

## **Lamella Roof Constructions by Hugo Junkers**

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### **Abstract**

In 1924 and 1925, Hugo Junkers (1859-1935) patented a steel lamella roof construction, based on the wood lamella roof design by Fritz Zollinger. Because of its simplicity and markable rigidity it was soon used for many large roofs worldwide, which could span up to 40 m. It combines prefabrication, light weight, easy erection and durability in a striking manner. Unfortunately, due to the World War II and its consequences only few of these roof structures still exist.

The most significant difference between the lamella roofs designed by Zollinger and Junkers was, beside the used different material, the construction of the joints. In contrast to Zollinger, the joints by Junkers were rigid in all directions. This paper describes the evolution of lamella roof designs from Zollinger to Junkers. Not so well known lamella systems by Jucho and Hünnebeck will be discussed as well. Advantages and disadvantages of each construction type will be presented, too. However, the focus points to Junkers lamella roofs.

**Keywords:** Junkers, Hünnebeck, Zollinger, Lamella Roof, Germany

### **1. Introduction**

Hugo Junkers, born 1859 in Rheydt (Mönchengladbach), was a mechanical engineer, entrepreneur and scientist. In 1894 he developed a gas water heater for bathrooms and achieved a considerable economic success. Thereupon in 1895 he founded the corporation “Junkers & Co” in Dessau. Junkers showed an impressive talent to realise his own inventions and make them economically successful. In 1897 he was appointed to a professorship for thermodynamics in Aachen and also studied engine production. After 1908 Junkers researched aerodynamics and the development of aerofoils for airplanes. This occupation led to the foundation of the “Junkers Flugzeugwerke AG” in Dessau in 1919 and established his reputation as an airplane designer. In his factory in Dessau an independent department for steel constructions was founded where bridges and halls were produced.

The topic of this essay are the lamella roof constructions invented and distributed by Hugo Junkers. In 1933 Junkers was forced on behalf of the Reichsluftministerium to retire from

his own corporation. He was not allowed to visit his factories and the city of Dessau anymore. He moved to Munich and died in 1935 in Gauting (Schmitt [15]).

## 2. The construction systems by Zollinger, Bartning, Jucho and Hünnebeck

Because Junkers' invention resembles the so called Zollinger roof, this construction is to be briefly described. Zollinger's lamella roof consists of timber planks, about 2 metres long, that are originally connected with only one bolt. In every crosspoint one plank runs through (Fig. 1). Fritz Zollinger applied for a patent (No. 387469) in 1921. The lacking flexural rigidity of the connection with only one bolt turns out to be problematic (Ewald [4]). This fact can be compensated by the use of a rigid roof planking. However, most attempts to improve the system aim at increasing the flexural rigidity of the crosspoints.

The further development of the wooden Zollinger-roof using steel instead led to several constructions in the 1920s. An early example for a steel model was the cupola of the exhibition pavilion in Milano (1925) by Otto Bartning. Its shape approximated the thrust line and realised the Zollinger-system using iron I-beams over a diameter of 17 metres. It was erected in only 18 days (Schaefer [13]).

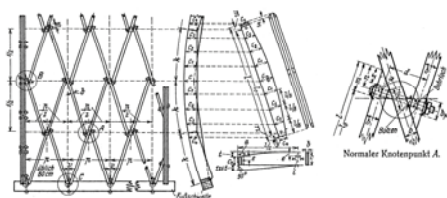


Figure 1: Zollinger roof (Gesteschi [5])

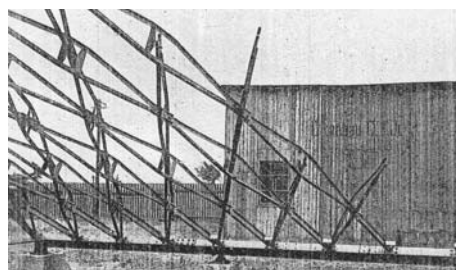


Figure 2: Roof structure by Jucho (Schellewald [14])

The corporation C.H. Jucho from Dortmund, which was very successful in the area of steel constructions, introduced a variant of the iron lamella roof in 1925. The lamellas used to have the shape of a spread I-beam. For the wooden roof planking additional light rafters were connected to the crosspoints of the mesh (Fig. 2) (Schellewald [14]).

The architect Emil Mauritz Hünnebeck had already worked out suggestions for an improvement of the Zollinger-system using wood, before he introduced his iron lamella roof in 1927. The U-beams made of steel-plate are about 2 metres long and notched on both ends. The flanges of four lamellas meeting in one crosspoint are connected with gusset plates on the outside. Only two webs are screwed together by an overlap connection. The remaining webs are not part of the connection. Hünnebeck was not able to realise an axial joint, even though he had tried to improve this defect in Zollinger's wooden construction (Ostenfeld [12]).

Hünnebeck's and Jucho's system as well were not nearly as successfully distributed as Junker's construction. A rare example is the hangar of the former air base in Stendal-Borstel (1935). However, here the lamellas were only used as a secondary supporting system for the roof planking. Figure 3 shows a joint of Hünnebeck's system. Not only the amount of screws but also the complicated design of the joint show the difference between Hünnebeck's construction and the Junkers system (Fig. 4)



Figure 3: Joint System Huennebeck



Figure 4: Joint System Junkers

In the 1950s twelve manufacturers in the USA join forces to improve and distribute the lamella system. Thereupon various structures are developed, consisting of framework lamellas that are reinforced by additional beams (Meschke [11]).

### **3 The Design of Junkers' lamella roof**

On November 25<sup>th</sup> 1924 Hugo Junkers applied for his first patent (No. 459038) for his iron lamella halls. The object of this patent is a predecessor with a different arrangement of the lamellas and the crosspoints. The additional patent No. 462881, applied for on November 10<sup>th</sup> 1925, improved and completed the basic system and represented the final construction (Fig. 5). The publications in the supplement of the "Deutsche Bauzeitung" and the magazine "Industriebau" introduced the system to the professional world in 1926 (Goedel [6]).

Hans-Jürgen Meschke describes the lamella roof because of its design as the "most accomplished interpretation" of the Zollinger construction (Meschke [11]). All in all it consists of only three standardized elements: the lamellas, the gusset plates and the roof beams. The lamellas are made of sheet steel 3 to 6 mm thick. Their design was inspired by aircraft construction, it "emerged from a rod that was used in the construction of aerofoils" (Erfurth [3]).

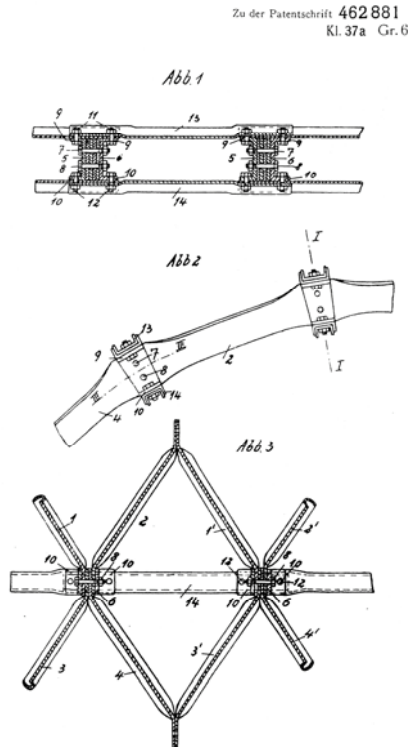


Figure 5: Lamella Roof by Junkers, Patent No. 462 881

The lamellas are about 1.5 to 2.5 metres long and up to 0.5 metres wide like in Zollinger's system. They go from one crosspoint to the next, there are no elements that run through over more than one rhombus. Four lamellas are connected flexurally rigid in one crosspoint. The specially shaped ends are arranged next to each other, clasped by two U-shaped gusset plates and easily screwed together by one or two rows of three screws each. On some roofs, screws that have been drilled open can be seen. This shows the influence of an aviation engineer. The gusset plates are folded on the top and the bottom. These angles are bearings for the roof beams that run through above and under the lamellas.

Thereby every rhombus is divided into two rigid triangles which enables the construction to conduct loads spatially. The roof planking consists of corrugated iron sheets, wood, pumice concrete or fibred concrete. If needed, rooflights can be inserted to illuminate the internal room. The horizontal forces are either conducted directly into the soil or into tension rods. From 1930 on the lamellas are provided with stiffening corrugations to increase the rigidity. In the five existing examples in Dessau both S- and C-shaped profiles with and without corrugations can be found (Fig. 6 and 7). Because Junkers' patent from 1925 shows only

various Z-shaped profiles and lamellas without corrugations it is probable that the C-shaped lamella with corrugations is a further development.



Figure 6: S-shaped lamella without corrugations and hole screws, probably standard design till 1930



Figure 7: C-shaped lamella with stiffening corrugations and normal screws, probably standard design since 1930

In 1926 the resemblance to the halls of the Zollinger syndicate led to a continuous patent litigation with Junkers' company. The Zollbau-Aktiengesellschaft demanded a profit participation as they see a reference to their own invention. Already in Zollinger's patent No. 387469 an iron design is mentioned. The claim was strictly refused in Dessau. At first the Junkers corporation offered a provision for using the chain of distribution of the Zollinger syndicate. But no settlement could be reached because the distribution organization of Zollinger's corporation "is in no way capable to cope with the distribution demands of Junkers' lamella roof construction" (Lauff [9]). In 1929 the conflict can finally be settled as the system was called "Junkers-Zollinger lamella roof" and marketed by both companies together (Ludwig [10]).

### 3.1 Forms

Junkers lamella roofs were more often executed in a segmental arch and more seldom in form of a pointed arch. Off the shelf, five different types of barrel vaults (Types 10 through 14) were available with a delivery time of 4 to 6 weeks. The typified variants with spans of 20, 25, 30, 35 and 40 metres only differed in size. They were delivered as complete solutions including gates, rooflights, windows, roofing and crane runway (Fig. 8) (Lauff [9]).

For shorter spans, shorter lamellas have to be used to accomplish a sufficient bending of the roof. This increases the number of crosspoints and also the necessary amount of work and material. In a lecture 1929 in Dessau, engineer Paulssen considered spans of less than 15 metres as inefficient (Lauff [9]). Yet we find that the roofing of the Dessau waterworks (constructed around 1930) has a span of only 11.60 metres.

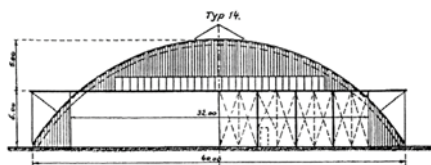


Figure 8: standardised hangar type 14 with 40 m span width (Lauff [9])

**5 • Normalisierte Typen!**  
 Vorläufig sind lieferbar:

Type	Spannweite	Höhe	Flugstrecke
Type 10	20 m	6,00 m	14,53x3,5 m
" 11	25 "	8,50 "	19x5,50 "
" 12	30 "	9,50 "	24x5,50 "
" 13	35 "	11, "	28x6 "
" 14	40 "	11, "	32x6 "

Diese Typen werden normalerweise komplett, also mit Toren, Oberlichtern und Spaltenfenstern, Wellblechendeckung und Kranbahn geliefert.  
 Verlangen Sie Preisliste D.

**6 • Lieferzeit:**  
 Type 10, 11 u. 12 etwa 4 Wochen nach Bestellung.  
 " 13 u. 14 " 6 " " teilweise auch ab Lager.

**KALORIFERWERK HUGO JUNKERS DESSAU**  
 Unsere Konstruktion ist in den meisten Kuppelrindern patentiert. — Änderungen bleiben vorbehalten.

Figure 9: Promotional brochure for Junkers' hangars (excerpt) (Lauff [9])

### 3.2 Structural analysis

The Junkers lamella roof is internally and externally statically indeterminate to a high degree. To be on the safe side, the roofs were calculated as two-hinged arches. The bearing force of the membrane and the fixed support at the cullis and gable were neglected. Thus the calculation was significantly simplified (Goedel [6]).

Because the barrel vault achieves constructive preconditions for a spatial conduction of loads through its upper and lower roof beams, the halls generally exhibit a considerable reserve of load bearing capacity. However, an important precondition for the spatial performance of the barrel is a rigid bearing at the gables. Not only wind and snow loads, but also crane runways were taken into account in the assumed loads. In a data sheet of the halls of types 10 through 14 the payload of the trolley, which sits on a crane runway in the apex, is stated as 2 tons (Lauff [9]).

### 3.3 Assembly

The documentation of a construction site in Kayseri (Central Anatolia, Turkey) in 1926 allows for a demonstrative depiction of the assembly process. After building the foundation, the construction of the hall started with the assembly of the scaffolding. Emanating from the bearings, which themselves were also steel L- or U-sections, the lamellas were bolted together and joined in the apex to form the final arch. Because of the lightweight lamellas, no cranes or heavy construction machines were necessary. The work scaffolding was moved lengthwise relative to the hall; the assembly could be completed with the cantilever method of construction. At the same time, finished areas could already be roofed. Just like the Zollinger construction, few low-skilled workers were able to execute the assembly. In Kayseri, just four skilled and ten unskilled workers were employed (Junkers 1926 [7]).

### 3.4 Advantages and disadvantages

The easy assembly of the construction is a big advantage. The low weight of the individual parts makes transporting and stocking them easily possible. Goedel [6] estimates that the total weight of the roof is reduced by 25 % compared to traditional roof truss constructions.

The comparably short spaces between the roof beams also enabled the use of thinner roof planking so that the whole construction proves even cheaper and lighter.

Concerns that the construction was prone to corrosion because of water condensing at the lamellas proved to be untrue. The distance between the lamellas and the roofing ensured a constant circulation of air in the construction. Furthermore the thin steel plates quickly adapted to the surrounding temperatures thanks to their high thermal conductivity. Thus water vapour could not condense on them (Junkers 1928 [8]). This statement, found in a company newsletter, and hence subject to scrutiny, can be fully approved after inspecting several halls now. The lamellas still have their original coat of paint in parts and show only sporadic corrosion after the long time of 70 years.

Worth mentioning is also the good acoustics of the barrel vault despite its sonically hard surfaces. The diamond-shaped profile suppresses distracting flutter echo.

The structural behavior of the thin lamellas proves critical in case of fire, when the elastic limit of steel is lowered due to rising temperatures. Foaming paint approved by building supervision can improve the time of fire resistance. Yet approval is required on an individual basis because the necessary  $u/A$ -value is not adhered to. Accompanying measures like fire alarm or extinguishing systems can help to set up a licensable concept of fire prevention. In high rooms according to occupancy lower fire prevention requirements may be demanded for the roof construction, because due to their height critical steel temperatures are not reached.

## **4 Examples**

Junkers' own air transportation company opened excellent export opportunities. The small individual packages, into which the halls were fragmented are suitable especially for air shipment. Halls were exported into 27 countries, including Brazil, the USA and Italy (Erfurth [3]). Due to imprecise statements of place of the assembled constructions abroad and missing year specifications, little is known about their disposition.

The remaining Junkers-roof-constructions in Germany are referenced in the map (Fig. 10) although it may not be exhaustive. (Letters to the authors referencing further locations are emphatically encouraged.) Due to the frequent application as aircraft hangars many halls probably fell victim to air strikes during World War II.



Figure 10: known existing Junkers lamella roofs in Germany

In Oberschleißheim near Munich, two halls with a span of 35 m each exist. Originally, they were part of a complex of three hangars with central naves in between (Lauff [9]). Another Junkers-hall remains on the airfield Köthen/Anhalt. It is a flat arched hall with adjustable tension rods and is one of the widest spanning halls with 40 metres.

In Dessau, where the headquarters of Hugo Junkers' company used to be, five steel-lamella-halls remain. The boathouse in Leopoldshafen today is used by the Junkers-Paddelgemeinschaft e.V. It is a Junkers construction with a pointed arch (Fig 11). The house, built in 1930, is relatively small: length  $L=12.6$  m, width  $W=14.25$  m. Only one assemblyman and three apprentices erected it in 14 days. The roof has the already described S-profile without stiffening corrugations. None of the other remaining examples in Dessau employ this form. At the crosspoints the two outer bolts are drilled open (Fig. 6). In 1945 a bomb hit the roof, the damaged lamellas can still be seen and prove the high redundancy of the construction (Fig. 12).

The hangar on the former airfield near Dessau-Bergensbusch ( $L=18,30$  m,  $W=19,40$  m) and the two lamella roofs of the city's waterworks in the Wasserwerkstraße ( $L= 43,85$  m,  $W=11,56$  and  $L=19,50$  m,  $W= 20,80$  m) show the same constructive design. The lamellas are C-shaped and provided with corrugations (Fig. 4). All of them were erected around 1930.





Figure 11: Boathouse Dessau, erected 1930      Figure 12: damaged lamellas after a bomb hit in 1945; situation 2008

The construction of the so-called Junkalorhalle on the area of Junkers' factory in the city's centre is apparently in surprisingly good condition (Fig. 13). Because of its location in the area of the former department for steel constructions it might even have been the production facility for other lamella halls. Currently it is argued whether the hall has to be moved or is allowed to stay in its original place as the surrounding factory premises are to be demolished and cleared.

The segmental arch with roof light is 25.32 metres wide, 39.46 metres long and has a rise of 7.92 metres. Until now it was assumed that the hall was erected in 1926. However, it was possible to date the construction more precisely to 1929 (Batz [2]). It was expanded north at an unknown time. In the older southern part the lamellas are 5 mm thick C-profiles without corrugations. The lamellas in the later erected northern part are also C-shaped but with corrugations and a thickness of only 4 mm (Fig. 7). It is probable that the corrugations were applied to increase the resistance against buckling and therefore allowed thinner profiles.



Figure 13: Junkalorhalle Dessau, erected 1929, situation 2008



Figure 14: car delivery hall of the Horch-Werke Zwickau, erected around 1930

Figure 14 shows a Junkers roof as it can not be found anymore. Around 1955 the former car delivery hall of the Horch-Werke was reformed to a cultural venue. Therefore the roof was lifted up 5.5 metres and the ground floor was remodelled. Due to the suspended ceiling unfortunately the construction is not visible anymore but still exists.

The application of lamella roofs in the late 1930s is confronted with the command “to attach great importance to saving iron” (Auto Union [1]). From this time on there less and less iron roofs were built; in many cases they were replaced by wooden frameworks.

## 5 Conclusion

The construction of the Junkers lamella roof is outstanding concerning its structure. Its minimal use of material, the easy assembly, good acoustics and its corrosion arrestive design make the construction a system that today would be praised as sustainable and effective.

Despite the problems with fire security the authors can not understand that the lamella roofs have not been built in Germany since the end of World War II. May this essay encourage to find and understand the knowledge in historic constructions and use it to accomplish today's constructive challenges.

## References

- [1] Auto Union AG: Schreiben des Vorstands an den Leiter des Arbeitsamtes Zwickau vom 20.12.1937 bezüglich des Erweiterungsbaus des AUDI-Werkes Zwickau
- [2] Baatz J., *Lamellendächer der Bauart Zollinger und Junkers*. Masterthesis, Technische Universität Dresden, 2008.
- [3] Erfurth H., *Im Rhythmus der Zeit – Hugo Junkers und die Zwanziger Jahre*. (2<sup>nd</sup> ed.), Anhaltische Verlagsgesellschaft mbH Dessau, 1996.
- [4] Ewald G., Zur Ausbildung der Knotenpunkte bei Rauten-Lamellen-Konstruktionen. *Bauen mit Holz*, 1985, Vol.25, No. 4, 222-223.
- [5] Gesteschi T., Fortschritte in der Ausführung neuzeitlicher Baukonstruktionen. *Die Bautechnik*, 1925, Vol. 6, No. 25, 327-344.
- [6] Goedel P., Eine neue Dachkonstruktion in Eisen (Junkers'sches Lamellendach). *Deutschen Bauzeitung Beilage Konstruktion und Ausführung*, 1926, Vol. 60, No. 17, S.125-127.
- [7] Junkers-Nachrichten 1926/4, S.59-63
- [8] Junkers-Nachrichten 1928/1, S.20-22
- [9] Lauff S., *Der Traum vom Bauen: Hugo Junkers und die Architektur*, Rhombos-Verlag Berlin, 2001.
- [10] Ludwig M., Rauten-Lamellen Dächer in Stahl: Verwandte Konstruktionen und der Patentstreit Zollinger-Junkers, in *Das Dach der Zukunft: Zollinger Lamellendächer der 20er Jahre*, Zimmermann F. (ed.), Fachhochschule München, 2003.

- [11] Meschke H.-J., *Baukonstruktion und –technik der hölzernen Wölbkonstruktionen – Vom Bogentragwerk zum Stabnetzwerk*. Dissertation, Technische Hochschule Aachen, 1989.
- [12] Ostefeld Chr., Sporthalle in Ollerup (Dänemark). *Deutsche Bauzeitung*, 1933, Vol. 67, No. 30, 584-585.
- [13] Schaefer P., Der Deutsche Ausstellungs-Pavillion auf der Messe in Mailand. *Deutsche Bauzeitung*, 1926, Vol. 60, No. 44, 366-368.
- [14] Schellewald, Neuartige eiserne Dachkonstruktion. *Der Bauingenieur*, 1925, Vol. 6, No. 28/29, 841-844.
- [15] Schmitt G., *Hugo Junkers – Ein Leben für die Technik*. Aviatic-Verlag GmbH, 1991