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PROCEEDINGS

VOLUME 2

Brian Bowen
Donald Friedman
Thomas Leslie
John Ochsendorf, eds.

Fifth International Congress on Construction History
Palmer House Hilton Hotel
Chicago, IL
3-7 June 2015

PROCEEDINGS OF THE FIFTH INTERNATIONAL CONGRESS ON CONSTRUCTION HISTORY

JUNE 2015, CHICAGO, ILLINOIS

Edited by

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Construction History Society of America

Proceedings of the Fifth International Congress on Construction History
edited by Brian Bowen, Donald Friedman, Thomas Leslie, and John Ochsendorf.

ISBN 978-1-329-15031-7

INTRODUCTION

These Proceedings in three volumes record the papers presented at the 5th International Congress on Construction History held in Chicago in June 2015. This conference follows four successful international congresses held previously: Madrid (2003), Cambridge UK (2006), Cottbus (2009), and Paris (2012).

Following trends set in the previous Congresses, the breadth and scope of the subjects addressed continues to be extraordinary. The topics cover the history of construction in every era, of buildings and civil works, their engineering and architecture and of the processes and organization used to build. This demonstrates the value of examining our industry's past in a comprehensive manner in order to inform the future.

We have not attempted to sort the papers into broad categories. However a listing of the organization of papers into sessions that was used at the Congress is included as a guide. The papers are presented here in alphabetical order by the first author's family name. The table of contents provides all of the paper titles and the index lists all authors.

THE EVOLUTION OF STREAMLINED AIRSHIP HANGARS

Roland Fuhrmann[1]

Keywords

hangar, wind load, aerodynamics in architecture, streamlined shape

Abstract

After 1908 the airship became an important aircraft for military and civil use, especially in Germany. Until the outbreak of World War I in 1914, the hangars that housed them came in a number of different designs. Most used door wings, the idea being, that the open doors would act as windbreaks and thus protect the airships against dangerous crosswinds when entering or leaving the hangar. In actuality, however, the surfaces of these doors in conjunction with the angular shape of the hangar itself disrupted the laminar flow of the environment, creating vortices that were even more dangerous than the crosswinds. One exception was the airship hangar designed by little-known German engineer Ernst Meier in 1910 and built in Dresden in 1913. Meier's hangar used spherical gable closures, later referred to as “orange-peel doors”. This design avoided the dangerous vortices of the door-wing design and had an important impact on the large post-war airship hangars in Germany and abroad, especially in the United States.

This paper will begin with a quick history of airship hangars before focusing on Meier’s first orange-peel door hangar in Dresden in 1913, showing how it differed from its predecessors and contemporaries. It will then look at the impact of this design on subsequent hangars, most notably the Airdock in Akron, Ohio, from 1929. Akron Airdock, still existing today, was directly influenced by Meier’s Dresden design. It was a great success and a benchmark for all future airship hangars, like those in California, Massachusetts and North Carolina. In addition to the inventor of this type of airship hangar, Ernst Meier, this paper will also show other engineers who enhance the aerodynamic hangar design, including Wolfgang Klemperer, Karl Arnstein, Paul Helma, Alfonso de la Peña Bœuf and Anton Tedesko.

Until now the construction history of airship hangars has either been investigated in a structural perspective (Sonntag 1913) (Wulf 1997) or from an angle focusing on national characteristics (Dean 1989) (Shock 1996). However, the recent finding respectively accessibility of the personal estates of engineers Ernst Meier and Karl Arnstein, two essential representatives of the aerodynamic hangar design, allows for a re-assessment with a new focus: Now the aerodynamic qualities of such structures can be analysed commencing with the history of the first ever such building, the Dresden Airship Hangar.

[1] BTU Cottbus-Senftenberg, PF 101344, 03013 Cottbus, Germany, post@luftschiffhalle.de

HISTORY OF ZEPPELIN HANGARS UNTIL THE FIRST AERODYNAMIC TYPE

„All that remains of the great age of the rigid airships is the giant buildings they left behind them.“ Martin Pawley, 1989.

Building Zeppelin type airships with a rigid structure establish special requirements, since the weight of the metal frames demanded higher quantities of lifting gas and therefore vast hangars. After their journeys the frail structures had to be kept in weather-proof buildings. Graf Zeppelin (1838–1917), the somewhat unorthodox inventor, had a simple solution. His airship hangar floated on Lake Constance and was moored at the one end. Thus it moved with the winds, always pointing leeward and thus exposing the smallest face to the wind. With stationary airship hangars, on the other hand, the procedures of moving the airship in and out, in particular passing the doors under crosswind, could lead to critical situations. To solve this some hangars could either be electrically rotated into the wind direction or they were round to revolve the airship inside. However, both options were very costly.

Therefore hangars were mostly fixed and orientated towards the prevailing wind direction. Based on the knowledge of aerodynamics then available, areas especially protected from the wind were built near the doors. This could be achieved either by protruding door wings or by erecting additional walls as windbreaks.

The building boom for airship sheds in Germany commenced in the year 1908, when Graf Zeppelin received a 6 mill. Goldmark donation, later known as the Miracle of Echterdingen. The subsequent competition for the huge Friedrichshafen airship dock boasted of 74 entries, proving the great interest of both consulting engineers and companies for structural steelwork. The airship hangar was established as a new architectural category.

All airship hangars built before the outbreak of the First World War neglected issues of aerodynamics. Those for military airships were designed in a spartan style, whereas sheds in cities were often subject to an implicit competition with municipalities vying to outdo each other in terms of splendour – procedures known from railway stations. The sole exception to this was an airship hangar erected in Dresden in the year 1913, rounded on all sides. The design of the arching hinged doors allowed for spherical gable closures on both ends. When opened, the two halves of the doors clung to the body of the hall with only negligible airstream obstruction and no critical air vortices arising.

This type of a hangar rounded an all sides was based on a patented construction by Berlin civil engineer Ernst Meier (1868–1934) in 1910. The first opportunity to realise his unusual concept was the Dresden hangar, where he was able to improve the spherical gable closures. The most striking feature was the geometric simplicity: a lying half cylinder with two quartered spheres at both ends. The shell-like doors consisted of halved trusses arranged radially and pivoted to the ridge of the final truss. The result was a folding case for the airship, perfectly suited to its contents and adopting the vehicle’s aerodynamic advantages for the first time. However, nobody at that time (apparently not even Meier himself) perceived the construction’s perfect flow behaviour. His principal objective was using the building materials economically, which he achieved by providing the entire shell with a stable curvature, thus reducing the enclosed space to the contours of the body stored inside. Ernst Meier’s work was completely unaffected from prevailing architecture traditions. The design he chose only followed functional requirements. Previously airship hangars exhibited the prevailing tastes: they had corner towers or resembled barns or factories, often depending on what the building company in charge specialised in. The issue of stalls produced by edges of buildings and wind turbulences close to these large airship

hangars was yet unknown. However, only an entirely streamlined body like Meier's design could prevent such occurrences.

In addition his construction was demountable, which attracted the German Ministry of War. For the military exercises in September 1913 two more hangars of this type were ordered to be set up at Liegnitz and Posen (today Legnica and Poznań/Poland), both being smaller than the Dresden version. These first three streamline shaped airship hangars remained singular oddities among German airship sheds: ahead of their time and misunderstood. Until the 1930s newly built hangars did not show any considerations of aerodynamics. The established tradition relied on doors straight and protruding and on box-shaped halls, although these very features caused a number of accidents related to issues of flow. Many airship harbours were also used for airplanes. The angular bulk of the airship sheds produced vortices dangerous for them as well as for the airships during manoeuvres on the ground. Furthermore, the buildings themselves, both free-standing and oversized, but structurally undersized, often suffered from major wind damages. This led to fundamental research on the issue of wind phenomena near buildings. Although the rounded design of Meier's hangars would have been the solution already existing, but nobody used it. Sometimes the easiest answer to a problem is very hard to come by and even if available, very hard to detect as being exactly that.

The owners of the buildings insisted on windbreaks being the appropriate remedy. On top of that Ernst Meier had suffered from bad luck: Overruns in construction time, defects in the execution of his hangars plus a patent infringement suit from a competitor, all contributed to Meier having become a marginalised figure. The specialist literature of his time did not discuss his innovative key structures. Soon they were forgotten. The hangars in Dresden and Liegnitz were demolished in compliance with the Versailles Treaty in 1921, the one in Posen followed after 1945.

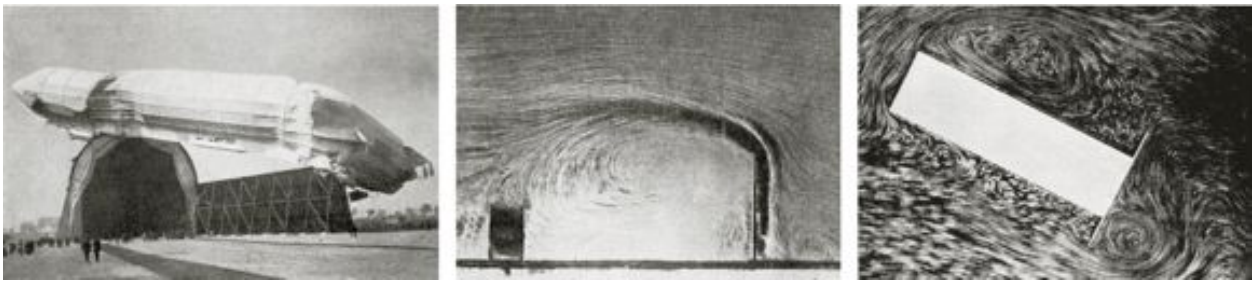
Figures 1, 2: Airship Hangar at Dresden, build in 1913 (Period Postcards, Author's Archive)

WINDBREAKS VS. STREAMLINING – AIRSHIP HANGARS TRIGGERED OFF THE STUDY OF AIRODYNAMICS IN BUILDING CONSTRUCTION

"The discipline of aerodynamics, a fruit of wartime aviation in the World War I, has finally been called upon to produce enlightenment and improvement in civil engineering." Emil Everling, 1924.

The first person to measure the impact of wind loads on building models was J. O. V. Irminger (1848–1938), managing director of Copenhagen gas works. He began publishing his surprising insights into the effects of wind suction in 1894 (fig. 6). Twenty years later Gustave Eiffel analysed "wind loads on airship hangars", which he considered to be "particularly important" thanks to the unusual height of these buildings, if one strove for sufficient stability at a reasonable price.

The French engineer used the hollow models with perforated surfaces developed by Irminger and measured the inner pressure during exposure to flowing air. He compared measurements on models of the airship hangars at Belfort (fig. 7) and Hamburg (both built in 1911). As expected the rounded cross section of the Belfort design was less subject to wind load than the Hamburg construction, where the "relatively sharp edges of the eaves caused high amounts of vacuums". However, Eiffel's results left no mark on the subsequent design of airship hangars.



Figures 3–5: Windbreak at Düsseldorf Hangar; the corresponding flow pattern; model of Lakehurst Airship Hangar (Krell, ZFM, 1928)

Acquiring the knowledge of the best form for airship hangars was a long process. Even the experienced pilots of Deutsche Luftschiffahrts-Aktiengesellschaft (Delag) were "uncertain and often changing in their judgments about the most appropriate form of hangars". (Militärluftfahrt bis zum Beginn des Weltkrieges 1914, Textband [1941] p. 114)

Erecting windbreaks was taken to be suitable for keeping away dangerous crosswinds at the doors, when these bodies both frail and huge entered or left the sheds. Research on the flow mechanics concentrated on the hangars' doors. Windbreaks and protruding door wings were seen to be the remedy for these issues. One of the first windbreaks was erected at Düsseldorf as extension of the airship hangar's sidewall. Experiments in wind tunnels studying the flow characteristics of vertical resistance areas had not yet taken place, which meant that the formation of leeside turbulences was unknown. Passenger airship LZ-8 "Deutschland" fell prey to this dangerous vertical suction on May 16, 1911 (fig. 3,4). The windbreaks were then taken down again. But even this telling accident had no effects on the subsequent design of airship hangars. Until the end of the First World War 17 patents were registered for wind protection installations at airship sheds. Neither was there anybody outside Germany to attach any importance to the streamline shape. Some airship harbours in France and Great Britain possessed huge windbreaks, and hangar design in the US followed the paths chosen in Great Britain. The Lakehurst Navy airship hangar, built in 1921, has doors, which, when open, stick out into the wind like the ears of Mickey Mouse. A double velocity of the ambient wind speed was recorded at the outer edges (fig. 5).
The inconsistent character of expert statements concerning the issue of the hangars' doors is striking: In May 1913 an expert panel of the Prussian War Ministry stated: "The type of doors chosen is not to inhibit the smooth flow of winds." This means flow optimisation, which is the current approach. However, but three weeks later the same commission decreed the direct opposite: "Protruding doors are more favourable for entering than non-protruding ones and thus to be desired." (Bundesarchiv Freiburg, PH 9V/47, p. 169)

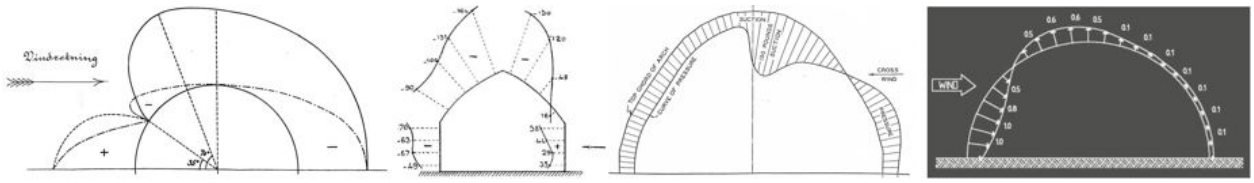
Hugo Eckener (1868–1954), director of Delag, was an instructor of crews for marine airships in the war. As an experienced pilot of Zeppelin airships he warned explicitly of dangerous vortices near high and closed compounds like airship hangars. "It is much better to moor the airship in an open and unprotected space than using the 'protection' of airship hangars" with

"downstreaming vortices occurring behind their steep faces". (Eckener: Kurze Anleitung für die Führung von Zeppelin-Luftschiffen für das Fahrpersonal der "Delag" [1919] p. 49, 50)

While working as an aerodynamic engineer at Luftschiffbau Zeppelin, Paul Jaray (1889–1974) performed experiments with models for airship sheds to optimise their flow characteristics. Between 1920 and 1922 he applied for six patents tackling this issue. He suggested to direct flows favourably trough and around the airship hangars by means of devices he called "wind steering wings". However, he did not alter the box shape of the hangars themselves. Jaray's patents were not executed, and they reveal conflicting opinions even within the Zeppelin company. Only his suggested rounded gable ends were adopted at Friedrichshafen Hangar in 1930.
Nevertheless building airship hangars was central to study the subsequent knowledge of wind loads and flow characteristics of buildings. Due to their exposed position and their enormous bulk they caused a significant amount of phenomena of flow mechanics and wind damages. In addition laminar flow in their immediate surroundings had an impact on airship traffic and led to exact studies and measurements.

Ludwig Prandtl (1875–1953) also investigated issues of winds near airship sheds. In his wind tunnel in Göttingen he tried to optimise the bad flow conditions at Leipzig Airship Hangar (built in 1913) by means of a roof spoiler, whose angle could be adjusted. Besides, Prandtl was consulted, when wind suction opened the flat doors of the box-shaped Stolp Hangar for naval airships (today Słupsk/Poland) on December 11, 1915 causing them to collapse. His report stated that "at such places, where flows are turning the corner, high amounts of vacuums can exist behind the corners." (DLR Archive Göttingen [1916]) Although Prandtl detected corners as culprits, he did not link his conclusions to a hangar form arching on all sides. The series of peculiar damages on box-shaped hangars due to gales continued. After one storm the huge Nordholz Hangar had its doors deformed leeward in outward direction. The measurement of the wind pressure afterwards, performed by Martin Grüning (1869–1932), revealed a lifting wind load by the factor 1.5, if compared to the positive wind load. Harold M. Sylvester studied the flow characteristics at Lakehurst Hangar in 1931 and concluded that all previous calculations of wind loads were deficient.

Knowledge from aerodynamics was slow to contribute to structural calculations. In Germany for example it was the introduction of DIN 1055-4 in 1938/39, which acknowledged negative wind loads for the first time.



Figures 6-9: Curves of Wind Pressure: Irminger 1894; Eiffel 1914; Arnstein 1928; IFI Aachen, CargoLifter 1998

AKRON IMPORTS THE DRESDEN DESIGN — A STREAMLINED SHAPE BECOMES THE STANDARD FOR AIRSHIP HANGARS

„The orange peel-doors are a success." Anton Tedesko, 1932.

Stress analyst Karl Arnstein (1877–1974) was among those twelve engineers from the Zeppelin company to move to the USA in 1924 to continue the construction of airships for the newly founded Goodyear-Zeppelin Corporation, since building airships in Germany was against the Versailles Treaty. Wolfgang Klemperer (1893–1965), an engineer of aerodynamics, took part of

the group. He came from Dresden and had even seen the airship hangar in his hometown. When planning began for the Goodyear-Zeppelin Hangar, still extant today, Klemperer, Arnstein and civil engineer Paul Helma (1883–1965) agreed on the aerodynamic superiority of Dresden Hangar. They successfully demonstrated these qualities on the model of the future airdock in the wind tunnel at New York University (fig. 8). Arnstein explained:

> "The aerodynamical advantages of a rounded structure with flush revolving doors were convincingly demonstrated by these tests in respect to the safety and structural economy of the building as well as the avoidance of aerodynamic disturbances, which are disagreeable hazards to the ground handling of the ship." (University of Akron Archives, Arnstein Papers [1928])

The experiments in the wind tunnel were to reconcile two different demands. On the one hand, the safety of aviation required a rounded design to reduce disturbances of the laminar flow even with an airflow coming in from all directions, in particular near the open doors. Secondly the structural design was to reduce weight by decreasing air resistance and wind load. Both demands correlated with each other. The results from the experiments in the New York wind tunnel were the first scientific demonstration of the superiority of this design for an airship hangar and with hindsight they confirmed, what Ernst Meier intuitively had developed in 1913.

For the concept of Akron Airdock Arnstein and his executing engineers, William C. State (1871–1933) and Wilbur J. Watson (1871–1939), also appropriated Grüning's results from evaluating the storm damages on military airship hangars in Germany. Thus the new hangar was to contain extra large dormer louvers for pressure balance against wind suction and designed to cope with a wind load of 80 lb/ft^2 (390 kg/m^2) in the roof areas. The assumptions for wind loads in the German rules for designing airship hangars anticipated only 24 lb/ft^2 (100 kg/m^2).

At the start of the planning phase, Arnstein asked for construction documents of the doors of Dresden Hangar, which he received "confidentially" from Berlin. Thus Meier's ideas fed into the design of Akron Airdock, without him ever knowing. Arnstein also requested images and experiential reports from Dresden, in order to convince US authorities with regard "to the practicability and usefulness of this design that appears to be somewhat un-American". The result was a triumph to become a yardstick for later airship sheds anywhere in the world. Arnstein succeeded in executing an improved version of the best design for an airship hangar developed by Meier fifteen years before (figs. 10,11).

Figures 10, 11: Goodyear Airdock at Akron/Ohio, build in 1929 (Period Photos, Author's Archive)

Thanks to its soft shape Akron Airdock had excellent flow characteristics. Goodyear pilots were fond of demonstrating this to their passengers by steering their blimp directly onto the hangar, then stopping the engines and having the airship softly carried over the hangar by the flow.

Akron Airdock meant a turning point in the design of airship sheds: All subsequent buildings in the US had streamlined contours: Hangar One in Sunnyvale/California (1933) was the next, fol-

lowed by those in Weeksville/North Carolina and in South Weymouth/Massachusetts (both from 1941).
The 1954 building manual for the US Navy made the design of the hangar with aerodynamic properties and spherical gable closures or calottes compulsory for hangars exceeding a clear height of 120 ft (35.6 m).

Only by a hair Meier's design for an airship hangar failed to be adopted in the realm of shell construction with reinforced concrete. In 1932 Anton Tedesko (1903–1994) presented his draft for a passenger airship hangar, Zeppelin Hall, Washington D.C. for International Zeppelin Transport Corporation, based on a Dischinger barrel according to the system Zeiss-Dywidag. This time the spherical gable closures, which were concrete shells as well, were to slide into the building. In 1935 Alfonso Peña Bœuf (1888–1966) published his design for an airship shed in Sevilla. Bœuf's draft entailed spherical gable closures made from steel, while the body of the hall echoed the wide-spanning ribbed vaults made of concrete, employed by Eugène Freyssinet (1879–1962) for the airship hangars he realised in Orly. Unfortunately neither of these two designs was executed.

Clearly all airship hangars built in Germany after 1930 were influenced by the aerodynamic design. Their hybrid form combined elements from the old box shape with those from the fully rounded hangars with optimum flow characteristics. As a rule the floor plan resembled the design of Akron Airdock. However, they employed vertical sidewalls to be equipped with doors consisting of cylinder-shaped segments, sliding on circular rails onto the longitudinal walls.
By the end of the 20th century Ernst Meier's design returned to Germany. The airship hangar for CargoLifter AG (figs. 9,12) from the year 2000 with rounded sides is the biggest one ever to have been built. Its basic features are reminiscent of the 1913 structure in Dresden. On top of the aerodynamic advantages it were economic considerations again, which led to the structure reflecting the shape of the airship to be stored inside.

Figure 12: CargoLifter Airship Hangar, now "Tropical Islands Resort" (Photo: Author, July 11, 2014)

CONCLUSIONS

The evolution of an airship hangar with an optimally streamlined form reveals a revolutionary idea way ahead of its time, but suffering from unrecognizing its qualities. Only after the design was appropriated once more in a foreign country, it was finally recognised as a success in the country of its origin.

Civil engineering as a whole has benefitted from the development of airship hangars. The study of airflows at such structures was not only relevant for engineers in the field of aviation. It proved to be pioneering work, since appropriating the laws of aerodynamics were pertinent to all modern construction. Thus airship hangars provided an important link for acquiring knowledge in the field of aerodynamics subsequently to be integrated into the field of general building.

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