Aeronautics patentees and their strategies, 1880-1918

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This work is preliminary and incomplete

Abstract

We examine patterns of inventors entering the field of aeronautics and aviation from 1800-1918 based on a curated collection of patent and publication data from around the world. We have some biographical information on many of these patentees. The proportion of new contributors to this field who can be identified as engineers rose from 32% to 42% over this time, and the term "aeronautical engineer" first appeared in 1909. We can make some inferences about the inventors' interests and strategies. The number of aero patent filings rose sharply from 1906 to 1910, then fell sharply and remained low in World War I, particularly for French and German inventors. Inventors often filed for patents on the same invention in multiple countries. Firms did not generally gather up patent rights in this field until World War I.

Introduction

When a major invention occurs, it can cause a kind of shock to an economic system. People had not expected it or planned for it. Its appearance changes what they think is possible and what they expect to happen. An industry of startup firms may appear to put the new invention to work. The airplane was such an invention, when it appeared in 1903-06. It was a macroinvention, in the language of Mokyr (1990), because it changed people's conceptions of what was possible and what to expect.

The airplane had a substantial pre-history. In the late 19th century growing numbers of engineers, scientists, and hobbyists experimented with flying machines. Many were drawn to visions of a flying craft that could flap its wings or soar as birds do, because this could be controlled in the air more effectively than a balloon. A technological and scientific field of "aerial navigation" gradually developed, with its own terminology that became standardized across languages. Early experimenters were largely concentrated in France, Britain, Germany, and the U.S. Some gathered in established balloon clubs and societies.

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. Still others focused on gliders with fixed wings, or propulsion

[1] Views and findings in this work represent only the author, not the Bureau of Labor Statistics. The author thanks Leo Zimmermann and John Herbert for exceptional research assistance.

with propellers that could work for balloons, or gliders, or helicopters. They envisioned a variety of possible "flying machines." There wasn't a dominant or standard design, and there was a diversity of views about what was likely to work in practice – a state of technological uncertainty.

They wrote about it, and shared information with one another. Growing numbers of journals and societies were devoted to ballooning, flying machines, and the challenges of "aerial navigation," which later came to be called aeronautics. Many were not secretive, partly because they understood that by sharing what they had figured out, they would be participants in a great drama of invention, and the others in the field would appreciate it. They would get credit, and maybe play an important role. Only rarely do any of them say in writing that they would think of starting a business in the field of flying machines; instead, they seem to think about the technical problem and to write as inventors. I find it helpful to think of this as an "open source" period with associated open practices (Meyer, 2013). Their open sharing can be rationalized if we think they put a high value on solving the technical flying-machine problem (Meyer 2007, 2015).

In the 1890s the field received new attention when there were public hang glider flights. The Wright brothers drew from these to create a controlled flight by a powered glider in 1903 which is called the first airplane flight. 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, airplanes were flown in dozens of exhibitions occurred and hundreds of new local aviation clubs appeared.

There is extensive documentation of this extraordinary transition, from a dream of controlled flight to an established manufacturing industry. There are thousands of contemporary patents, and journal articles, and meeting notes, and exhibitions, and letters between experimenters, and books they wrote at the time. In our time, terrific history books have been written giving narratives of aeronautical invention and aviation.

To address the overall issues of how people and societies create and adopt macroinventions, it will be helpful to have a more complete statistical picture of the flows of information and activity that led up to the invention. Several researchers have made public lists of relevant patents of the time. In this effort we try to combine them all into a database with every relevant patent from any country. That has turned out to be a large project. There are superb international bibliographies of early aeronautics, and I've computerized them up to 1909 and I'm partway through computerizing up to 1916.

In this work we'll look at people who filed patents and published articles about aeronautics in the period before and after the invention of the airplane. One goal is to understand the flow of technical and networking activity that led to this invention. They may show an open-source pattern, and they may illuminate how various institutions, like patent offices, helped to bring the macroinvention into practical existence.

A related goal is to understand the flows of patents and how they were affected by the changing environment, technically and otherwise. Patent specifications have a consistent form throughout the dramatic developments in the history of flying machines. In principle aeronautical patents can be compared to the classes of patents in other fields too.

The main work here is to have collected and organized the data. We describe the patents in our period in the next section, our sources to get them, and how we identify the ones relevant to aeronautics of the time. Most are related to ballooning until about 1904. Then is a great boom in the number of aeronautics and aviation patents after the airplane's invention, and a shift away from balloon designs toward fixed-wing glider and airplane designs. Each patent, and each bibliography entry for an aeronautical publication in this period, is described on a wiki page and in a row of a database. This supports keeping track of them and their relations to one another. We have some information about 14,000 relevant patents in this field in 1880-1918, and the data is slowly improving and expanding over time as we follow up various leads.

I have grouped the published contributors to the aeronautics/aviation field into "entering classes" based on the year when we first observe them to have a relevant aero patent or publication. We have at least a little information on about over a thousand of these individuals who contribute to the field in 1880-1918. Many rushed into the field in 1907-1910, and then there was a sharp decline in entrants. In the World War I period there was a decline in patents, and a particularly sharp decline in the number of French entrants visible in the field. This makes sense historically as they did not wish for their inventions to be visible to their opponents in the war, but we do not see the effect so strongly among British entrants.

We can examine some aspects of professionalization and industrialization of the field through the patent data. Of those contributing to this field for which we can identify an occupation, about 40% were engineers, and the proportion went up over time., presumably because the field became increasingly professionalized activity, and also because the leading work advanced quickly and required more training and equipment.

One of the indicators of technological uncertainty in the early years is that few aero patents were filed by companies; the relevant inventors were experimenters and hobbyists with a scientific bent. Most aviation companies do not seem to have collected or developed a patent portfolio when they started, but the numbers rose In World War I, a quarter of aero patents were filed by companies. By then, there was a real aviation industry, with real revenues from military sales, and conducting professional research and development.

Patents of that time

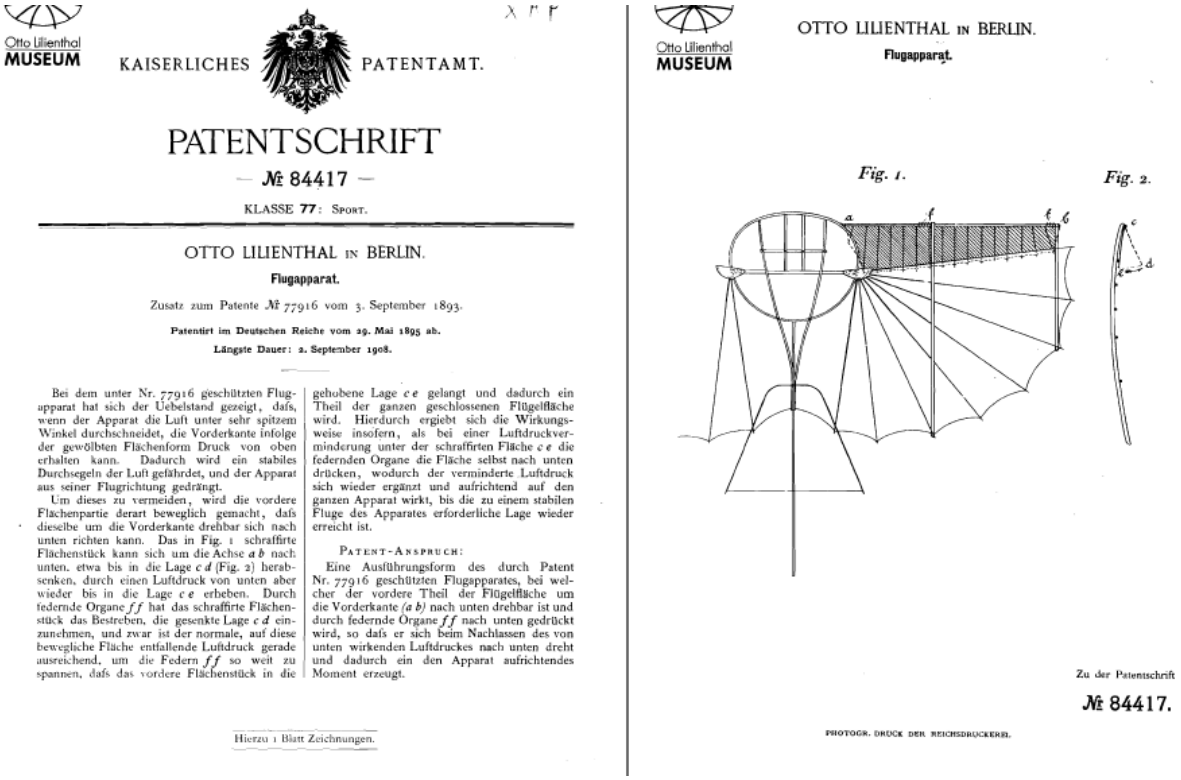
We focus on patents as indicators of creative technological effort and activity, not as intellectual property. The concept of a patent and the system for administering a patent was evolving and becoming more standardized. Formally, a patent is a legal claim that an invention is novel, feasible, and useful. The inventor applies to a government for a patent, stating what the technology is, showing diagrams of it, and making legal claims of originality. (Inventors then did not have to demonstrate feasibility as much as they would 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 number the patents and publish the inventor's description. Patents differed across countries for a variety of reasons. There was variation in whether the patent offices tracked certain kinds of information about each patent, and its legal applicability, its term of applicability. They became more standardized over time.

In many fields, such as railroad or mining engineering, patents were generally put to commercial use within a year. Commercial sales were a smaller factor for balloons and aerial

navigation. Inventors were trying to make based controlled sustained flying work, and not generally trying to make or improve an established product. However in aeronautics, we see little in the way of patent-related licenses, major products, litigation, or conflicts before 1908, and patent rights have not shaped the field generally after World War I (Mowery, 2015). It is not entirely clear why so many inventors filed for patents in this early period, but there are hints. Inventors would have wanted to receive credit for their work if it turned out to be were significant, and patenting was an established practice among engineers. It was also a way to publish their work so that others might build on it to get flying machines to work, apart from whether it brought honor or revenues to the earlier creators. Patenting was portrayed as useful and constructive in *Scientific American* and other publications (Cresee, 1902; Alexander, Miller, and Pierce, 2014). Patents could be filed by firms, or assigned to firms, but empirically we see we see little of this in aeronautics before 1914 compared to other fields.

We would miss some inventions and publications by depending on the patent record only. 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 has some similarity to current "open-source" views. Once a growing industry appeared it made sense that inventors would make an 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 early open-source phases and the industrial phase, which economists have not modelled much. An understanding of the airplane case may help understand such transitions. In any case, patents per se do give a substantial, detailed, and diverse record of technologically creative activity in this field.

Figure 1 shows a patent specification from 1893. The invention is an important glider designed by Otto Lilienthal of Berlin, with wings in roughly the shape of a soaring bird. The patent filing illustrates certain elements common in 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"), the date it was granted, and a diagram. This application is only two pages long, shorter than most patents of the period and much shorter than current patent filings. Its title is "Flugapparat," meaning "flight apparatus." Patent officials classified it by its technology, but the classification in this case is "Sport." At that time, the German system did not contain any more precise aeronautics category.



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 IN BERLIN.

Flugapparat.

Fig. 1. *Fig. 2.*

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 of these countries 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 aviation. The data make it possible to compare the number of domestic and foreign patentees to determine whether patentees came mainly from these four countries, or rather just chose to patent in these countries; such results are not yet available.

The different national patent systems had substantially different technological classification systems. These classifications are designed mainly to organize patent office work and to help inventors and agents outside the patent office search what has been patented.

Sources and challenges of patent data

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

Most patents are first-time specifications of original work. These are primary patents. There are two other types of "secondary" patents which we count here as if they were the same: *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.

Foreign filings are substantively identical to a previous patent application 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 foreign filings became clearer over time. The Paris Convention of 1883 provided an incentive to make the connection with foreign patents explicit. In uncertain cases, our guiding principle is that if the diagrams in two patents are the same, one is a foreign filing of the other; if the diagrams are not similar, they are distinct originals.[2]

The set of an original (or parent) patent and its 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 record these links more explicitly and correctly in the data, and in future work can discount the secondary patents.

Relevance to aeronautics

It can be difficult to select which patents were relevant to potential inventors in aeronautics and aviation in the period before the technological paradigm of the fixed-wing airplane was clear. Formal patent technological classifications of the time do not always identify aeronautics clearly. Classifications also differed by country, and the official patent category systems handled the new field of aeronautics differently. 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 aeronautics so a museum and several books explicitly listed this patent.

Second, there is underlying ambiguity or uncertainty about which patents had implications for aeronautics. It was not a field of research and development, and there were alternative models – balloons, rockets, helicopters, and flapping-wing ("ornithopter") designs. It was not clear which of these would be really successful if any; the technology was associated with deep uncertainty. Journals and reference works sometimes identified patents which contemporaries associated with aeronautics. We treat any patent appearing on such a list as relevant to aeronautics. Such sources include Brewer and Alexander (1893), Nielson (1910), and the various issues of *L'Aerophile* and other journals which listed patents. These lists do not provide much detail, but for some patents this is all the information we have about them.

Some patents focused on other fields such as automobiles or machine parts were secondarily relevant to the development of flying machines. We do not generally include these in our data unless aeronautical applications are specifically mentioned in the specification. One important category is motors or engines. We rarely include such patents, although the development of lighter power sources was important in the development of flight. Steam engines and internal combustion engines were both put to use on experimental

[2] La Mela et al. independently developed a similar definition in their research on patent families of that period. Matti La Mela, David Andersson, and Fredrik Tell, 2021, Patent families and the value of historical patents, 1884-1914, presented at Baltic Connections conference.

aircraft models by 1870. Aerial propellers are certainly relevant, and are classed with some less relevant groups of rotor technologies, and we decide on a case-by-case basis which of the others to include. Generally we count marine propellers, windmills, and fans as relevant to aeronautics, and churns as not, based on overlap between technical issues and patentees, and the opinion of specialists.

Quality hurdles met by each patent

The quality and length of patents varied 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.[3] 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 the nominal invention was not new – that it was "prior art," in the language of patent law, and if a plaintiff convinced the court, 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. 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 data on patents are on the Inventing Aviation web site at http://econterms.net/aero. Each patent has a wiki page with standardized data on each patent's filing year, grant year, inventors, title, and so forth. The page can also give a plain-language description of the patented invention, show images from the diagrams, links to external sources referring to the patent, and include our own classifications for it. There are also wiki pages on inventors, authors, companies, publications, and airplane clubs and societies, interlinked with the patent pages. The data make it feasible to compare patent flows across countries, across time, and across technologies.

A wiki is useful for historical research with ambiguous and uncertain data, such as misspellings, obsolete classifications, and unclear relevance to aeronautics. The data can be recorded with best guesses and notes to return to, and classifications can be changed. Variant spellings can be quickly redirected to the spelling we chose as the standard. 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

We 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

[3] The high Prussian standards relative to other countries are discussed with legal and administrative detail by Donges and Selgert (2020). The German system also included a tier of intellectual property claims with lower standards, more directly applicable to immediate products, called Gebrauchsmusters. We are collecting some data on these, too, but do not use them in the data set of this paper.

the U.S. We use the year of first filing as the time indicator; a patent was normally granted or rejected within a year. The timing of filing gives us the best indication of the inventor's activity. 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 1905 as shown in Figure 3. This is similar to the rates of growth of patents overall, in all fields, in that period. Then annual patent applications for aeronautics technologies more than quadrupled between 1907 and 1910. These change in trend was similar across countries. The spike in patents included a temporary increase in balloon and related designs and topics, but largely reflected a shift to fixed-wing airplanes. The shift to fixed-wing designs as a proportion of patents began before 1906 but continued over this period.

Since then, aeronautics never again represented so large a proportion of all patents. The absolute numbers of aeronautics patents declined in 1912 and fell sharply during World War I. A new industry was beginning to appear, but it was not highly profitable. As far as we can tell, few of the patent-filers actually worked in the new industry.

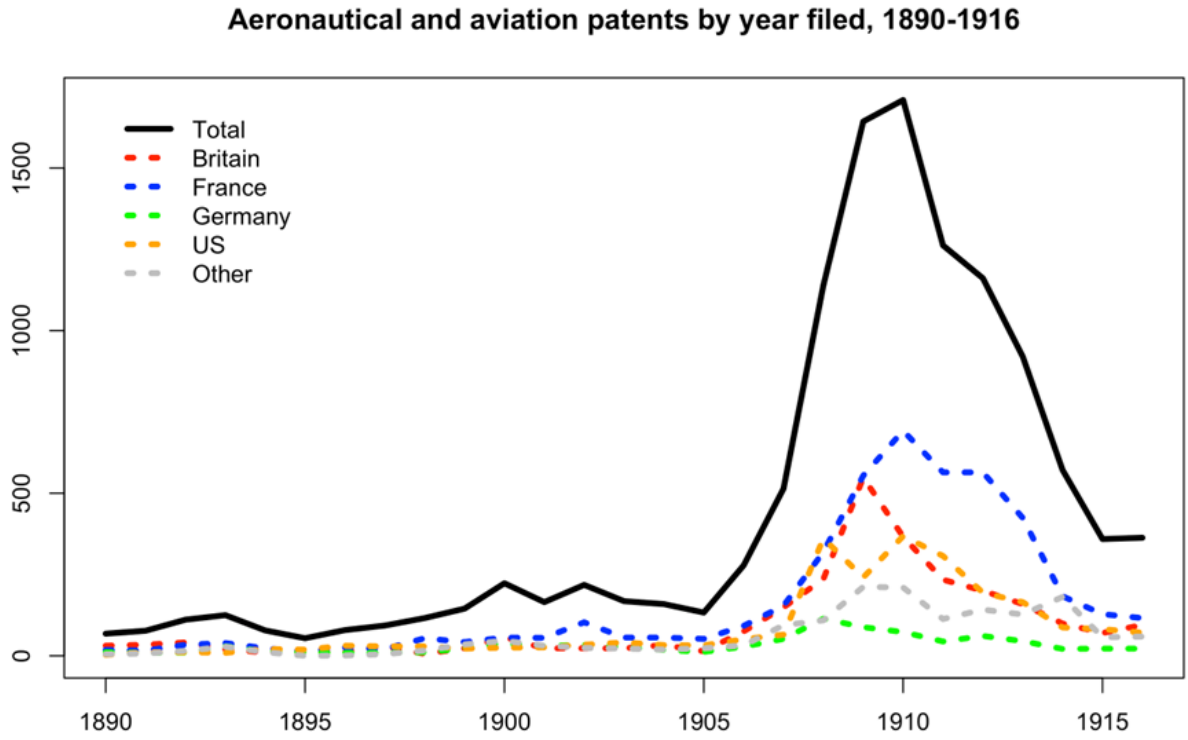
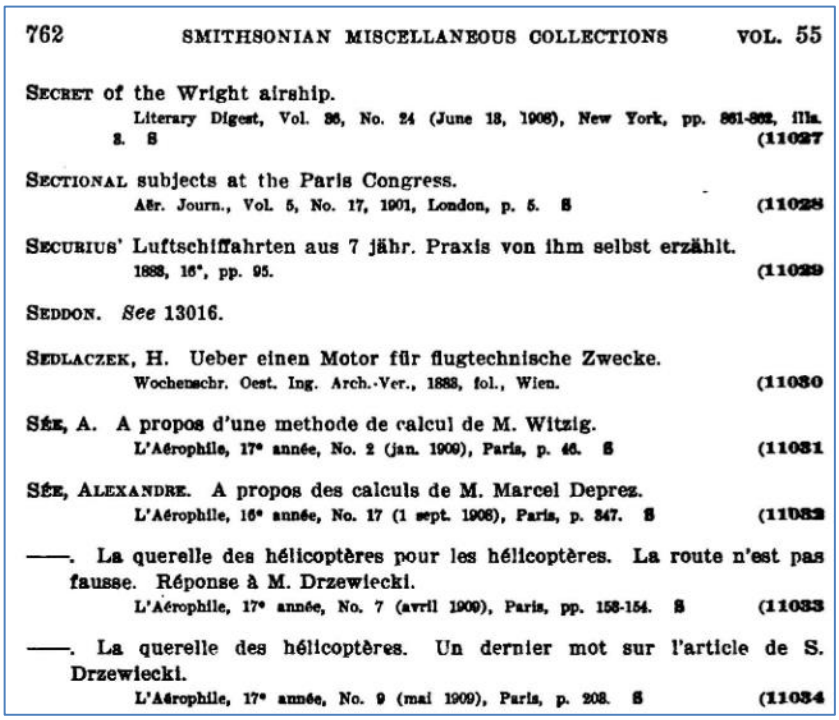


Figure 2 – Patents per year related to aeronautics and aviation

Patent counts rose sharply after 1906. Figure 4 shows patent counts by filing year. 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 is mainly an artefact of their system inviting "provisional patent" applications, which would hold an inventor's place with a legal filing date, and legal "priority" rights of as of that date, but the patent specification might be skimpy. The inventor had another six months to file a "complete

specification," and many did. We track both dates, but treat the earlier filing as the filing date here, which causes a mismatch since other countries have only the later, complete, filing date. A corrected peak for the British spike would be some months later than it is in the chart. As the data develops, it will be possible to construct this chart with monthly or daily precision, to see if there was any difference in the timing of the peak for the different countries.

There is another source of data matching the spike. We have bibliographic entries for thousands of aeronautics publications at the time, collected by Smithsonian Librarian Paul Brockett and published in a series of volumes of *Bibliography of Aeronautics* starting in 1910. Each entry from the first volume has been digitized and made into a wiki page. It can be linked to and from as a source for information to build a wiki encyclopedia of early aeronautics. A section of a page from Brockett (1910) is shown in Figure 3.



762 SMITHSONIAN MISCELLANEOUS COLLECTIONS VOL. 55

SECRET of the Wright airship.
Literary Digest, Vol. 36, No. 24 (June 13, 1908), New York, pp. 861-862, illus.
2. S (11027

SECTIONAL subjects at the Paris Congress.
Aër. Journ., Vol. 5, No. 17, 1901, London, p. 5. S (11028

SECURIUS' Luftschiffahrten aus 7 jähr. Praxis von ihm selbst erzählt.
1888, 16°, pp. 95. (11029

SEDDON. *See* 13016.

SEDLACZEK, H. Ueber einen Motor für flugtechnische Zwecke.
Wochenschr. Oest. Ing. Arch.-Ver., 1888, fol., Wien. (11030

SÉE, A. A propos d'une methode de calcul de M. Witzig.
L'Aérophile, 17e année, No. 2 (jan. 1909), Paris, p. 46. S (11031

SÉE, ALEXANDRE. A propos des calculs de M. Marcel Deprez.
L'Aérophile, 16e année, No. 17 (1 sept. 1908), Paris, p. 347. S (11032

——. La querelle des hélicoptères pour les hélicoptères. La route n'est pas fausse. Réponse à M. Drzewiecki.
L'Aérophile, 17e année, No. 7 (avril 1909), Paris, pp. 153-154. S (11033

——. La querelle des hélicoptères. Un dernier mot sur l'article de S. Drzewiecki.
L'Aérophile, 17e année, No. 9 (mai 1909), Paris, p. 203. S (11034

Figure 3 – A sample page of bibliographic entries from Brockett (1910)

Figure 4 shows estimated annual counts of publications in the field of aeronautics based on Brockett's 1910. These exclude patents, but the counts grow at a similar exponential pace, shown in figure 4. These two charts give proxy measures of the growth of aeronautics as a field, and show similar patterns of change. It is sometimes difficult to compare rates of patents and publications rates in technological history. It is helpful to see this similarity in patterns in this case.

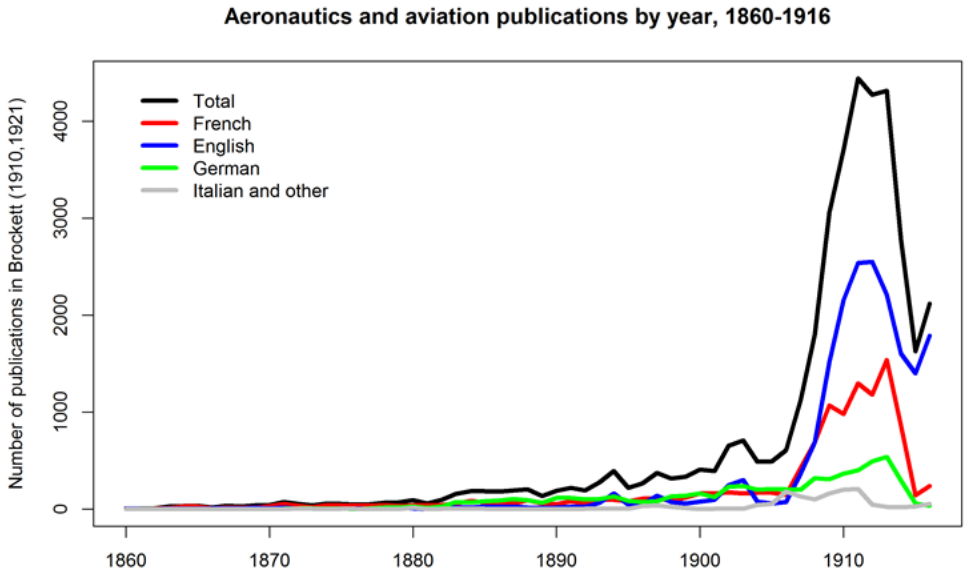


Figure 4 – Aeronautics and aviation publications per year, mainly from Brockett (1910)
Figures after 1909 are estimated based on Brockett (1921)

There are other sources beyond patents and publication to measure innovation in this field to use in the long run. Petra Moser has extensively drawn from exhibition data as a source of innovation data that was not tied to the patent system. We can count references in the contemporary literature; elsewhere I have simply counted the number of pages on which Octave Chanute's (1894) broad survey of the field refers to each of many inventors, and compared this index to rates of patenting and publication. Since patents really discuss each microinvention in detail, that it will also help to computerize them more completely.

Some important inventors did not patent. Major aeronautical inventors Alberto Santos-Dumont and Lawrence Hargrave did not patent their aeronautic inventions on principle, because they wished to move the field along as quickly as possible toward having practical aircraft. Other helpful participants were mainly publishers, or pilots, or business people; the patent streams are a fantastic source but do not cover the full technological revolution.

Direct measures of patent documents

We gathered basic information from each patent specification. For many of the French, British, German, and American aero patents 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. In a comparison (not shown) the length of aero patents and the numbers of diagrams and claims is different across countries but did not much change over time. I have not compared aero patents to other technical fields on these dimensions.

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.

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; inventions were quickly cited by patents in other countries.

A few effects were country-specific. Patents numbers declined more in Germany and France during World War I than in other countries. The spike in aero patents was especially high in Britain, as shown in Figure 1, and seems to have been associated with especially many startup companies there, more than in other countries.

The Wright brothers filed major patent infringement lawsuits in the United States in the period of the spike. They won in the United States 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.

The sharp decline in aero patenting rates

Why did aero patents decline so much after the peak in filings in 1910? I infer that there are several overlapping reasons. (1) The patenting frenzy was unsustainable, and probably includes huge numbers of duplicative or unusable designs because they were filed so close to simultaneously. It seems reasonable to think (but I cannot prove) that once patent examiners had mastered the new field, and had time to see the filings across countries, they accepted fewer duplicates. (2) The field advanced quickly, so newcomers understood that they could not make a useful patentable contribution without some specific experience, training, and equipment. (3) Relatively standard monoplane and biplane designs became established, reducing the interest or scope for patenting radically creative designs. (4) The industry did not have great revenues, apart from exhibitions, and the interest in exhibitions seems to have peaked in 1910, so there was some kind of shakeout, although we do not see exact data on when firms exited the field. Revenue data is not easy to come by, but military and postal contracts were not large and passenger traffic was minimal around 1911. There were journalistic and scientific reasons to fly, but little revenue from it.

As World War I began, research and development expenditures on aircraft rose sharply, but patenting continued to decline. A central reason was that inventors were inclined not to file patents in the countries on the opposing side. And because patents are public documents, many inventors would not file patents for militarily relevant technologies in their own country either, because the enemy could see such documents.

The governments had specific authorities, also, to delay the granting of patents, or to grant them but keep them secret. 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. In the data here we sometimes see extraordinary delays before a patent application was granted, and can eventually measure the delay in patent granting relative to pre-war durations. I have not seen many actual examples of governments nationalizing or hiding granted patents; it must be measurable however. tries and time periods, to see the effect of changes in the environment including the war.

Aeronautics patents fell more in the 1914-1918 period than patents did overall, presumably because airplanes were used directly in the war, so there was more reason for various actors to keep inventions secret. (Field, 2022, finds a sharp decline in aeronautical patents during World War II. I think this occurred for the same reasons.) 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 before 1916 but approval was delayed.

There are other direct effects. Research on airplanes was sponsored both by companies and by governments, but probably did not lead as directly to patenting. And young men who might have been inventing were sent into battle. Overall, 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. The central French aero journal *L'Aerophile* reduced by half its frequency of publication during the war.

Technology and design shift

We can show a technological shift toward airplane designs taken by inventors in these patents The next figure shows estimated proportions each year of aero-related patents that are built around a balloon design or a fixed-wing design. This is based on a simple classification developed apart from the various national systems of classification, informed by our knowledge of the terminology and often by looking at the patent text and diagrams.4 as terminology in the patents, their diagrams, and our own classifications of patents into these simple categories, based on our judgement drawn from the classifications assigned by patent examiners and by our readings of the patent specifications. These are not mutually exclusive categories, insofar as some designs were "hybrids" with both a gasbag and fixed wings; more importantly, many patents were associated with propellers or scientific instruments which could function with either kind of design. In the 1906-1910 patent spike, balloon and helicopter patents rose in number along with glider and airplane designs, but not to the same degree. We can measure the difference roughly. It is shown in the next chart.

[4] Patent offices classify application by their technology, partly in order to be able to allocate applications to be evaluated among their staff. The novelty of the airplane meant it was planted somewhat arbitrarily in the different systems then. The French patent office put ballooning and then gliders and airplanes into categories with marine navigation. Germany classified aero applications with kites into a "Sport" category all the way from 1877 through World War I. The Hungarian system, envisioning aircraft as transportation from the beginning, put them under Railways. The U.S. had quickly evolving categories, starting in "hydraulics" and "pneumatics". Only the British system had a simple standalone category for "Aeronautics" as early as 1884. The U.S. and British patent offices unfortunately did not put the classification on the patent specification itself so it is harder to make use of the information directly. The diverse practices of patent offices were comical but this helps illustrates the technological uncertainty of specialists at the time. (A broad history of 19th century patent classifications does not seem to be available; I am trying sporadically to develop one.)

In the period before 1900 when the proportion jumps from year to year because the sample is small, over half of the aero patents clearly adopted a lighter-than-air design. This falls to under 20% after 1910. The proportion which have a fixed-wing design increases from under 20% in the 1880s to over half after 1908. This shift occurs most sharply in 1903-5, before the Wrights' successful flight was widely known, and before any airplane manufacturing began. That illustration of paradigm change suggest, that many inventors were well-informed and responsive to news. This finding, from this same data, can hopefully be clarified using data on inventors to illustrate forms of substantive and strategic change in the aero field, before or apart from the rise of an industry (Meyer, 2024).

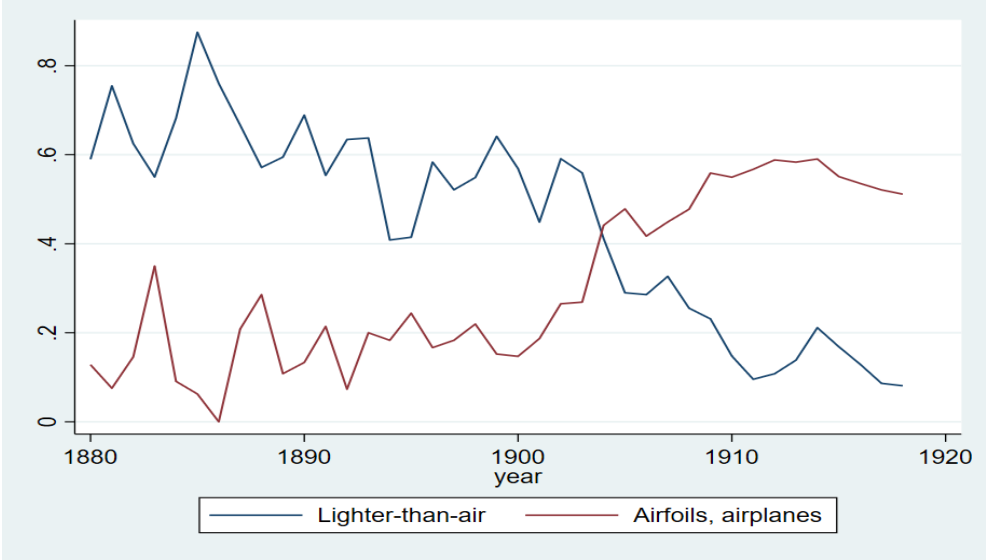
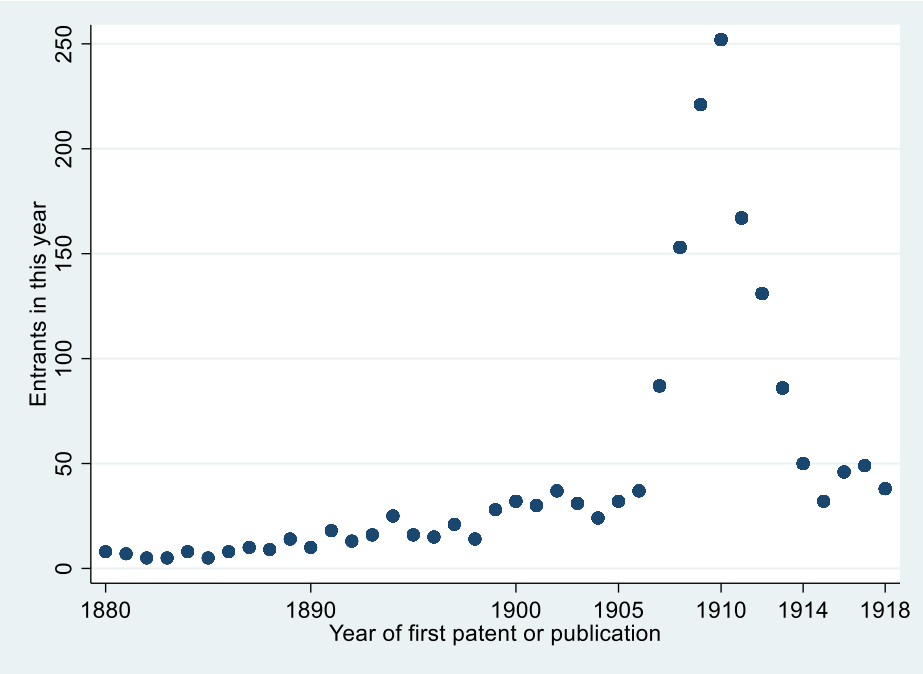


Figure 5 – Transition in patent filings from balloons toward fixed-wing design

Entering classes of inventors

Let's define an "entering class" of contributors to the aeronautics field, defined by the first year in which the individual files for an aero patent, or publishes an article, or is the subject of an article (our bibliographic source does not always distinguish author from subject), then there is a very steep spike in the numbers of entrants. It rises suddenly in 1907, which means that the 1906 increase in patents was mainly not a result of a particular inflow of contributors, but more production – more excitement – from the ones who were already in the field. Then from 1907-1910 an extraordinary flow of new participants in the field bursts in. That inflow drops quickly after 1910. I observe from biographies (discussed later) that most of the entrants of 1908-10 seem to disappear from the field; they may file one patent, perhaps in several countries, but then are not seen again.



Looking at entrant classes helps us detect one source of the decline in patenting in the war time. Few new French or German contributors to the patent and publication flows appear in the war years. The proportions drop sharply as is visible in Figure 6. I believe they were no longer willing to publish in a literature that their wartime opponents could see.

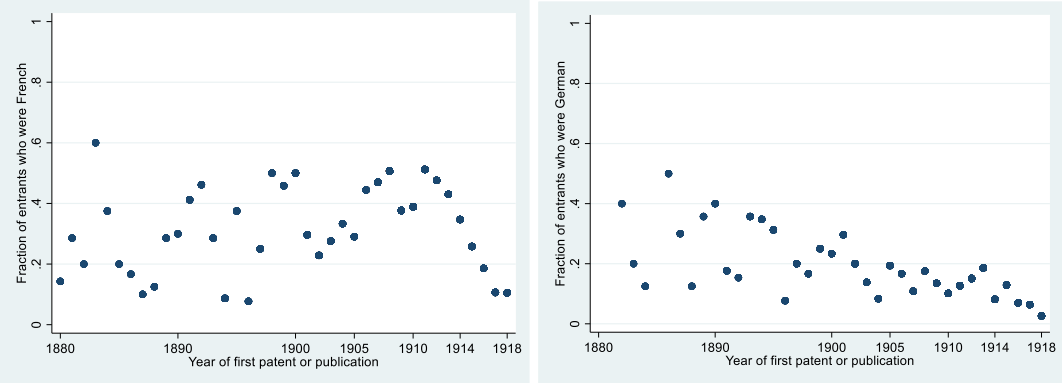
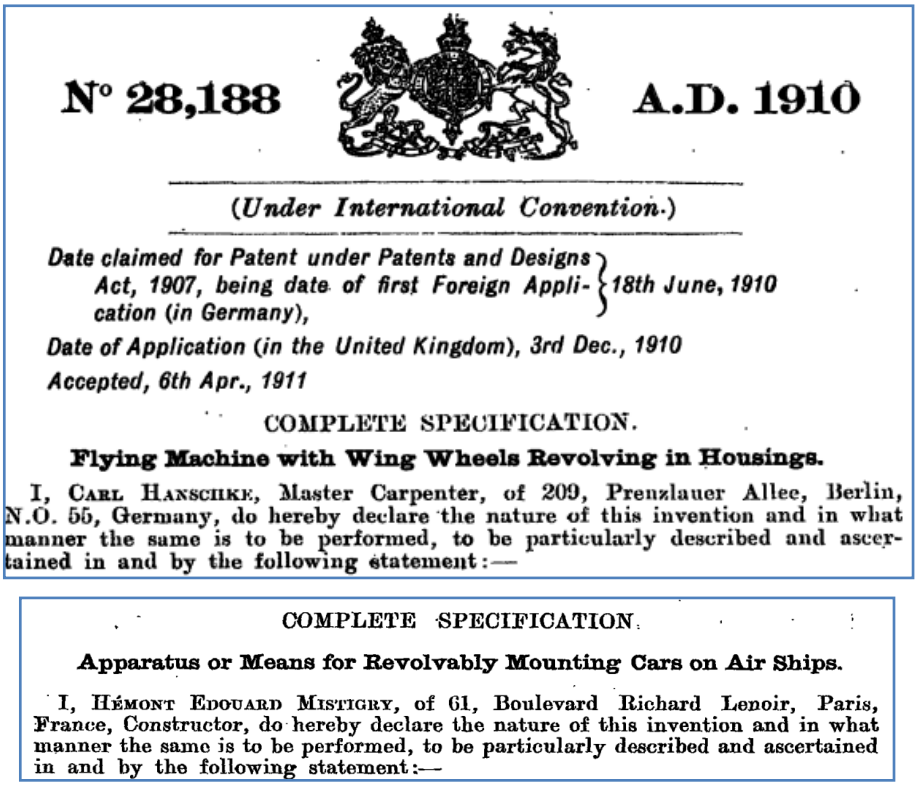


Figure 6a and 6b– Declining aero entrants during WWI from France and Germany

Occupations

We create small biographies of contributors to the early aero field on the wiki. These pages automatically. The page lists the individual's patents and publications, if there are any. We include information about the person's location (city or province), birth year, and relevant institutions such as aircraft companies they worked for. We have about 2300 such mini-biographies.

We can identify an occupation for about two-thirds of these individuals. Most often it comes from any British patent they filed, because apparently the British applications asked for occupations. Such data is especially good and complete for British individuals, but below are two example blocks from patent specifications that show foreign addresses and occupation.



N° 28,188 A.D. 1910

(*Under International Convention.*)

Date claimed for Patent under Patents and Designs Act, 1907, being date of first Foreign Application (in Germany), 18th June, 1910

Date of Application (in the United Kingdom), 3rd Dec., 1910

Accepted, 6th Apr., 1911

COMPLETE SPECIFICATION.

Flying Machine with Wing Wheels Revolving in Housings.

I, Carl Hanschke, Master Carpenter, of 209, Prenzlauer Allee, Berlin, N.O. 55, Germany, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

COMPLETE SPECIFICATION.

Apparatus or Means for Revolvably Mounting Cars on Air Ships.

I, Hémont Edouard Mistigry, of 61, Boulevard Richard Lenoir, Paris, France, Constructor, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

Figure 7a and 7b– British patents showing inventor occupations and locations

We draw occupation information from other sources too, most frequently Wikipedia biographies or other online biography, contemporary journal articles, or a book of history.

There was great diversity in the occupations. The most common category was engineers; about 40% were engineers of some kind. The term "aeronautical engineer" appears on patents starting in 1909. Some occupations were "balloon maker", "balloonist", or "meteorologist". (Meteorology was a field where balloons were specifically useful.) Large numbers gave technical occupations: mechanic, machinist, architect, chemist, dentist, physician, veterinarian, or technician. Others included some possible relation to aeronautics: Ship's captain, Military officer, photographer, or industrialist. Then we have a variety with no obvious connection to aeronautics: jeweller, artist, landlord, lawyer, merchant, farmer, teacher, carpenter, or clergy. The field was open and "democratic" in the sense of Khan (2005), that is, inclusive.

We link our biography page to a Wikidata page if there is one for the individual. A Wikidata page has an identification number and basic biographical information used among other things to link together the articles on the same topic in different languages. It is open and public and editable, and we expand or correct such data if we can. The existence of a Wikidata page usually comes about because the individual was treated as notable, on some language's Wikipedia, or was recorded in a significant historical database.

We can report general properties of the data on these individuals in the table below. Approximately 40% of these individuals for whom we can identify an occupation we engineers. This proportion rose over time, from about 31% to 42%. This is a signal that the field was professionalizing over time.

The individuals on whom we have biographies in the earliest period are much more likely to have Wikidata entries now than are the ones we have from a later period. It may be that they are remembered as more historically significant. In the third row of the table we can see also that the earliest participants appear to participate or contribute more. This is partly

selectivity, since data from later events, after 1918, are excluded. It may also be that the earliest participants had the strongest intrinsic motivation to stick with the field. The interpretation of these fields is not straightforward but they are notable trends in the data.

	1880-99	1900-05	1906-10	1911-14	1915-18
New participant was engineer	31.5%	31.5%	45.7%	40.5%	41.9%
Participant has Wikidata id	23.5%	19.3%	10.8%	7.8%	7.9%
Participant's known patents+publications	10.8	6.8	6.1	4.5	3.8
Sample sizes, which vary for the cells above	>160	>110	>462	>250	>110

Table 1: Attributes of new contributors in different cohorts

One aspect of the engineer proportions calls for further research. The chart below shows the proportion of each year's entrants who we can identify as engineers. The proportion is noisy because of small samples but definitely trends up over time. However in two periods it drops sharply relative to the previous period: 1906 and 1914-15. These are years of particular shocks – where the spike in patents begins, and the start of World War I. For some reason these great changes in the environment cause the entrant class to have fewer engineers. It seems to be a pattern; perhaps some other group is more flexible or opportunistic. I have checked the numbers of entrants who were identified as "industrialists" or "manufacturers" or in the military, and did not see a jump in those years.

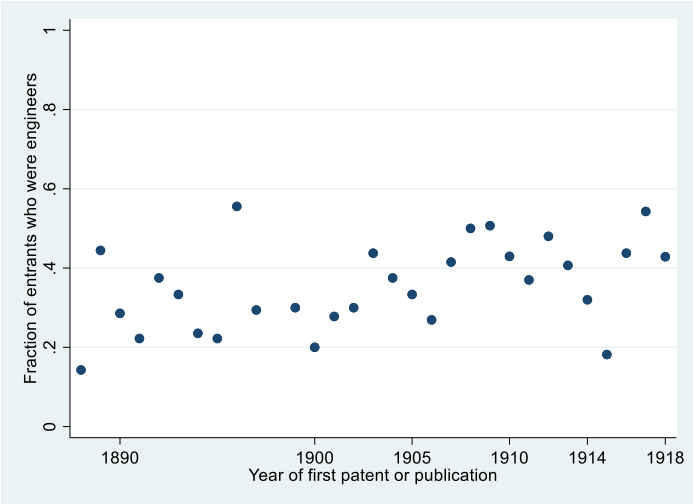


Figure 8 – Rising proportions of new contributors were engineers

Roles of firms and professionals in patenting

In the aero patent data we can track certain administrative trends, summarized in the table below. These statistics are new to this paper, and much more precise than any previous presentation. The data have errors but certain trends are clear.

First examine how often a company had a specific ownership of the patent rights stated on the patent itself. This data is shown in the top two rows of Table 2. The administrative details were different from country to country. Most patents name a specific set of inventors – persons. In most countries an organization could also be an applicant, which usually would have been a company that funded the research. It could also be a trade association, a university, or a patent agency but these were not common. Any applicant would have rights to use the invention afterward. Some companies did not even list any person as an inventor, but only the firm. In any country, patent rights could be sold to a person or company; in most

countries that data was kept in registries which are not shown on the patent specifications themselves and is not incorporated into the data here. (See the works of Anderson and Tell, La Mela et al, and Streb et al for research that uses registry data from Germany, Sweden, and Finland. An important use for such data is to infer the financial value of a patent by the number of times it has been renewed and whether rights to it were purchased.) In the U.S. the normal pattern for such a relation was that the inventor's name was shown, and often assignees was shown on the patent spec itself. For aeronautics, the assignee(s) were frequently individual people, and they could also be companies. In the data here, there is some duplication or overlap in the reporting of an assignee who was also an applicant; the concepts are not sharply distinct in the data here.

But a key finding is clear. These relations between inventors and companies or other buyers and supports were a little more common over time from 1880 to 1914, rising from roughly 5% of patents to 10%. But in the war period, the number rises sharply to approximately 25%. That is, a quarter of patents in the war period were clearly owned (or co-owned) by a company. The war revenues made for big organized manufacturing companies, and they built intellectual property portfolios. In the U.S. in particular, patents were a subject of much litigation from about 1910-1917, and then a patent pool was formed among the large manufacturers under pressure from the wartime U.S. government.

We can usually tell if the inventor had hired a patent agent – always, in the case of a French, British, Swiss, or U.S. patent, but rarely in the case of a German patent. Almost all operated in only one country, specializing in that country's patent office, and they often handled applications from foreign inventors. The proportion of patent applications that were submitted by agents rose a little bit over time, as is shown in the third row. It is possible that the same pattern held for non-aero patents. We have an interest in what contributions the patent agents made. Do they help the innovative process? Not clear overall, but there is a famous example however where an agent helped get a patent application accepted. The Wright brothers' main patent submission was rejected by the US Patent Office examiner in 1903, and only when they hired an agent could they get the submission rewritten in a way that distinguished their invention from prior art and convinced the examiner to accept it. Some patent agents published patent abstracts or focused in particular areas; a couple published on aeronautics in particular. (E.g. Armengaud, in France; Victor J. Evans in the U.S., and several in Britain.) We are collecting data on each of many hundreds of patent agent to ascertain their roles better. The U.S. patent agency Munn & Co. strongly encouraged inventors to file for patents with assertive advertising and narrative storytelling about inventors (Cresee, 1902).

The third kind of relation, tracked in the fourth row of the table, is the proportion of patent submissions which were "secondary filings." These are the "additions" to previous patents and "foreign filings." As part of the work of integrating patents into the database, we check to see if a patent with nearly identical diagrams were submitted in multiple countries. If so, we mark the second one filed as a "child" or "secondary" patent of the first one. We are only partway through doing this in the data. The table shows that over 40% of our patents were secondaries, so the overall level of innovation was much lower than the level of patenting. In the war time, the fraction of secondary filings fell sharply, which mainly was a side effect of the inventors' no longer filing in the enemy countries.

Table 2. Proportions of patents with certain roles and connections

	1880-99	1900-05	1906-10	1911-14	1915-18
A firm was an applicant	1.3%	1.8%	4.5%	8.0%	24.3%
Patent was assigned	3.9%	3.4%	2.2%	2.1%	4.8%
Patent agent filed the application	37.8%	39.6%	45.3%	53.7%	46.0%

Patent was secondary filing	45.1%	40.9%	39.4%	42.0%	31.8%
Sample sizes, which vary for the cells above	>850	>690	>4250	>3650	>2130

Conclusions

The data show that over the radical changes in this period – from aviation as only a dream, to aviation as a focused industry of wartime manufacturing -- the numbers of aeronautics-related patents filed grew slowly but steadily by perhaps 5% a year from 1880 to 1906, then jumped sharply upwards to a peak in 1909-11, then declined. 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 obviously affect the U.S. numbers compared to other countries.

This is one of a series of papers about this data as it improves gradually over time. In this paper we define an entering class of aero contributors based on the year of their first aero patent or publication. The number of entrants drifts up over time until 1907, when it bursts up. Interestingly this is AFTER the airplane has been publicly demonstrated, and the number of aero patents has started to spike. In the war time, the number of entrants from France and Germany declined sharply. They did not patent any more in one another's country, and they reduced patenting in their own too, presumably because they do not want their enemies to see a new technical innovation that could be put to use on warplanes. We do not see this effect nearly as strongly among British or American patentees.

Based on mini biographies of aeronautical contributors, we find that a somewhat growing fraction of them were professional engineers from 1900 to 1918, as the technology evolved from a strictly experimental phase toward an industrial production phase.

Few patents appear to be funded by company research and development until World War I. The pattern of individual inventors, operating in an open source way, declined. Patentees were increasingly likely to be doing business with firms over time, and in the war a quarter of the patents were applied for or assigned to firms – a much higher number than previously. The new airplane manufacturing firms tended not to have great portfolios of patents when they started – they had the capacity to build airplanes without any intellectual property, I think – but in the war as production built up they also accumulated intellectual property.

The patterns identified here help us illustrate, and to try to measure or adjust for, the gaps between "flows of innovation and rates of patenting. We would like to understand both, and the relations between them both statistically and institutionally.

Appendix A: Data sources for historic patents

We have used many sources of information. I list here the main or largest ones. The European Patent Office (EPO) keeps a global database of patent documents with metadata. This is the most complete source, with complete data from US and Germany, and data for Britain extending back into the 19th century, and pdfs for French patents back to their 1902 reform. 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.

Author Simine Short and Gary Bradshaw of the University of Mississippi created a substantial list of US patent related to aviation at http://invention.psychology.msstate.edu/PatentDatabase.html.

The Lilienthal Museum has an extensive online list of patents, mostly from German-speaking countries, at https://www.lilienthal-museum.de/olma/pat_ar.htm.

There were published lists of aero-relevant patents at the time. Brewer and Alexander (1893) and Neilson (1910) had book-length reference works listing such patents. Issues of *L'Aerophile*, and other contemporary journals would publish such lists periodically. US Patent Office (1883) noted and listed French patents.

Ted Beatty's collection of Mexican patents had many aeronautical ones and was nicely easy to download and search.

We extended from these collections by searching google patents, espacenet, and national patent office sites for patents with similar technical classifications (especially US Patent Class 244), and patents with aeronautical terms in their titles, and for other patents by individuals who had ever patented in this area. Research assistants John H. Herbert and Leo Zimmermann were spectacularly effective at figuring out patent office sites from amny countries.

To fill in the desired data fields requires looking at the original patent-specification 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 made a searchable database available. The US Patent and Trademark office has scanned all its patents back to 1836. because of a design change to its web site a couple of years ago it does not seem to be possible to automatically construct the URL to a patent specification PDF from its number any more. However espacenet hosts all these documents. National patent offices, especially the French Institut national de la propriété industrielle (INPI) and the German Deutsches Patent- und Markenamt (DPMA), have 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 search by a patent's exact number to find its information, making it difficult to browse for aero.

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 online searches are easier.

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 if in our judgment 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. For several countries the search is challenging, as the full inventor names or numbers are not recorded in an accessible way.

Table A1 shows counts of patents drawn for this study from https://econterms.net/aero, restricted to those relevant to aeronautics and in the 1880-1918 time frame. Missing data within the records means the sample used for each chart or table in the paper is somewhat smaller. Along with the countries listed below, the data set includes small numbers of patents from Argentina, Brazil, Chile, Cuba, Finland, India, Japan, Luxembourg, and Sweden. India had a patent office distinct from Great Britain's, and its patent specification can be found in the online INPASS system. Thus there are about 20 countries with relevant patents. More data awaits to be incorporated, from every country.

Table A1. Patent data by country

Country	Patents	Notes on the country's early aero patent data
France	4682	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	3315	All granted patents are digitized and available on USPTO site and on Espacenet. Original technical classifications of patent are not easily available.
Great Britain	3218	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	1175	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	465	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	343	Patent office distinct from Hungary's. Many patents are on Espacenet; almost all are indexed by DPMA.
Belgium	341	Patents of the period are generally not online. The government published catalogues with patent summaries called *Recueil des Brevets d'Invention* volumes, available in USPTO's STIC library. Some patent indexes are available at the Joseph Cuvelier repository at the State Archives of Brussels.
Canada	171	Granted patents documents are digitized and available from CIPO & espacenet
Italy	163	Patents were summarized in the government gazette *Bollettino della proprietà intellettuale*
Switzerland	146	All patents have some data at DPMA. Most specifications are in espacenet
Spain	107	Most are indexed at espacenet and by the Oficina Española de Patentes y Marcas, but the specification documents are not often available.
Russia	92	Scanned by the Russian patent office and put online
Australia	56	Available from the Australian Patent Office web site
Denmark	52	Patents start about 1864. They are on espacenet.
Mexico	51	Drawn from Ted Beatty's data set, online (see Bibliography)
Norway	48	Short descriptions available were available in publications in library in Trondheim
New Zealand	28	Patents from early aero era are available on IPONZ web site.
Netherlands	20	Patent office established 1912. Patent available on the national patent office web site

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