telegrams. They exchanged both information and encouragement. The Wrights continued to follow open practices in the following years. Wilbur Wright accepted an invitation by Chanute to describe the brothers' experiments in an address to an engineering society. The brothers published articles about aeronautics and about their experiments. They invited visitors, including Chanute himself, to their beach camp at Kitty Hawk, North Carolina, where they performed their flight experiments. Kitty Hawk was hard to get to, but like Hargrave and Chanute, who had chosen beaches for their experiments, the Wrights wanted a strong wind from the ocean so a glider could get a lot of lift without having to travel fast, and they wanted any landings or crashes to be on a soft beach so the craft would survive and could be used again. We also know that the relationship between Chanute and the Wrights was specifically important to the Wrights' later invention of controllable powered aircraft.

Others copied the Wrights. Ferdinand Ferber, an aerial navigation experimenter in France, had worked with a glider designed along the lines of Lilienthal's. In 1902, Chanute sent Ferber copies of a lecture by Wilbur Wright and included illustrations of the Wright gliders. Ferber then abandoned the Lilienthal design and built a glider of the Wright type. After a talk by Chanute in Paris in 1903, further photographs and drawings of Wright craft were published in France and Wright-type craft were built by other important French experimenters, including Ernest Archdeacon and Robert Esnault-Pelterie. (Gibbs-Smith 1966: 54–56; Gibbs-Smith 1974). The Wright craft were directly imitated in Europe more than a year before the Wrights had flown their first airplane successfully and continued to be copied until they began enforcing their later patent.

Thus in key instances, imitation led to advances. The designs of Penaud, Lilienthal, and Hargrave were copied by Chanute; the Wrights copied Chanute's glider; then the Wright gliders were ancestors of most airplanes in Europe as well as the United States. It seems that the experimenters had a norm—even if a design had been patented, copying it was allowed.

4. Inculcation, Monitoring, and Enforcement

The exchange between Wright and Chanute quoted above shows one way sharing norms were nurtured. In writing that "only those who are willing to give as well as to receive suggestions can hope to link their names with the honor of its discovery," Wright may have stated his actual beliefs; we cannot know for certain, but it is certainly the case that he chose to make statements of belief in cooperative sharing in his uninvited first letter to an important man in the field. In essence, this letter was Wright's bid to become part of the inner circle of Chanute's correspondents. Chanute was a unique and authoritative figure, an important author on the subject of aeronautics and aviation, a person who knew the major experimenters, a man who had done major experimentation himself, and a person whose preferred norms of scientific interaction were known. Wright likely knew that Chanute propounded sharing norms and chose phrases that would harmonize with Chanute's preferred norms. In this way, Wright asserted his qualification for membership in an implicit community that Chanute was known to imagine and believe in. Wright acknowledged in advance his intellectual debt to Lilienthal and to Chanute himself in the design that he would put into practice.

In our language as analysts of commons: Chanute, a central figure in the community, had asserted that there was or should be an aviation commons. He had declared his preferred norms for this commons and invited interaction on the basis of those norms. Wright was interested in aircraft, but probably not as interested in the scientific commons as Chanute was.[21] Nonetheless, Wright stated his acceptance and belief in those norms in his request for Chanute's acceptance, support, and advice. Both parties understood that if he were going to make aircraft, Wilbur Wright would benefit from Chanute's experience, contacts, and mastery of the field, possibly including tacit knowledge that Wright would not get from public documents. Wilbur also wanted to be in good standing with the influential Chanute, apart from any specific information he might get.

The parties understood, I think, that intellectual property laws were not likely to limit Wright's future actions. There was no history of using the mechanisms of intellectual property law on designs and devices for aerial navigation. We do not know what either of these men actually believed about whether or not the imagined future inventor of the airplane would make a profit. The exchange suggests, however, that support for the copying norm may have been an important step in obtaining entry to the inner circle of correspondents in the field.

One important scientific norm is the norm against making exaggerated or dishonest claims, particularly as to priority of discovery. In science generally, punishments for violating this norm are rare, spotty, and slow, however. That also was the case among aviation experimenters. For example, while there were criticisms of the honesty of experimenters Gustave Whitehead and Augustus Herring, they were not actually punished very much so far as I can tell. Whitehead claimed to have flown a real airplane in 1901, but the evidence for this is weak, and it is not clear why, if he had done this, he would have stopped

[21] Chanute imagined a scientific society and acted as if it were there. In sociological language, it was an *imagined community* in his mind. He made it more real—reified it, and institutionalized it—by using his influence to declare it existed and by acting according to its norms. There were no sharp membership definitions identifying a single community of investigators of aerial navigation. The analysis of Macey (2010) helps frame socially constructed commons such as this one.

his experiments. Herring convinced engine expert Glenn Curtiss to cofound a company with him based partly on the false claim that Herring held aviation patents. Presumably, the reputations of Whitehead and Herring suffered in the 1900s, but any such punishment in the commons context was weak.

Clément Ader, the military engineer mentioned earlier, who did not participate in the commons, made claims after 1906, that he had flown in the air in the 1890s. His claims produced a great deal of conflict. A widespread nationalistic view developed among French aeronauts and aviators that Ader had flown first and been cheated of credit. Aviation historian Charles Gibbs-Smith carefully investigated Ader's experiments and claims and found convincing contemporaneous evidence that Ader did not make a controlled flight in the 1890s. The documented evidence of the time by Ader's funders in the French military did not report a controlled flight; the wings on his craft were too small and weak for controlled flight; his main experiments occurred along a circle not on a straight runway that would have enabled his craft to build up speed; the military eventually withdrew his funding; and Ader, who was independently wealthy and probably could have continued his experiments, ceased his aviation experiments at that time. Moreover, Ader's claims to have flown in the 1890s first appeared only after 1906, by which time others were known to have achieved flight (Gibbs-Smith 1968).

Examples such as these were rare, however, and the norm of giving proper credit appears to have functioned reasonably well. The viability of these norms probably was important to the success of the commons. In principle, potential contributors to a commons will refrain from contributing if they believe others are likely to profit from their contributions, while they themselves do not benefit. People are averse to being made "saps" or "suckers" (Gordon 2010). In the aeronautical context, potential participants had several reasons to expect not to be put in such a position, however. Potential participants could see that there were systems of documenting contributions through publications, patents, and other mechanisms of visibility. These mechanisms of recording priority of discovery made misappropriation of credit more difficult. They could observe that smart and wise people were contributing to the published literature and that there was no history of anyone misappropriating credit for such contributions. Because aeronautical knowledge wasn't very useful during this period, there may not have been particularly large incentives for misappropriation. As a result, though there were exceptions such as Ader, misappropriation of credit does not seem to have been a serious problem for which a serious punishment system was needed.

There was also a norm against secrecy. It was understood within the community that if an experimenter was keeping key findings secret he was implicitly choosing not to support progress by others. There were gentle criticisms of secrecy in some cases, for example by Chanute against Clément Ader. Since Ader was not an active participant in the commons, however, he was not particularly sensitive to any reputational sanctions.

These norms were sustained informally, as "soft law." I find little evidence that there were any formal processes to inculcate, monitor, or enforce them. It seems to me that it was possible to violate the norms nearly with impunity; a violator would not even lose access to open-minded figures such as Chanute. The significance of the norms, to my mind, is that they were strong enough to sustain the developments that in fact led to the invention of the airplane. The story of the Wrights is utterly interwoven with these developments. Without Chanute and the open scientific community of which he was a part, the invention of the airplane would have taken longer and it does not seem likely that the Wrights would have stuck with their research experimentation long enough to do it.

V. After Reaching the Goal of Controlled Flight

The aviation knowledge commons did not survive its own success in reaching the goal of controlled flight. As airplane manufacture became a new industry, assertions of exclusive rights increased. Eventually, the competing assertion of such rights posed serious problems for the supply of aircraft to the military during World War I. The U.S. government then stepped in to create a new kind of patent-based sharing regime—a patent pool.

A. Jockeying for Position in the New Industry

By late 1902, the Wrights had made important technological advances in control systems and in the shapes of wings and propellers. They behaved strategically, according to principles different from those of the commons. Crouch (1989: 296) puts it this way:

> 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 [of 1901 and 1902] had changed their attitude.

The environment changed after the Wrights obtained their patent, which was filed in 1903 and granted after much back and forth in 1906. According to one historian, the Wrights tried to avoid photographers, reporters, and other visitors from 1903 all the way up to 1908, when they felt ready to manufacture and sell airplanes and to enforce their patent (Tise 2009: 37–41). They started a U.S. company, attempted to get military contracts, and started to license to new companies in Europe. Their patent was interpreted broadly by the U.S. courts, and they enforced it vigorously, not only against manufacturers but also against aerial performers and exhibition companies.

Effectively, the Wrights switched away from the commons narrative entirely. They adopted another nineteenth-century narrative: the narrative of the great inventor (such as Thomas Edison or Alexander Graham Bell) who makes a breakthrough, then owns it through a patent, and manufactures it in quantity. That narrative incorporates a public purpose too: mass production makes new breakthroughs broadly available to ordinary people, and prices fall.

The Wrights' secrecy and tight hold on patent rights led to conflicts with Chanute, airplane maker Glenn Curtiss, and others. For narrative clarity it would be easy to personalize this story as a conflict between Chanute and the Wright brothers. But the conflict was intrinsic to the new situation; even if Chanute and the Wrights disappeared, the conflict would remain as the environment underlying the earlier commons changed. By 1908, multiple inventors had flown airplanes, both in Europe and in North America. The basic technological uncertainty had been resolved; specialists knew that airplanes would work and believed there would be a market for them and for related inventions and patent rights. The aviation commons would be under strain once a truly useful airplane was on the verge of appearing. Indeed, counts of aeronautical patents jumped in 1907, as shown in Figure 10.2, and went much higher after that. (Please refer to "Figure 10.2 Count of Aeronautics-Related Patents by Year, 1860–1907. Source: Author's sample, under development," located between pages 360 and 361). In this sample of patents, the annual flow had been increasing at a rate of 4–5 percent up to 1907, then in this start-up industrial period it spiked sharply at a much faster rate.

A wave of airplane companies appeared starting in 1908. Many were relatively open to outside visitors and to clubs, but they also were driven toward the industrial logic of competition, of conducting product-focused research and development, and of keeping certain findings and inventions secret. Though patents per se were old news, a new population of aeronautical experimenters entered the scene with different norms about sharing information. Intellectual property principles came to the field of flying machines.

After the modern airplane was invented and an industry of airplane makers was established, social activity centered around aviation shifted. There were huge and growing numbers of local aviation clubs and a growing number of aviation publications. The new clubs could focus on aviation as a real activity, using manufactured airplanes and parts, as well as on the long-standing goals of discovery and invention. The makers of airplanes were mostly manufacturers; the manufacturers had patents; and now the patents functioned as intellectual property.

The numbers of aviation-related conference and exhibitions grew, according to my data, from somewhat more than one a year from 1900 to 1907 to four in 1908, eleven in 1909, and thirty-five in 1910. An enormous ten-day exhibition near Los Angeles in January 1910 drew 250,000 attendees. In 1911 or 1912, after many people already had seen the flying machines for the first time, the numbers declined.

B. THE ENFORCED PATENT POOL

The Wrights sued exhibition companies that showed aircraft that infringed on their key 1906 patents, as well as Curtiss's manufacturing company. In the process, they lost public support, but they were generally successful in U.S. courts, which defined theirs as a "pioneering" patent, deserving of broad scope. European courts judged it to cover, more literally, a particular kind of control system in which the tips of the wings were controlled and were wired directly to the tail.

The legal battles over the Wright patents became more vicious, and the positions of the opposing parties more entrenched. Allies of Glenn Curtiss made extended efforts to undermine the Wright patent by claiming that it purported to cover designs that were prior art. Allies of the Wrights, allies of Curtiss, and others accumulated patents and used them to block one another's progress (Johnson 2004). The companies were investing more and more, but it was in a zero-sum battle, not resulting in significantly better aircraft from the U.S. industry.

The conflict occurred partly because the earlier commons was too weak and had not prepared the community to manage a situation in which participants held such an important patent. The information was never legally in a commons and the norm-based equilibrium was destabilized when the technological situation and paradigm changed. The Wrights were able to use their technological edge to get a legal monopoly on almost all aircraft, normal competitive industrial dynamics were stymied, and there were unproductive battles in the courts.

Experts disagree on whether this "patent thicket" and its associated hostility delayed the progress of either aviation technology or commercial aviation in the United States. (With future data, I hope to determine quantitatively whether there were significant differences between U.S. and European firms, publications, patents, and so forth after 1910.)

Eventually, the U.S. government intervened to end the patent battles. During World War I, the U.S. military intended to buy airplanes, but the largest airplane makers, associated with the Wrights and with Glenn Curtiss, were locked in patent battles. In 1917, top officials of the U.S. government pressured the major airplane makers to enter a cross-licensing agreement—a patent pool—and to create a joint organization called the Manufacturers Aircraft Association. According to the analysis of Bittlingmayer (1988), this government intervention enabled the airplane makers to overcome anticommons in which at least two companies—the Wright-Martin Company and the Curtiss Aeroplane Company—had mutually blocking patents. While this arrangement was a commons, it was not a return to the old style that was open to all; in this cross-licensing commons, only airplane companies were members, and the property in common was well defined (Johnson 2004).

VI. Conclusions

The inventive commons of the 1810–1910 period built up shared knowledge of discoveries and designs in the aeronautical field. Devoted, self-directed experimenters, in many countries were driven by their own enthusiasm to create aircraft, models, and other key inventions, which after a very long time brought forth actual airplanes that could carry passengers, thus addressing a long-time dream. By contrast hierarchical, directed research and development on this problem was rarely attempted and did not solve it. Technological uncertainty was very great, and so it was left to a public commons, with experimenters following open-source practices, to solve it.

There is ambiguity about what materials were in this implicitly shared scientific library, because for one thing the boundaries of useful aeronautics research were not clear. The point I emphasize is that the patterns of behavior which worked to advance the field were specifically advocated by a number of the most effective experimenters. They had a vision of what the open scientific enterprise could achieve, and very slowly, it achieved that vision. Many of the materials that made up the commons were not legally in the public domain and initially were not easy to access. It was important that some, notably Chanute, specialized in communications, sending hundreds of letters, advocating sharing, and writing a clear book that brought dispersed knowledge together in an accessible place. Chanute was an active evangelist. Others showed leadership in other ways: Hargrave published his experimental results without filing any patents; Langley demonstrated that a serious academic could study the subject of aerial navigation and flying machines; Lilienthal was a respectable engineer but also a charismatic demonstrator of gliders who got public attention. Thus there was a kind of space for potential entrants to see that the field of flying machines was a real one.

The commons space supported the copying by one innovator of another's design, which helped them to specialize and, in a way, standardize on a design. The actors in the commons space also did not attempt to enforce their patents in the early stage before the goal of aerial navigation was achieved. When an airplane finally was built, it was based mostly on designs which were in common view. Once an airplane was built, however, the commons was vulnerable to commercial pressures and patent enforcement. When patenting lead to stalemate, the government stepped in to impose a different kind of knowledge commons—a patent pool. Thus, a knowledge commons supported the creation of a new industry which has grown for a century afterward.

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