The great aviation patent spike of 1910

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Abstract
This paper shows how aeronautics and aircraft patents in the 1880-1914 period reflect the technological and industrial environment. Findings are based on a detailed data set of most of the international aeronautics patents in this period. There was a long term steady increase in the numbers of aeronautics patents. When it became widely understood that controllable airplanes were a viable technology, there was a sharp increase in patents from about 1906 to about 1910. An industry of airplane makers started up at that time. After 1911, the numbers of patents declined. This spike seems to have been driven both by growing numbers of individual patent filers and by inventors filing patents in more countries. It does not seem to be have been driven by the research efforts of airplane manufacturers. Airplane firms took on more ownership of patents during World War I.

Keywords: patents; innovation; aeronautics; aviation; technology; new industry; startups

Introduction

In the late 19th century an increasing number of engineers, scientists, and hobbyists experimented with flying machines. Many were drawn to visions of how to fly as birds do, or in some other artificial way that would be more effectively controllable than a balloon. A technological and scientific field focusing on "aerial navigation" gradually developed, with its own terminology that became standardized across languages. These experimenters were mainly in France, Britain, Germany, and the U.S.

The aerial navigation experimenters used several fundamentally different technologies. Hot air balloons and hydrogen balloons were known to work, and some experimenters made more-steerable versions, called dirigibles. Others made models with mechanical flapping wings, called ornithopters. Others focused on gliders with fixed wings, or propulsion with propellers that would work for either balloons or gliders.

Increasing numbers of journals and societies were devoted to ballooning, flying machines, and the challenges of "aerial navigation," which was later called aeronautics. This paper shows measures of patenting activity in these areas. In the 1890s the field received new attention when there were public hang glider flights.

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[1] Preliminary and incomplete; please do not cite. Disclaimer: Views expressed here are the author's and not necessarily those of the Bureau of Labor Statistics. I thank Leo Zimmermann and John R. Herbert for their extremely valuable research assistance. Comments are welcome.

Dramatic public demonstrations of powered gliders around 1906 changed how many people thought about the field. The numbers of publications and patents increased sharply beginning in 1907. A wave of new airplane-making firms started up across the industrialized countries in 1908. In the next few years, dozens of exhibitions of airplanes were held and hundreds of new local aviation clubs appeared.

Patent flows show a sharp change too. Annual patent applications for aeronautics technologies more than quadrupled worldwide from 1907 to 1910. Since then, aeronautics has never represented as large a proportion of all patents. The absolute numbers of aeronautics patents declined in 1912 and fell sharply during World War I.

This paper will compare attributes of patents over time to identify aspects of this peak around 1910. The context was turbulent and confusing. Airplanes worked, on a small scale, and an exhibition of them could draw a crowd, but they were not generally useful or robust. A new industry was appearing, but it was not profitable. So far as we can tell, relatively few of the patent-filers actually worked in the new industry. And many patents were associated with technologies other than the newly dominant airplanes: balloons, dirigibles, helicopters, and ornithopters. An analysis of the patents could illuminate what the inventors were thinking, both technologically and in terms of how they would relate to the new industry. Patent data, though peculiar, makes up a consistent and comparable stream of information across time and countries, even as the historical context changed drastically.

The data show that the numbers of aeronautics-related patents grew by about 5-7% a year from the 1870s to 1906, then jumped sharply upwards until 1909-1910, then declined in or after 1911 and continued to decline in World War I. These trends were similar across countries. The spike in patents included a temporary increase in balloon and other designs and topics, but is mainly associated with a shift to fixed-wing airplanes. That is, the shift to fixed-wing designs as a proportion of patents begins before this and continues in this period.

When inspecting what is different about the patents in the spike period from their predecessors, we have only partial answers. There is some increase in the numbers of foreign filings – that is, a patent that is substantively a duplicate of one in another country, by the same inventor. There is a slight increase in the number of patents explicitly associated with a company, but the overwhelming number still appear to be by individual inventors who have not yet sold the rights. Few patents appear to be funded by company research and development until World War I.

The next sections discuss what patents were in the period under study, some of the challenges in interpreting and comparing them across time and place, and some preliminary statistical results of these comparisons.

Patents of the time

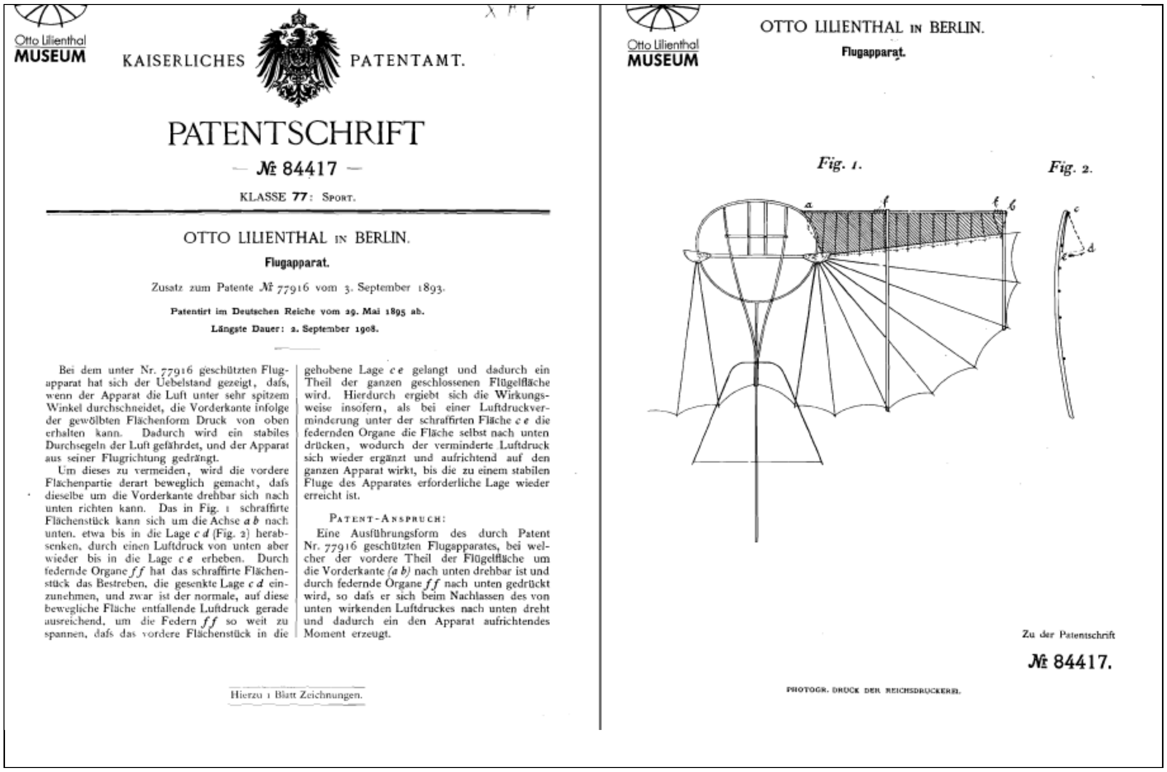
For our purposes here, a patent is an indication of creative technological effort and an attempt to certify it. The concept of a patent and the system for administering a patent was evolving and becoming standardized. Formally, a patent is a legal claim to intellectual property which is novel, feasible, and useful. The inventor applies to a government for a patent, stating what the technology is, showing diagrams of it, and making legal claims of originality. (The inventors did not have to demonstrate feasibility then as much as they do now.) If the government grants the patent, the inventor has a right to a temporary monopoly to sell versions of the technology specified in the patent in that country. The governments numbered the patents and published the inventor's description. Patents different across countries somewhat, more than now, but by 1880 they generally met this description.

In many fields, such as railroad or mine engineering, a patented technology would be put to use commercially within a year. Commercial sales were a smaller factor for balloons and aerial navigation. The inventors were trying to make flying work, and less often trying to make or improve a product. We know of no patent infringement disputes in this area before the Wright brothers. So why did the inventors patent in a field like aerial navigation? It would be helpful if they had written their reasons for patenting in this area. We can make some inferences.

Many of them were engineers, and it was a professional pattern and a potentially prestigious professional accomplishment to record their work as a patent. If there were a future in aviation, the patentees could get some credit or make some claim to the proceeds. Then too, patenting was sometimes glorified in that era. Thomas Edison, Alexander Graham Bell, and Nikola Tesla had been recognized as founders of industries and held control of companies partly by patenting their inventions. The most important U.S. patenting agency, Munn & Company also published Scientific American, which emphasized patenting as useful, constructive, and a way to help create the future (Alexander, Miller, and Pierce, 2014). Cresee (1902), a Munn publication, told readers that most patents were profitable for the inventors. Furthermore in technical publications lists of patents were published regularly, giving visibility to those who patented their inventions.

For aerial navigation, some early experimenters thought it was best not to patent – not to make any claim of intellectual property – at least until the technology had been shown to work. Lawrence Hargrave and Alberto Santos-Dumont took this view, which we may call an "open-source" view. Once an expanding industry existed, it is clearer why the inventors would make the effort to patent. They could sell or license a patent's technology, much more easily than by manufacturing a product themselves. There is a complicated historical transition between the open-source phase and the industrial phase, which economists have not much modelled, and an understanding of the airplane case may help.

Figure 1 shows an example patent specification from 1893. The invention shown is an important glider designed by Otto Lilienthal of Berlin, with wings in roughly the shape of those of a soaring bird. The patent filing illustrates certain elements most 19th century patents: a number in the national government's ordering scheme, a title, the patentee's name and location or citizenship, the date it was applied for ("filed") and the date it was granted, and a diagram. This one is only two pages long, shorter than most patents of the time and much shorter than patent filings now. Its title is "Flugapparat," meaning "flight apparatus." Patent officials classified it by its technology, but the classification in this case is "Sport." No more precise aeronautics category existed in the German system at that time.



Otto Lilienthal MUSEUM

KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 84417 —

KLASSE 77: SPORT.

OTTO LILIENTHAL IN BERLIN.

Flugapparat.

Zusatz zum Patente № 77916 vom 3. September 1893.

Patentirt im Deutschen Reiche vom 29. Mai 1895 ab.

Längste Dauer: 2. September 1908.

Bei dem unter Nr. 77916 geschützten Flugapparat hat sich der Uebelstand gezeigt, dafs, wenn der Apparat die Luft unter sehr spitzem Winkel durchschneidet, die Vorderkante infolge der gewölbten Flächenform Druck von oben erhalten kann. Dadurch wird ein stabiles Durchsegeln der Luft gefährdet, und der Apparat aus seiner Flugrichtung gedrängt.

Um dieses zu vermeiden, wird die vordere Flächenpartie derart beweglich gemacht, dafs dieselbe um die Vorderkante drehbar sich nach unten richten kann. Das in Fig. 1 schraffirte Flächenstück kann sich um die Achse *a b* nach unten, etwa bis in die Lage *c d* (Fig. 2) herabsenken, durch einen Luftdruck von unten aber wieder bis in die Lage *c e* erheben. Durch federnde Organe *f f* hat das schraffirte Flächenstück das Bestreben, die gesenkte Lage *c d* einzunehmen, und zwar ist der normale, auf diese bewegliche Fläche entfallende Luftdruck gerade ausreichend, um die Federn *f f* so weit zu spannen, dafs das vordere Flächenstück in die gehobene Lage *c e* gelangt und dadurch ein Theil der ganzen geschlossenen Flügelfläche wird. Hierdurch ergiebt sich die Wirkungsweise insofern, als bei einer Luftdruckverminderung unter der schraffirten Fläche *c e* die federnden Organe die Fläche selbst nach unten drücken, wodurch der verminderte Luftdruck sich wieder ergänzt und aufrichtend auf den ganzen Apparat wirkt, bis die zu einem stabilen Fluge des Apparates erforderliche Lage wieder erreicht ist.

PATENT-ANSPRUCH:

Eine Ausführungsform des durch Patent Nr. 77916 geschützten Flugapparates, bei welcher der vordere Theil der Flügelfläche um die Vorderkante *(a b)* nach unten drehbar ist und durch federnde Organe *f f* nach unten gedrückt wird, so dafs er sich beim Nachlassen des von unten wirkenden Luftdruckes nach unten dreht und dadurch ein den Apparat aufrichtendes Moment erzeugt.

Hierzu 1 Blatt Zeichnungen.

Otto Lilienthal MUSEUM

OTTO LILIENTHAL IN BERLIN.

Flugapparat.

Zu der Patentschrift

№ 84417.

PHOTOGR. DRUCK DER REICHSDRUCKEREI.

Figure 1 – Otto Lilienthal's 1893 patent

Four countries granted by far the most aeronautics patents: France, Britain, Germany, and the U.S. In each country patents of all kinds, and for aeronautics in particular, grew exponentially for decades up to 1906 at rates of 5-7% per year. The spike that followed was distinct to the field aviation. The data set makes it possible to contrast the numbers of domestic patentees and foreign ones to see whether the patentees came mainly from these four countries, or rather they chose to patent in these countries; such results are not available yet.

Patent data sources and their challenges

Documentation and availability of historic patents

Patent specifications and data are published by national governments. Historical data from before the early airplane period is not always online, or not conveniently so. We received a data set from the European Patent Office via the UN's World Intellectual Property Organization. For the earliest periods, much of it must been gathered eclectically by searching for key words, patent categories, or individuals in various online systems and compilation volumes. The specification document is often not available for 19th century patents and we make inferences from some brief summary or database record. For more about the sources, see appendix A.

Most patents are first-time specifications of original work. There are two other types of patents which we count but would consider as secondary. These are *additions* and *foreign filings*. An *addition* is auxiliary information about an invention filed with one national office. If approved it becomes part of the package represented by the original patent, and has the same priority date, as if it were part of the original. In our data, additions were common in France and Belgium, but uncommon elsewhere. We can identify about 450 of these so far.

Foreign filings are substantively identical to a previous patent application, but filed in another country. It is not always clear that a patent specification is a foreign filing; it may not explicitly refer to its predecessor. Documentation on this became clearer over time. The Paris Convention of 1883 gave an incentive to make the connection explicitly. In uncertain cases, our working principle is that if the diagrams in two patents are the same, one is a foreign filing of the other, and if the diagrams are not the same, they are distinct originals.

Overall, additions and foreign filings make up about 9% of the sample so far. A set of an original (or parent) patent and secondary patents is nowadays called a patent family. The secondary patents, also called child patents, are less important than new original (parent) patents as indicators of new inventive activity, but for this paper we count them as patents just like the first/original patent. Over time we are recording these links more explicitly and correctly in the data, and in future work can discount the secondary patents.

Relevance to aeronautics

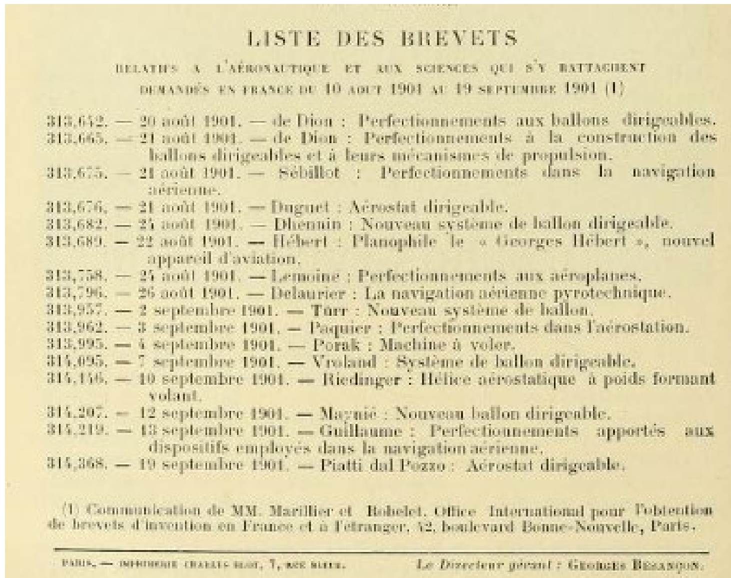
Which patents are relevant to aeronautics and aviation? Drawing that line is difficult for several reasons. First, it is not always easy to get general lists of all patents especially before 1890. The U.S. is the easiest country for this as it has scanned all patents back to 1837 online.

Second, the technological classifications of the time do not identify aeronautics clearly. The classifications differed by country, and the official patent category systems of the time adapted differently to handle the new field of aeronautics. We apply keywords to each patent to standardize these, and for many historic patents the newer IPC and CPC technological classifications have been applied. In the case of Lilienthal's patent, the title includes the term for flight, which is one clue, and the patentee was famous for his accomplishments in this area so a museum and several books have listed this patent.

Third, there is the underlying uncertainty about which patents had implications for aeronautics at a time when it was not known that the soaring-bird model of an aircraft would be more successful than balloons, rockets, helicopters, or flapping-wing ("ornithopter") designs. Potential new technologies are associated with deep uncertainty.

Journals and reference works sometimes identified patents related to aeronautics according to contemporaries. Figure 2 shows an example. Like many such lists, it helps identify which patents were relevant, but does not give much detail about each patent.

Figure 2. List of aeronautics-related French patents from a 1901 issue of the journal *L'Aérophile*



LISTE DES BREVETS

RELATIFS A L'AÉRONAUTIQUE ET AUX SCIENCES QUI S'Y RATTACHENT
DEMANDÉS EN FRANCE DU 10 AOUT 1901 AU 19 SEPTEMBRE 1901 (1)

313,652. — 20 août 1901. — de Dion : Perfectionnements aux ballons dirigeables.
313,665. — 21 août 1901. — de Dion : Perfectionnements à la construction des ballons dirigeables et à leurs mécanismes de propulsion.
313,675. — 21 août 1901. — Sébillot : Perfectionnements dans la navigation aérienne.
313,676. — 21 août 1901. — Duguet : Aérostat dirigeable.
313,682. — 24 août 1901. — Dhennin : Nouveau système de ballon dirigeable.
313,689. — 22 août 1901. — Hébert : Planophile le « Georges Hébert », nouvel appareil d'aviation.
313,758. — 24 août 1901. — Lemoine : Perfectionnements aux aéroplanes.
313,796. — 26 août 1901. — Delaurier : La navigation aérienne pyrotechnique.
313,957. — 2 septembre 1901. — Torr : Nouveau système de ballon.
313,962. — 3 septembre 1901. — Paquier : Perfectionnements dans l'aérostation.
313,995. — 4 septembre 1901. — Porak : Machine à voler.
314,095. — 7 septembre 1901. — Vroland : Système de ballon dirigeable.
314,156. — 10 septembre 1901. — Riedinger : Hélice aérostatique à poids formant volant.
314,207. — 12 septembre 1901. — Maynié : Nouveau ballon dirigeable.
314,219. — 13 septembre 1901. — Guillaume : Perfectionnements apportés aux dispositifs employés dans la navigation aérienne.
314,368. — 19 septembre 1901. — Piatti dal Pozzo : Aérostat dirigeable.

(1) Communication de MM. Marillier et Robelet, Office International pour l'obtention de brevets d'invention en France et à l'étranger, 42, boulevard Bonne-Nouvelle, Paris.

PARIS. — IMPRIMERIE CHARLES BLOT, 7, RUE BLEUE. *Le Directeur gérant* : GEORGES BESANÇON.

We do not classify and catalog every patent with technological relevance for aeronautics, if it does not mention of the field. We only rarely record patents on motors or engines although the development of light ones was important for the development of heavier-than-air flight. Both steam engines and internal combustion engines were put to use on aircraft. Most patents on motors do not mention aeronautic applications. They were and are classified differently. Most were oriented to automobiles, and some to locomotives. Many other areas including machine parts and materials had relevance to aviation. For the purpose of this study we focus on patents which declare themselves relevant by noting aeronautical applications in the patent specification We have marked some patents as marginally relevant (e.g. marine propellers and windmills), and can include some such marginal cases in some statistics for comparison.

Quality hurdles met by each patent

The quality and length of patents varies substantially. The national patent offices had idiosyncratic rules, criteria, and fees for granting a patent. These were described from time to time in handbooks, generally written by attorneys offering international patent services. Some required each patent application to be evaluated carefully by a patent examiner for whether it met the main criteria of originality, feasibility, and usefulness. The German patent office had the highest standards. The U.S. Patent Office also required each patent to be examined. These examiners were professionals with some technical training and experience.

The British and French offices did not have an examination system, but instead a registration system, with lower criteria. Patents would be judged acceptable for registration without a careful technical evaluation, and a fee collected. The originality of the patent would be left for disputes in court. In a patent lawsuit, a potential user of the technology could show evidence that prior art already included the patented technology, and if successful such a lawsuit would limit or nullify a patent's claims.

Patents granted in the British and French systems therefore met a lower standard than those in the German system, and were more numerous than German ones. From reading the patents, it seems likely that there was more duplication among the British and French granted patents, and they are less likely to be clearly written and sharply defined. There may be some way to measure or demonstrate this. We are collecting information on the practices of national patent offices.

The ever-improving data on patents are online at the Inventing Aviation web site at http://econterms.net/aero. Each patent has a wiki page there. The wiki pages have standard data on each patent's filing year, inventors, title, and so forth, and also space for images from the diagrams, links to external sources and references to the patent, and space for our casual description of it, our own classifications for it, and any related narrative or discussion. Wiki pages on inventors, authors, companies, publications, and airplane clubs and societies are also linked to the patents. With some additional knowledge about patent institutions, the data make it feasible to compare across countries, across time, and across technologies.

Each patent has a variety of ambiguities and uncertainties, e.g. misspellings, classifications, and relevance to aeronautics, which can be addressed on the wiki pages. This wiki technique can be useful to other historians who wish to get summary statistics from data in which each object is complicated, ambiguous, and interrelated with others.

Aero patent counts across countries and time

The goal is to standardize the data enough to compare patents across countries and over time on several dimensions. Most of the relevant patents were filed in France, Britain, Germany, or the U.S. A challenge is that patents do not each stand alone as singular accomplishments. We show some preliminary comparisons, treating foreign filings and additions just like original patents for now. Patent counts in aeronautics grew at rates of 5-7% per year in these countries up through 1906 as shown in Figure 3. This is similar to the rates of growth of patents overall, in all fields, in that period. For about a third of these, the filing year is imputed from the grant year.

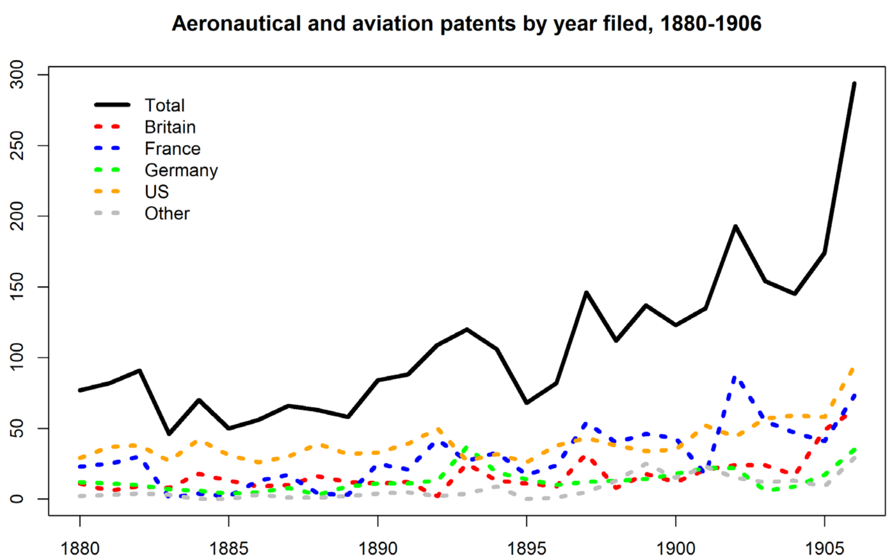


Figure 3 – Patents per year related to aeronautics and aviation before the airplane industry began, showing exponential growth then a sharp increase in 1906. When filing year is not available but grant year is available, (grant year minus one) is used as an estimate.

An estimate of publications excluding patents, in the field of aeronautics from Brockett's 1910 *Bibliography of Aeronautics* grows at a similar exponential pace, shown in figure 4. These two charts give proxy measures of the growth of aeronautics as a field.

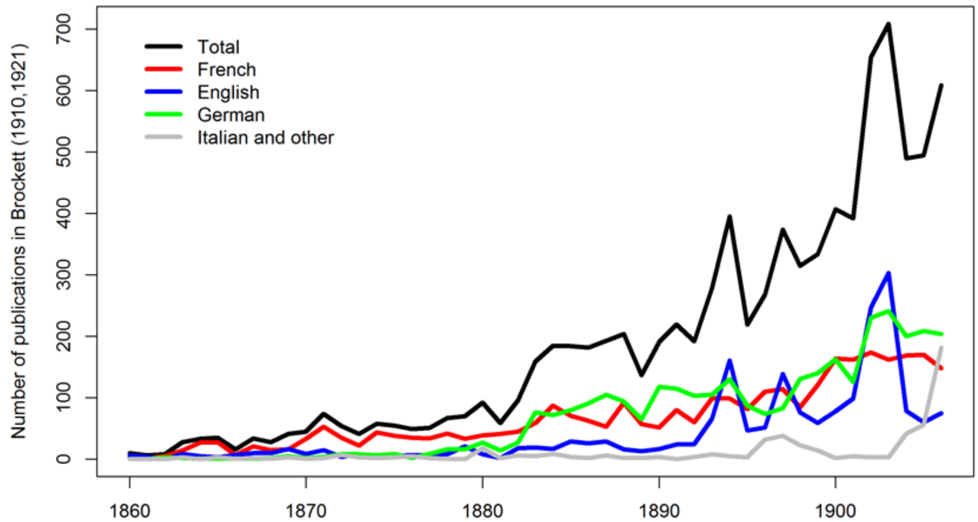


Figure 4 – Aeronautics and aviation publications per year, mainly from Brockett (1910)

Patent counts rise sharply after 1906, peaking in 1909. Figure 5 shows patent counts by filing year, that is, the year the inventor filed the patent application. A chart by the year granted is a bit more spread out. For some patents we have not yet filled in a proper grant year; in these cases we filled in the year of filing plus one; this is a plausible estimate in general. British patents peak ahead of other countries here, which may be an artefact of our imputation of filing years. After more data cleanup, the peak for British patents may match the others.

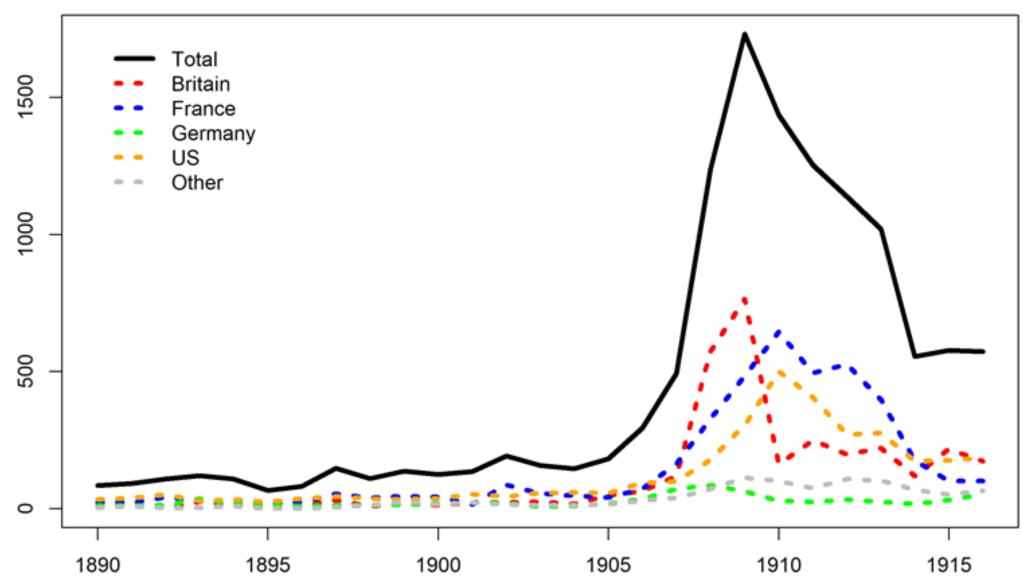


Figure 5 – Aeronautics-related patents per year for selected countries 1890-1916. Filing year is estimated by (grant year minus one) if it is not otherwise available.

What did the inventors do to cause the spike?

The spike in patent numbers is stark. It was associated with the new technical and financial opportunities in aviation. If we could understand that better, it could give us a sense of which institutions help the invention and the industry appear. Here are some hypotheses about inventor behavior in the spike period to test in the patent data over time.

- *More people were drawn to aeronautics, and filed patents in an area that is new to them -- perhaps a Gold Rush – it was new and hot and apparently feasible*
- *Inventors are filing more additions to patents than they did before.*
- *Inventors filed in more countries than before ("foreign filings")*
- *In some other way, inventors filed more patents for each invention than before*
- *Inventors put more time or resources into aeronautics experimentation than before*
- *Inventors started or joined firms and built intellectual property in them*
- *Inventors sold more of their patent rights to firms than before*
- *Inventors filed patents for inventions they'd already made, or would have made anyway, but wouldn't have patented*
- *Inventors filed more patents for inventions that overlapped or duplicated other patents*

These are data-scientific questions, that is, questions about what the patent data can tell us. Their answers do not fully address the larger motivating questions of how there came to be an airplane and an airplane industry, and what institutions and people helped that happen. Cultivating the data to answer these questions may help address the big questions however.

Direct measures of patent documents

Looking at each patent individually we can gather basic information about the documents. For many of the aero patents of France, Britain, Germany, and the U.S. we have the numbers of text pages, of legal claims made, and of diagrams. For the sample of patents for which these are coded, German aeronautics patents had on average about two pages of text. They were shorter on average than those in other countries, and had fewer diagrams, and made fewer legal claims. U.S. patents were the longest, averaging four pages, and they made more legal claims.

Kuhn (1962) hypothesized that when a new scientific paradigm appeared, texts about it would be lengthy as the writer had to explain the concepts at length. With time, as the paradigm became established, the texts would use a more concise standard vocabulary. In this data, however, holding country differences constant, there does not seem to have been much change in the length of aeronautical patents over time even as new concepts and designs became dominant. Perhaps the heavier-than-air paradigm still called for lengthy explanation in 1910 documents.

The text of the patents can be used in other ways eventually. Kelly, Papanikolaou, Seru, and Taddy (2020) have used the digitized text of all available U.S. patents to see which ones were influential in the sense that later patents used their terminology. According to their measures, the 1906 Wright patent is one of the most influential of all time. In future work we may look at its exact phrasing and compare to other terminologies, although we do not have digitized text.

The roles of firms

The new airplane industry did not have much revenue in this period, and it is difficult to measure. It appears that most revenues to the new industry came from exhibitions in this period, not yet from sales of aircraft. Exhibitions were sometimes huge; thousands of people came to the Reims 1909 exhibition, and the largest ever was in Los Angeles in early 1910 which had hundreds of thousands of attendees who paid on average on the order of a dollar for a day's admission. Other revenues to these new firms came from contracts to sell airplanes to the national militaries, and an occasional experiment with air mail. Airplanes were first used in war in 1911-1912. Revenues were small until World War I. Worldwide estimates of production and revenues do not seem to be available. Bilstein (2001) cites estimates of the value of U.S. aeronautical exports as about $100,000 in 1912 and $226,000 in 1914. Chadeau (1987, p. 435) estimates similar rates of growth in French airplane manufacture and exports, again from a small base.

The early airplane makers spun off or branched in from other industries. Klepper (2009) defines spinoffs as those where a major figure in one firm came from another, and finds that by this definition spinoffs were common in the early U.S. automobile industry around the same time. It is possible to apply that definition in this data. This project has identified 300 firms or organizations which made airplanes or were significant suppliers to airplane-makers. Many appear just once in the evidence because they were assigned a patent or are referred to in a newspaper or advertisement but are not known to have continued. To the extent it is possible to identify the company founders so far, they came mainly from engineering and manufacturing industries, e.g. machine parts, engines, cars, boats, motorcycles, and rail cars.

Firms could have several potential roles in a patent filing:

1) A firm or other organization may be a named applicant for a patent, along perhaps with a particular inventor. In these cases, the firm probably paid for the research and development that produced the patented invention.

2) A firm might buy or license the intellectual property. The legal phrasing is that they would be "assigned" the patent rights.

3) An inventor may have hired a patent agent – either an individual or a company – to help file the patent application to the patent office. In French and British patents the role of the agent was recorded on the patent document; in U.S. ones it can usually be inferred, with some difficulty, based on signatures on the diagrams. Firms may have used their own staff lawyers or other experts as patent agents, rather than hire one.

Figure 6 shows measures of the prevalence of these from a sample of our patents as a proportion of aero patents annually. Countries differ in their procedures; these are overall figures. These measures do not change much at the time of the patent spike. The rise in the number of company applicants is significant in the World War period, and is mirrored by a fall in the use of patent agents, possibly because companies had their own attorneys.

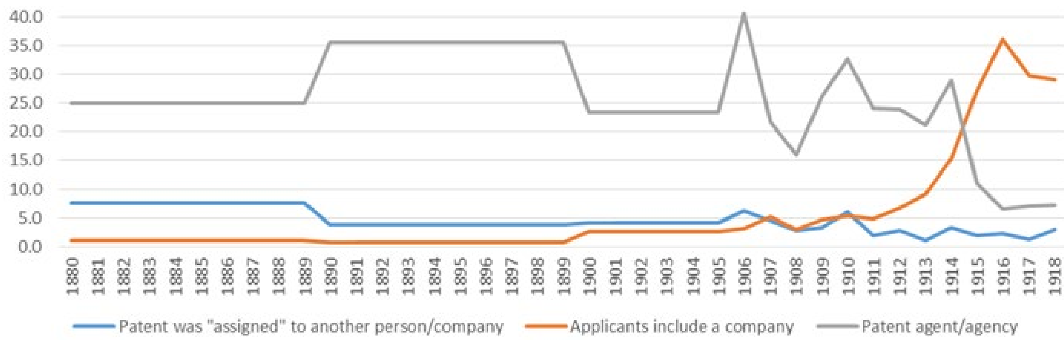


Figure 6 – Roles of firms in patents; shown as percentage of coded patents each year; figures for 1880-1889, 1890-1899, and 1900-1905 are averages to avoid spikes from thin data

Differences across countries

Four countries granted by far the most patents in aeronautics: Britain, France, Germany, and the U.S. Basic trends in patent flows appear to be similar across these countries. The other industrial countries have similar trends, perhaps delayed a bit. Many inventors were aware of work in their field in other countries and inventions are almost as quickly cited in other countries as in the first country.

A few effects are country specific. Patents numbers decline more in Germany and France during in World War I than in other countries. A great spike in aero patents in 1909-1911 (see Figure 1) is especially high in Britain and may be associated with more startup companies there than in other countries.

The Wright brothers filed major lawsuits in the United States in the period of the spike. They won in in the United but not in other countries. It is not clear from the data so far that this caused differences in aviation patenting patterns between the U.S. and other countries, either in terms of numbers or technological topics. The lawsuits were famous and influential, and there may yet be a detectable effect, but in principle the lawsuits could either have encouraged inventors to work on aeronautics and apply for patents, or driven them away.

Technology trends

Fixed-wing designs made up a larger fraction of these patents over time, as did patents related to control, stability, and safety. However, in the spike period there was an increase in patents for balloons and helicopters along with the recently-proven fixed-wing aircraft, suggesting that the patent boom was associated with a broad sense of opportunity and relevance, not tightly bound to the newly proven technology. Classification by technology required overcoming some challenges and adding to the original data, and it has been done for a large sample but not all the patents in Figure 3.

Figure 7 shows the proportion of patents associated with several issues and technologies. A patent may be associated with one or several technologies and we have not tried to adjust to scale to make each patent equally represented in the chart. We do not distinguish here between monoplanes and biplanes here because patents often could apply to either. Most of the early craft were biplanes, often made of wood. Monoplanes became more optimal when stronger metal materials and higher speeds are feasible. Some appropriate categories such as scientific instruments and navigation-and-control equipment are not yet included in the chart.

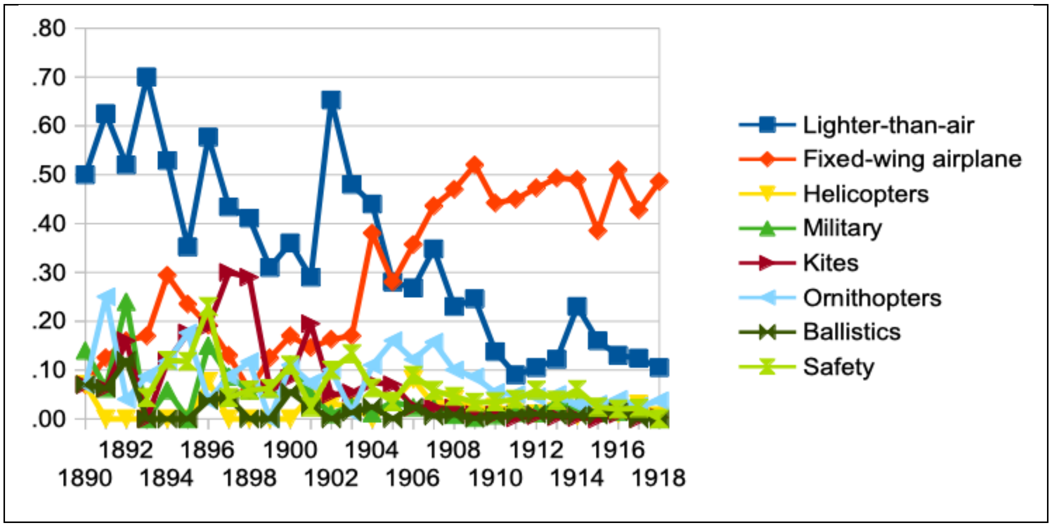


Figure 7 – Technology themes associated with aeronautic patents 1890-1918

From 1890 to 1918 the patents clearly associated with lighter than air craft decline as a fraction of aeronautical patents from around 50% to around 10%, and the patents associated with the new fixed-wing aircraft designs increased from about 10% to about 50%. We see the rise in fixed-wing aircraft starting in 1903, and it exceeds the balloons around 1909. Thus the fixed-wing aircraft was the new dominant design before it supported a strongly revenue-producing industry. Other technologies also seem to have a reduced proportion over time, and it may be possible to make a definitive finding about that at as the sample improves in the future.

Based on comparing the frequency of categories of aeronautical patents to others (mainly in Belgian data for now), it appears that aeronautics fell a bit more in the 1914-1918 period than other categories did. Presumably that is because it was a technology usable in the war, and there was more reason for various actors to keep new invention secret. In peacetime patents were usually granted or rejected within two years of filing, a significant number of the patents granted in 1919 and 1920 had been filed in 1913–5 and delayed.

Secondary patents

We have classified whether a patent is a foreign filing or addition in about 2/3 of the patent records. For all years and countries together, about 40% are in one these categories of “child patents” according to our estimates so far. This rises to about 46% in the 1909-1911 spike period. So that change is associated with some, but not much, of the increase. We have not yet tested whether additions (within the same country), or foreign filings, increased particularly. These are questions to be addressed further as the data fills out.

The decline after the spike

Why did aero patents decline after 1911? Here are three likely and overlapping explanations.

- The patenting frenzy simply went to unsustainable levels, and probably included more duplication among patents than before. Once patent examiners had mastered the new field, they didn't accept as many duplicates.

- The patent boom represented a blossoming of alternative designs in this period of excitement, but then the basic airplane designs were increasingly standardized, and patenting further required more specialization, more equipment, more time, so fewer inventors could do it.

- Revenues could not sustain all the firms, and there was an industry shakeout as many firms merged or went out of business. Military and postal contracts existed, but were not large enough. Passenger traffic was minimal. There were journalistic and scientific reasons to fly, but little revenue from it. Exhibition sales were the earliest source of big revenues, as huge numbers of people wanted to see an airplane fly, but by 1912 most of them had had their chance to see it. The numbers and sizes of exhibitions may be in decline by then, and presumably revenues too.

As World War I began, research and development expenditures on aircraft went way up but patenting did not. The underlying reason, presumably, was that aeronautics had military applications, and war technologies should not be openly published by people in country A, since they could be put to use by opposing country B. Patent rights from foreigners were sometimes seized – nationalized -- by the governments at war. Some patent applications were held up in the patent offices until the war was over. Others were granted but kept secret. Our database does not have enough cases of this to make empirical statistical statements yet, but in the long run we can measure the difference between filing date and grant date across countries and time periods, to see the effect of changes in the environment including the war.

Since airplane research and development went up while patenting did not, patent numbers are a poor metric for rates of innovation during the war. Counts of aeronautics publications have the same problem – they also fell before the war and stayed low during it, as a number of aeronautics journals explicitly reduced their frequency of publication during the war.

Conclusions

The data shows that the numbers of aeronautics-related patents grew by on the order of 7% a year from the 1870s to 1906, then jumped sharply upwards to a peak in the 1909-11 period, then began to decline. The decline may be associated with an industry shakeout. The numbers continued to decline in World War I. These trends are similar across countries. The spike in patents includes a temporary increase in in balloon and other designs and topics, but mainly is associated with a shift to fixed-wing airplanes. That is, the shift to fixed-wing designs as a proportion of patents begins before this and continued in this period. The patent-infringement lawsuits by the Wright brothers did not seem to affect the U.S. numbers compared to other countries

When inspecting what is different about the patents in the spike period from their predecessors, we have only partial answers. There is some increase in the numbers of foreign filings – that is, a patent that is substantively a duplicate of one in another country, by the same inventor. There is a slight increase in the number of patents explicitly associated with a company, but the overwhelming number still appear to be by individual inventors who have not yet sold the rights. Few patents appear to be funded by company research and development until World War I.

Appendix A: Data sources for historic patents

The European Patent Office (EPO) keeps a global database of patent documents with metadata. This is the most complete source. Julio Raffo and Intan Hamdan-Livramento of the UN's World Intellectual Property Organization made a data set from about 13,000 of these in the Patstat database available to Inventing Aviation and much of that data is now online in the wiki. These were based on searches in particular technical classifications.

To fill in all the desired fields requires looking at the original patent-grant documents, like the one in Figure 1. Most of these have been scanned by the national governments and are available from the public-facing EPO site http://espacenet.com. We search it frequently to fill in details from patents for which we have partial information, and to find others by the same inventors or with some other searchable characteristic. Google patents has many of these in a conveniently searchable way. Espacenet's coverage has been increased in recent years for the 1890-1910 period; we periodically discover historic patents there that seem not to have been there before. Espacenet does not include most patents filed before 1890.

Several national patent offices have digitized all their historic patents, or make a searchable database available. The US Patent and Trademark office has scanned all its patents back to 1836. National patent offices, especially the French INPI and the German DPMA, have some searchable information on the earlier patents. The Canadian, Australian, New Zealand, and Hungarian patent offices make some information about all their historic patents available online. Some of these systems require one to know a patent number to search for its information. We do not know how complete our coverage is but presumably we have most of the aeronautical patents worldwide before WWI by now.

Most of these governments published regular gazettes listing newly approved patents. Some of these are available online on Hathitrust, the Internet Archive, google books, and other online sources. Published volumes from national patent offices and the U.S. Patent Office of the time listed foreign patents. These are available at the US PTO's Scientific and Technical Information Center (STIC) library. There is more to do there, but it is closed during the covid era.

We judge whether a patent is relevant to aeronautics and aviation either by its classification or by reading it. If it refers to aircraft, we include it. In ambiguous cases we include a patent record, but mark it as only marginally related to aircraft. Our data includes some patents which are not related to aircraft in our judgment if they have certain attributes that help us – e.g. that it was filed by a person who also filed aircraft patents, and helps fill out their history, or if any secondary source has indicated that it was relevant to aeronautics. The wiki includes most relevant patents but not engines, yet.

The table below lists the countries with the most patents in our database, and the most significant sources. The main sources are espacenet, google patents, USPTO, and DPMA. For the oldest patents we usually don't have complete information, e.g. not the author's full name. From several countries the search is challenging as the inventors names are not recorded, or not recorded in a standard way.

Table A1. Patent data by country

Country (Abbreviation)	Patents in data	Notes on the country's early aero patent data
France (FR)	5036	Digitized and available on espacenet back to about 1900. There are a variety of earlier sources with summaries or lists: Online INPI.fr historic patent database, searchable from http://bases-brevets19e.inpi.fr/index.asp?page=rechercheAvancee. Patents were indexed in the *Catalogue des brevets d'invention* and *Bulletin Officiel de la Propriété Industrielle* in the 1880s; and in USPTO's *Subject-Matter Index of Patents for Invention, France* (1883); *L'Aérophile* issues 1898-1905 listed aero patents specifically; *Aéro-Manuel*, 1914, lists some aero patents
United States (US)	4790	All granted patents are digitized and available on USPTO site and on espacenet. Original technical classifications of patent are not easily available.
Great Britain (GB)	3724	Digitized and generally available on espacenet back to 1895-1905; they seem to be extending back further over time. Technical classifications used at the time are not easily available. Summaries of aero patents appeared in Brewer and Alexander's 1893 book, in Neilson (1910), and in many issues of *Aeronautical Journal*. *The Abridgements of Patent Specifications* listed others and some information about classification.
Germany (DE)	882	Patents began 1877; All German patents have data available at DMPA; most are digitized and online at espacenet, DPMA, or Otto-Lilienthal Museum. Regular lists of aero patents appeared in *Jahrbuch über die Fortschritte auf allen Gebieten der Luftschiffahrt* and *Deutsche Zeitschrift für Luftschiffahrt*. Alexander-Katz (1912) lists some. We exclude Gebrauchsmuster patents (quick patents) from this study for now.
Hungary (HU)	327	Hungary's patent office was distinct from Austria's. All historic patents are on the current Hungarian patent office web site, but generally not on espacenet.
Austria (AT)	153	Patent office distinct from Hungary's. Many patents are on espacenet; all are indexed by DPMA.
Belgium (BE)	148	Patents from the early aero period are not on espacenet. Catalogs with summary information are in *Recueil des Brevets d'Invention* volumes, available in USPTO's STIC library. Some patent indexes are available at the State Archives of Brussels, Joseph Cuvelier repository, or digitized.
Italy (IT)	90	Summaries of patents are listed in the government gazette *Bollettino della proprietà intellettuale*
Canada (CA)	78	Granted patents documents are digitized and available from CIPO & espacenet
Switzerland (CH)	70	All patents have some data at DPMA. Most specifications are in espacenet
Spain (ES)	66	Most are indexed at espacenet and by the Oficina Española de Patentes y Marcas but the specification documents are not often available.
Norway (NO)	49	Many patents from early aero era are not on espacenet ; Short descriptions available were library in Trondheim
New Zealand (NZ)	27	Patents from early aero era are available on IPONZ web site, not espacenet
Denmark (DK)	21	Patents start about 1864. They are on espacenet.
India (IN)	16	Had a patent office distinct from Great Britain's; Patent specification can be found in the online INPASS system.
Australia (AU)	16	Australia's early aero patents are all available from the Australian Patent Office web site; we think they are not generally on espacenet

Bibliography

Alexander, Tyler, Tori Miller, and Amanda Pierce. 2014. *Scientific American* as a mid-nineteenth century middleman: the periodical's role as a liaison between the public and inventors. Project Report. Worcester Polytechnic Institute, Worcester, MA.

Bilstein, Roger E. 2001. *The Enterprise of Flight: the American Aviation and Aerospace Industry.* Smithsonian Institution Press.

Brewer, Griffith, and Patrick Y. Alexander. 1893. *Aëronautics*. London. Reprinted in 1965 by Boekhandel en Antiquariaat, B. M. Israel N.V. Amsterdam.

Brockett, Paul. 1910. *Bibliography of Aeronautics.* Smithsonian Institution.

Brockett, Paul. 1921. *Bibliography of Aeronautics, 1909-1916.* Smithsonian Institution.

Chadeau, Emmanuel. 1987. *De Blériot à Dassault: Histoire de l'industrie aéronautique en France, 1900-1950*. Fayard.

Cresee, F. A. 1902. *Practical Pointers for Patentees: Containing valuable information and advice on the sale of patents: an elucidation of the best methods employed by the most successful inventors in handling their inventions*. New York: Munn & Co., Scientific American Office.

Gibbs-Smith, Charles. 1966. *The Invention of the Aeroplane, 1799-1909*. London: Faber & Faber.

Head, James. 2008. *Warped Wings*. Mustang, Oklahoma, USA: Tate Publishing.

Kelly, Bryan T., Dimitris Papanikolaou, Amit Seru, and Matt Taddy. 2020. Measuring Technological Innovation Over the Long Run. Yale ICF Working Paper No. 2018-19, Available at SSRN: https://ssrn.com/abstract=3279254

Khan, B. Zorina. 2005. *The Democratization of Invention: Patents and Copyrights in American Economic Development, 1790–1920*. New York: Cambridge University Press

Klepper, Steven, 2009. The original and growth of industry clusters: The making of Silicon Valley and Detroit. *Journal of Urban Economics,* September.

Kuhn, Thomas S. 1962. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Meyer, Peter B. 2013. The airplane as an open source invention. *Revue economique* 64:1, (January), 115-132.

Meyer, Peter B. 2018. Linking records of early aeronautical experimenters across data sets. Presentation at World Economic History Congress. http://econterms.net/innovation/images/3/39/AeroMeyerWEHC2018.pdf

U.S. Patent Office. 1883. *Subject-matter Index of Patents for Invention, France, 1791-1876* Inclusive. Washington: Government Printing Office