LEONARDO TORRES QUEVEDO, 1902-1908. THE FOUNDATIONS FOR 100 YEARS OF AIRSHIP DESIGNS

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Abstract

On 5th May 1902, Spanish engineer Leonardo Torres Quevedo applied for a Patent in France for "Improvements in dirigible aerostats", complemented, with a "Note on the calculus of a dirigible balloon with interior suspension and keel" presented together to Madrid and Paris' Academies of Science. He had conceived a complex inner structure, all along the envelope of the aerostat: a longitudinal frame of triangular cross section made up of non-rigid ropes, permeable curtains and metal cables which "rigidify" altogether through the excess of pressure level of the gas. Again inside the envelope, vertically placed at its bottom and suspended from inside cables attached to the top of the envelope, an articulated plane metal keel, together with the triangular structure, would support the gondola, which was designed to be attached from outside to the bottom of the envelope. The number of possible solutions to the problem of aerial navigation through airships included in this Torresquevedian contribution, i.e. the number of different systems for manufacturing dirigible balloons, would almost cover the whole twentieth century in airship designs.

1. TORRES QUEVEDO'S 1902 GENERAL CONCEPTION

1.1. The 'problem of Flight' in 1901

Spanish engineer Leonardo Torres Quevedo is becoming well known all around the World for his outstanding contributions to the History of Science and Technology [5].

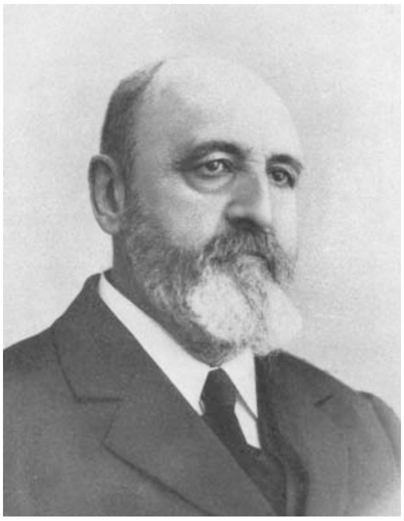

Fig. 1. Leonardo Torres Quevedo (1852-1936)

He patented in 1887 the 'transbordador', that was to become, once it was opened to the public in San Sebastián (Spain) in 1907, the first cable car for passengers in history. While technicians were constructing mechanical machines as a help for arithmetical operations, Torres Quevedo created in 1893 algebraic machines which solved algebraic equations and printed the solutions. He invented in 1902 the first remote control device, the 'telekine'. By 1912 he built an automatic chess player, the first machine provided with 'artificial intelligence'. In 1916 the 'Spanish Aerocar' became the first cable car for passengers in North America. In 1920 he presented in Paris the first effective computer, the 'electromechanical arithmometer' [5] [10] [19]. Etc.

But in 1901 Torres Quevedo embarked on the search for the solution to one of the biggest challenges that mankind faced at the beginning of XXth Century: Flight [6] [7] [8]. In those days Aviation did not exist and it would not become a real solution to the problem until WWI. The only aircrafts were balloons and what would become known as airships: a kind of dirigible balloon which then lacked any in-depth scientific study.

By that time there were basically two principal systems: *rigids*, built according to the designs of German Count Ferdinand von Zeppelin; and *non-rigids,* the best known being those tested in France by the Brazilian sportsman and millionaire Alberto Santos Dumont. The former had an internal rigid metal frame housing several hydrogen cells, and a fabric envelope which covered the whole structure. They had a stable form, but could not be folded when deflated, the volume of the exterior suspended elements resulted in considerable resistance and they also suffered transverse oscillations. The latter had an impermeable envelope without rigid elements which was inflated with hydrogen. They could be disassembled and were easily transportable when deflated, but they were dependent on internal overpressure in order to maintain their shape, and needed ridging along the whole envelope to prevent the gondola from bending the airship in the middle [3] [10] [11].

A third semi-rigid system was to be tested the following year: Henri Julliot's 'Le Jaune', built in France by Edouard Surcouf for the Lebaudy brothers. It had a metal plane horizontal keel attached outside the bottom of a gas bag without any internal element, and made is maiden flight in 1903.

1.2. Torres Quevedo's solution to 'the problem'

On 5th May 1902, Torres Quevedo applied for a Patent in France for 'Perfectionnements aux aerostats dirigibles' ("Improvements in dirigible aerostats"), complemented, with a "Note sur le calcul d'un ballon dirigeable a quille et suspentes interieures" ("Note on the calculus of a dirigible balloon with interior suspension and keel") presented together to Madrid and Paris' Academies of Science [2] [7] [20].

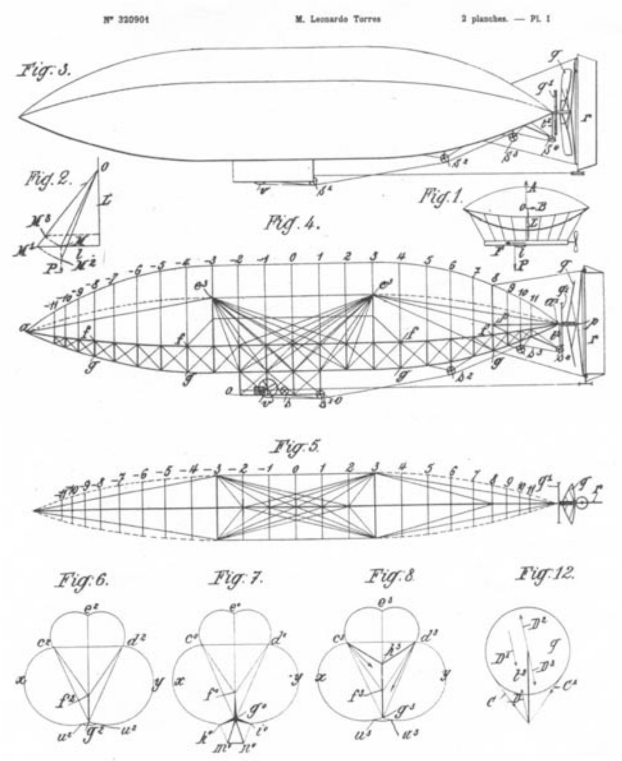

Fig. 2. Drawings in Torres Quevedo's 1902 patent

He had designed a semi-rigid airship with a complex inner structure, all along the aerostat, which constituted a complete revolution for his time.

Opposite to the usual cylindrical envelope, and with the objective of minimizing its stress and subsequent permeability, Torres Quevedo conceived a trilobed envelope with three longitudinal cables (ropes) placed in the intersection of every two lobes. Inside the envelope, and on the basis of those three cables, a longitudinal frame of triangular cross section was to be completed, made up of non-rigid ropes, permeable fabric curtains, metal cables and longerons. Longitudinal cables and frame would 'rigidify' altogether through the excess of pressure level of the gas, so that, when inflated, it would act as an internal rigid structure.

Again inside the envelope, an articulated plane metal keel was vertically placed at its bottom and suspended from inside cables attached to the top of the envelope. The keel, together with the triangular inner structure, would support the gondola, which was designed to be attached from outside to the bottom of the envelope without any external rigging.

The number of possible solutions to the problem of aerial navigation through airships included in this Torresquevedian contribution, i.e. the number of different systems for manufacturing dirigible balloons, would almost cover the whole twentieth century in airship designs.

The international resonance of the new developments had a huge effect on the aeronautical world. By the end of 1902 the report at Paris's Academy of Science was included in the French journal *L'Aerophile*, and a summary in English was published in the British *The Aeronautical Journal*.

2. THE FIRST EVOLUTION, 1904-1908: THE TRILOBED *AUTORIGID* AIRSHIP

2.1. The *Centre for Aeronautical Research*

On 4th January 1904 Spanish Government created the first civil institution in Spain devoted to the solution of both the 'problem of Flight' and the 'remote control' of devices [8] [9]: the *Centro de Ensayos de Aeronáutica* (*Centre for Aeronautical Research*).

Soon afterwards, on 27th January 1904, he presented a new paper to the Academy of Science in Madrid entitled "Globos atirantados" ('Stretched balloons'), with the first evolution from the general 1902 system. In this paper Torres Quevedo suggested the possibility of eliminating all rigid elements in the interior structure (i.e. the hull), and of removing the keel in such a way that the interior pressure of the gas contained within the envelope would make the airship 'self-rigidifying'.

In March 1905, with the collaboration of the Army Engineer Captain Alfredo Kindelán Duany as Technical Assistant, the construction of the first airship began at Madrid's Beti-Jai 'pelota' court. At the beginning of June 1906, the joining of the envelope to the funicular frame (made up of only non-rigid elements) was complete, and the balloon was inflated to 640m³ in the *Parque del Real Aero-Club* in Madrid.

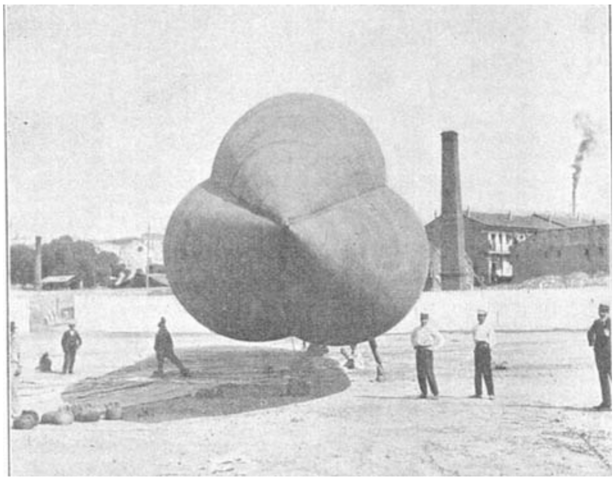

Fig. 3. The 640m³ autorigid envelope in Madrid, 1906

With the shape of the aircraft proven to be stable, on 11th July he applied for a general patent for "Un nuevo sistema de globos fusiformes deformables" ('A new system of collapsible cylindrical balloons'): the internal frame of triangular cross section made up with flexible ropes and porous fabric curtains would act, when inflated, as a 'rigid' structure, also determining the airship's characteristic trilobed shape. Without any metal longeron or keel, the gondola and engines would be suspended form only internal rigging. The *autorigid* airship was born [8] [10].

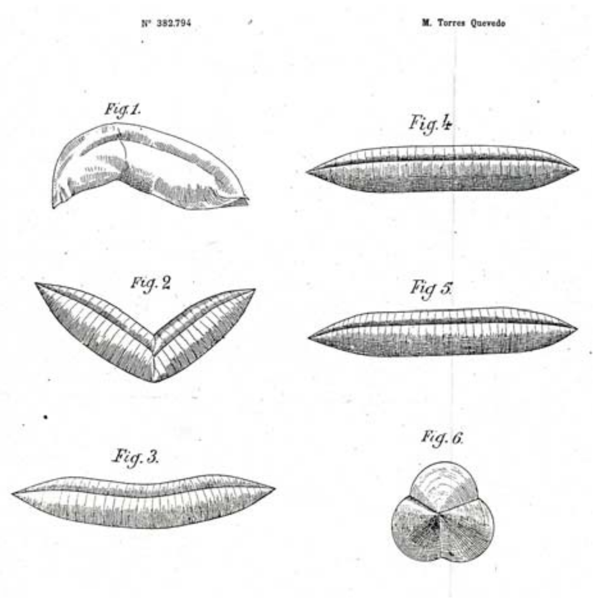

Fig. 4. French patent of the trilobed autorigid system

A few days later the balloon (at that time still just a gas bag without cabin, engines, propellers, etc.) was moved to the *Parque Aerostático Militar* in Guadalajara, 60 km east of Madrid.

2.2. The "Torres Quevedo no. 2", 1908

By July 1907, once he granted the patent in France and the United Kingdom, the airship 'Torres Quevedo no. 1' had come into existence (fully equipped with gondola, engines, helm, rudders, etc.) and plans were made for the first piloted trials. The system brought together the advantages of preceding airships and eliminated their disadvantages: the airship was flexible (which meant that it allowed for any possible impacts), it was deflatable, transportable etc., and at the same time was rigid due to the interior pressure that stretched the interior frame to a stable form. Torres Quevedo had solved the problem of Flight by means of *auto-rigid* airships.

However, subsequent tests of in-flight stability were postponed in order to change the envelope for a more impermeable one, while keeping the original funicular frame. This required the volume to be increased to 960m³ in order to maintain lift. The result was too many delays, and the tests on the new airship 'Torres Quevedo no. 2', with the engine running and passengers in the gondola (the passengers being Kindelán, Pedro Vives and Torres Quevedo himself, along with other military aeronauts from Guadalajara) would not take place until 11th July 1908 [10] [11].

Fig. 5. The "Torres Quevedo nº 2", June 1908

Although six years had passed since 1902 (which was too long for any normal technological innovation to continue to be considered 'updated'), Torres Quevedo's creation continued to be a new discovery with extraordinary international relevance, and thus he seemed to have reached his goal. In Spain the public tests were meant to take place in September in the presence of King Alfonso XIII. Abroad the trials were anticipated with high expectations, given the lack of outstanding effective innovations in the rest of Europe (remember the 'Ville de Paris', 'Nulli Secundus', 'Parseval' and not many noticeable more).

However, in August 1908 Torres Quevedo parted company with the Army and in September he found himself forced to leave the Park in Guadalajara. Despite this, on the 20th February 1909 he requested an additional certificate to the 1906 patent, for 'Improvements introduced in the main patent', but it would not be issued until 13th May 1909. Following various mishaps, he moved all the material to a rented hangar in Sartrouville (Paris) to the company *Astra,* a new Aeronautical Society integrated in the conglomerate of entrepreneur Henry Deutsch de la Meurthe, which was directed by Edouard Surcouf, who had been familiar with Torres Quevedo's work since 1901 [10] [11].

3. THE COMMERCIAL SUCCESS OF THE TRILOBED *AUTORIGID* SYSTEM

3.1. The French *Socièté Astra*

In October of 1909 the 'Torres Quevedo no.2' (having undergone several modifications) was inflated again for a flight around the outskirts of Paris. Despite some setbacks that took away from the expectations of the test, the advantages of the Torresquevedian system remained clear and France expressed its interest in the Spanish airship.

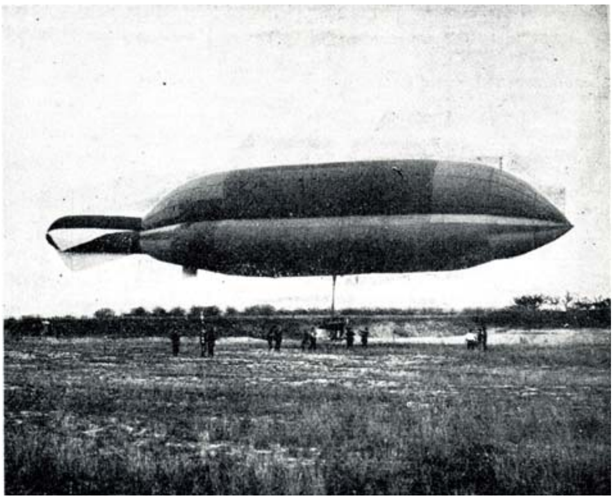

Fig. 6. The "Torres Quevedo nº 2" in Paris, 1909

With earlier authorisation from the Spanish authorities on the 31st December 1909, the contract with the Astra society was signed on the 12th February 1910. The agreement included a *patriotic* clause which stipulated "the condition that the use of said system in Spain should be free", which, unfortunately, would never be used. Torres Quevedo's ideas continued to be the most relevant news in the aeronautical world at that time…and he would receive royalties of 3 francs for every m³ of each airship sold [5] [9] [10].

In Issy-les Moulinaux (south-west of Paris) in February 1911, the successful trials of 'Astra Torres no.1' began. The airship was the first with the 'Torres Quevedo no.2' to be built in France by *Astra* and it had a capacity of 1600m³. The results were spectacular. It was faster, more stable and more manoeuvrable than all the systems before it. It won the 'Deperdussin' prize and the French army incorporated it into their operations.

In short, the system that the gifted inventor had thought up ten years earlier proved to be the best aircraft in the world in 1911, when the first -and it must be said 'primitive'- aeroplanes were having continuous accidents. On a personal level, Torres Quevedo achieved great success and proved himself as one of the leading aeronautical engineers in the world at the beginning of the second decade of the twentieth century [5] [11].

Fig. 7. The "Astra-Torres nº 1" in Paris, 1911

3.2. The 'Mooring mast', 1911

In this respect, before he began the tests on 'Astra-Torres no.1', our talented engineer would again surprise the international community with another fantastic contribution. On the 2nd February 1911 in Belgium he applied for privilege of invention for "Moyens de campement pour Ballons dirigibles" ("Improvements in Mooring Arrangements for Airships"). The new creation consisted of a post with a superior pivoting platform, designed especially in order to be able to moor Torres's airships outdoors. There were three cables placed respectively in the longitudinal intersections of the lobes which joined at the tip of the nose in order for it to be steered, thus evenly distributing the tension throughout the airship. What is more, the airship could turn around the axis of the post, orientating itself automatically with the direction of the wind, always with the least possible resistance [9] [10].

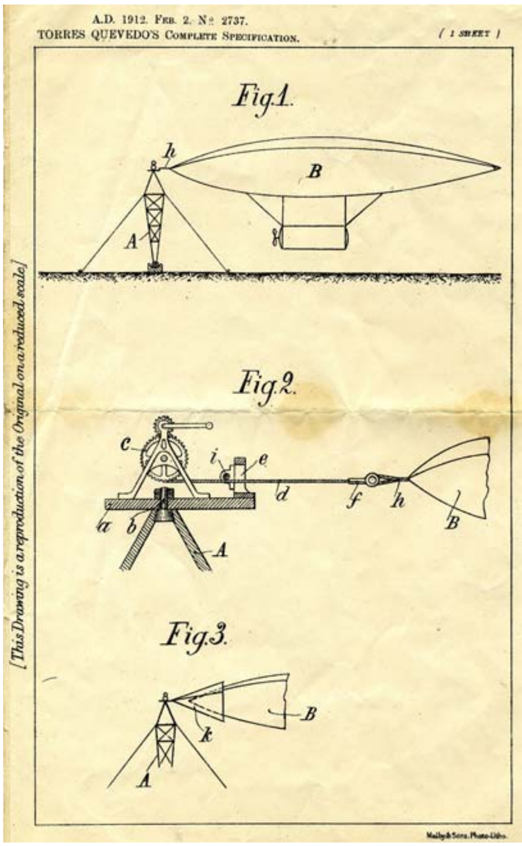

Fig. 8. British patent for the 'Mooring Mast', 1912

The new invention (with application in France and the United Kingdom from 2nd February 1912) was a complete success and it became the mooring system used by every kind of airship. It is exactly the same that existing models still use now in the 21st Century.

3.3. The success of the 'Astra-Torres XIV'

However, at this time it was principally the start of the invention's commercial stage. So, in May 1911, petrol magnate Henry Deustch de la Meurthe took charge of the 3,400m³ 'Astra-Torres no.2', as if it were a private yacht and he used it in his travel business the *Compagnie Générale Transaérienne*, which ran trips between France and Switzerland. Shortly afterwards in 1912, Astra received an order from the English Admiralty for the 8000 m³ 'Astra-Torres XIV'. At the same time the French Army ordered the 23,000 m³ 'Astra-Torres XV' (later renamed the 'Pilatre de Rozier'), which had similar dimensions to those of the German 'Zeppelins' and could reach speeds of around 100 km/h [3] 10] [11].

The handing over of the 'Astra-Torres XIV' (the 'HMA no.3' to the Royal Navy Air Service) meant international recognition for the system with this ship beating the world speed record for an airship, registering 83.2 km/h during the reception trials, a speed which reached 124 km/h with the wind in it's favour.

Fig. 9. World Record of the "Astra-Torres XIV", 1913

The orders kept coming, and a few months later the Royal Navy Air Service would receive the 11,327 m³ 'Astra Torres XVII' (HMA no.8) and the 3960 m³ 'Astra Torres XIX' (HMA no.10) [1] [12] [16] [C].

3.4. The first airships carrier

However, evidence of Quevedo Torres's genius did not stop here. On 30th July 1913, with World War I, and hence the new requirements of aggressive armies just around the corner, he had presented the Descriptive Report 'A new type of vessel named *camp vessel*' in application for a patent dated 12th December 1913. In was about a real aircraft carrier, conceived especially for the 'Astra-Torres' types, with mooring post and hold to house up to two inflated units, hydrogen cylinders etc. Yet again, Torres Quevedo was ahead of his time. Up until then no country, not even the United Kingdom, had even thought of the possibility of combining aeronautics with ships in this way, even though every nation was beginning to regard it as vital now that they were heading towards the outbreak of war.

Nevertheless (all be it ten years later!) the Spanish Armed Forces built what would be the first Spanish aircraft carrier based on this design, the first ‘Dédalo’. A second one would be built several decades later. However, historians have never attributed this to Torres Quevedo, and in the end, the ‘Dédalo’ would never hold/carry ‘Torres Quevedo’ airships, but ‘SCA’ and ‘O’ class Italian models which would play a part in the Alhucemas landings in 1925 during Spain’s war against Morocco [9] [10].

4. TORRES QUEVEDO’S *AUTORIGID* AIRSHIPS AT WORLD WAR I

4.1. Torresquevedian airships in the RNAS

At the outbreak of the Great War, the French army’s only two available ‘Astra-Torres’ were used at the trenches. But in this position they were extremely vulnerable, and turned out to be inefficient. In fact, ‘L’Alsace’ was destroyed in October 1915, as was ‘Pilatre de Rozier II’ in January 1917. France ended up without any ‘Torres Quevedo’ airships, like Belgium, as the same happened to ‘La Flandre’, a 14,700 m³ airship that they had acquired in 1916.

Fig. 10. British Coastal class trilobed airship, “C-26”

In fact it was the British Navy (and not the Army) that saw most clearly the advantages of using airships in antisubmarine war as a way to guarantee protection of naval convoys which were vital for supplies, a task which the aeroplanes of the time were unable to carry out. They began to make their own trilobed ‘autorigid’ aircraft, 4,180 m³ ‘Coastals’, taking advantage of Airship Ltd’s (an English affiliate of Astra) constitution and the experience they had gained in building Astra-Torres. All in all they built 34 units, four of which were sold to Zarist Russia in July 1916, although Torres Quevedo did not get a penny for them as the English patent had expired some years earlier for not having satisfied the appropriate annuals.

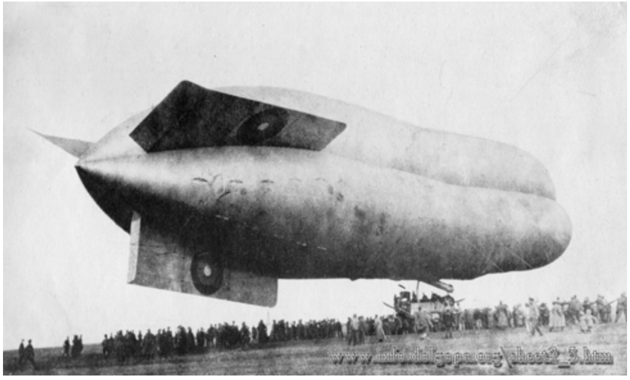

Fig. 11. Russian Coastal class airship “Chernomor 2”

Throughout 1917 the first nine units of a new model of airship were developed, with more than double the capacity. The 10,190 m³ ‘North Sea’ ships were completed along with another 9 airships in 1918, only one of which would be sold in the USA in November of that year, the ‘NS-13’. Between the two series, 10 new and improved ‘Coastals’ were built, as were the 5950 m³ ‘Coastal Stars’, which were dedicated to vigilance and the antisubmarine war in the North Sea, the English Channel and the Western Approaches. Next to Britain’s impressive panorama of construction and use of Torresquevedian airships, the French Navy paled in comparison. So, before ordering new airships of the ‘Torres Quevedo’ system from Astra (and that only happened once our inventor reduced his commission to 1.5francs per m³), they had to buy a British ‘Coastal’, the ‘C-4’ that, renamed as the ‘AT-0’, became a starting point for the new ‘Astra-Torres’ ships [1] [14] [16] [C].

4.2. ‘Astra-Torres’ for France, USA and Japan

So now, at the beginning of 1917 all four units, from the ‘AT-1’ to the ‘AT-4’ of 6,500 m³, would be delivered. This would be the case for the following five ‘Astra-Torres’ (from the ‘AT-5’ to the ‘AT-9’ of 7,600 m³) in the summer of that year and later, in 1918,for the remaining eight airships (from the ‘AT-10’ to the ‘AT-17’ of 8,300 m³). All of them were used for continued vigilance of the coast and for tracking German submarines at the Bay of Biscay, the English Channel and the Mediterranean Sea (from bases at Marseille, but also in Tunisia and Algeria) [3] [4] [11].

Fig. 12. French Astra-Torres airship "AT-1"

When the USA entered the First World War in 1917, their airship pilots trained in England with the 'NS-7' and in France with the 'AT-1' and the 'AT-13'. What is more, the US Navy took charge of the new 'AT-18' (10,700 m³), at Astra, that would be delivered once the conflict had ended to be used for the development of the North American aeronautical programme of the interwar period. On the other hand, in 1922 it was the Imperial Japanese Navy that bought the latest unit built by Astra, the 'AT-20', also 10,700m³, marking their expansion across the Pacific, leading them into conflict with the USA during World War II [10] [11] [14].

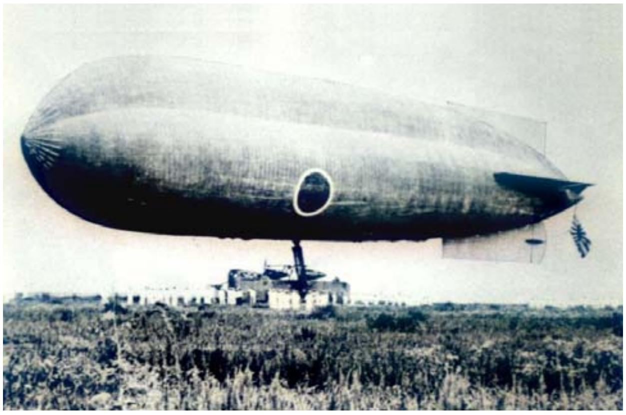

Fig. 13. Japanese Astra-Torres airship "AT-20"

5. THE TRILOBED *AUTORIGID* SYSTEM 1936-1978

5.1. Zodiac's trilobed *autorigid* airships

More than a decade later, and in an international context dominated by rigid models based on the Zeppelin' system, another French company, now the *Société Zodiac* (better known later for their rubber dinghies) again took on the construction of Torresquevedian airships. It started in 1930 with small bi-lobed 'Vedette', and culminated in 1936 with two units with a trilobed *autorigid* envelope identical to those of the 'Astra Torres, the 3,400 m³ 'V-11' and the 4,100m³ 'V-12', sold to the French Navy ten years after they removed the final models constructed by *Astra* [3] [13].

Here, another 1902 solution could be used at last in a trilobed airship: the cabin was located attached to the bottom of the envelope due to the use of small-length propellers, something unthinkable before the end of the Great War.

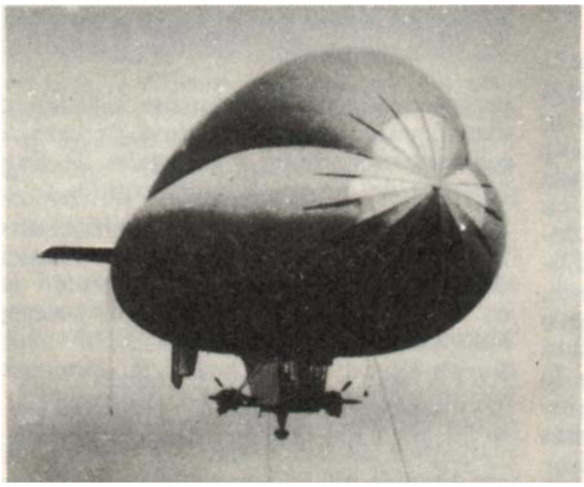

Fig. 14. French Zodiac autorigid airship "V-11"

Apart from these trilobed French airships, tetra-lobed captive balloons were also designed by the US Navy in the forties [10].

5.2. The double trilobed catamaran 'Dinosaure'

But surprisingly enough, in 1977, the French engineer Villevielle took up again Torres Quevedo's *autorigid* system 70 years after he patented it in France. Villevielle designed for the *Mètèorologie Nationale* a double trilobed catamaran airship, the 'Dinosaure'. It was meant to be used for meteorological research, and the studies for its feasibility were made in conjunction with the *Office National d'Études et Recherches Aérospatiales*, the *Société Nationale Aéronautique et Spatiale*… and the company *Zodiac Espace* [10].

Zodiac, the last French firm to build trilobed *autorigid* airships, provided their experience and got involved in the project of a 3350 m^3 catamaran airship, 26 m long and 31 m wide. Finally, in June 1978 trials were made of only a 47 m^3 scale model, the 'Dino 2', 7.60 m long and 6.90 m wide.

Fig. 15. French double trilobed airship 'Dinosaure'

Also in France, the firm *Voliris* was established in February 1999 in order to develop and manufacture high-tech airships. Among their projects they are studying a new hydrogen trilobed airship, the 'H-2' under the direction of Gerard Durand, although not many details are known so far [H].

6. TORRES QUEVEDO'S INNER SUSPENSION

6.1. The Note on the 'inner suspension', 1902

As Paul Appell reported in 1902 for Paris *Academie des Sciences* about Torres Quevedo's project, "the main innovation introduced by the author is based upon locating the suspension rigging inside the envelope". That is why we can state he was well ahead of his time… more that 25 years ahead of his time [2] [7].

In order to prevent the envelope sagging, before Torres Quevedo all non-rigids used one or another of the following external solutions: 1) long extensions of the gondola; 2) netting or bridles for the rigging on the gas-bag; or 3) from 1912, 'eta patches', i.e. cables attached to the envelope by kidney-shaped adhesive patches which spreaded the load evenly over the gas-bag surface.

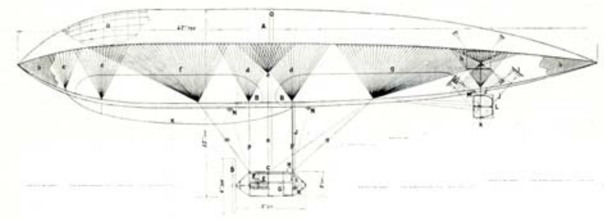

Fig. 16. Astra-Torres' longitudinal ridges and suspension

The extent of the idea introduced by the Spanish engineer was not fully realized in those years when rubberised fabric envelopes needed such a complicated internal suspension as designed in 1906 for the *autorigid* Astra-Torres type. Here two longitudinal ridges, one on each side of the upper lobe, would anchor the suspension cables, directed to the third ridge, where the two lower lobes meet.

But research in new materials was to change and facilitate several much simpler improvements.

6.2. Goodyear´s oversimplification, 1929

It was not until 1929 when *Goodyear* 'rediscovered' in the USA the key in Torres Quevedo's 1902 contribution: unlike all former French, British, German or American non-rigids, the control car of the experimental "K-1", carried flush against the envelope, was to be suspended by means of inside cables attached to upper catenary curtains cemented to the inside of the envelope [3] [10] [14].

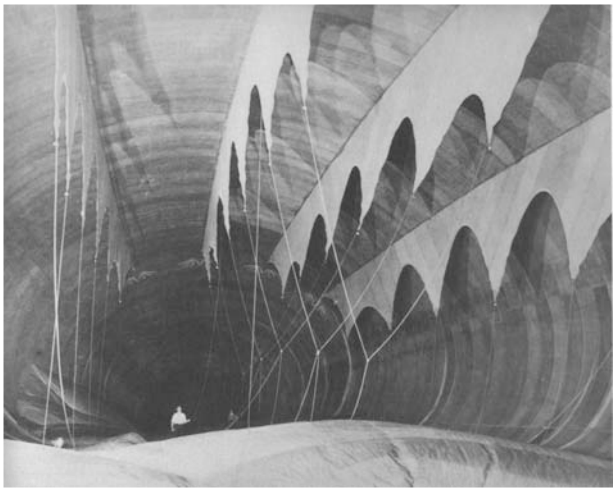

Fig. 17. The internal rigging in US Class K airships

Looking backwards, the inter-war period was the age of the big rigid airships: German Zeppelin (also operated in the USA and France), British 'R' series, American-built rigids filled with helium, etc. But successive disasters put a dramatic end to this system before World War II: British 'R-38' (1921, 44 deaths), French 'Dixmude' (ex-Zeppelin 'LZ-114', 50 deaths), US 'Shenandoha' (1925, 14 deaths), 'R-101' (UK, 1930, 48 deaths), US 'Akron' (1933, 73 deaths), and German 'Hindenburg' (1937, 36 deaths). This last disaster, the most famous of the tragic list, put an end to rigid airships, which were dismantled and never built since then.

Opposite to this 'international defeat' of the rigid airships, *Goodyear*'s oversimplification of Torres Quevedo's complex design would become, with a delay of 27 years, the starting point for the standard system used in every blimp since then and up to the present, well into 21st Century: US Navy *Goodyear*'s 'E' to 'N', and 'GZ' classes, *American Blimp Corporation*, *Airship Industries Skyship*, *Aeros*, etc [A] [D] [E] [G].

To provide lift, the multilayer laminated envelopes used in most of them are filled now with non-flammable helium. Although, while studying the new *RosAeroSystem* hot-air airship 'AV-1R', we find that she also has two upper catenary belts and suspension cables, so that in the cross section the envelope has a three-fractional shape [F].

That same three-fractional shape is to be found historically in most blimps bearing those catenary belts. Of special significance being US Navy's N-Class ZPG-2W and ZPG-3W, the largest non-rigid airships ever built (again by *Goodyear*), with a capacity over 40,000 m^3 [14].

6.3. The *Cargolifter* project

One of the most impressive, although not yet completely successful project, in known as 'Cargolifter'. In 1996, German company *Cargolifter AG* was created with the goal of offering a logistics service based upon a heavy lift airship, the 550,000 m^3 'CL160'. In 2002 the company announced insolvency, and new capitalist have gone on with the project [B] [E].

'CL160' was designed as a semi-rigid airship, with a keel made of aluminium, running the entire underside of the ship, with the function of transferring, absorbing and distributing the payload and all the installations that are responsible for lifting cargo. Again, the aluminium keel, is suspended from two reinforced catenary curtains through 12 cables attached to each of them, similar to blimp's internal rigging.

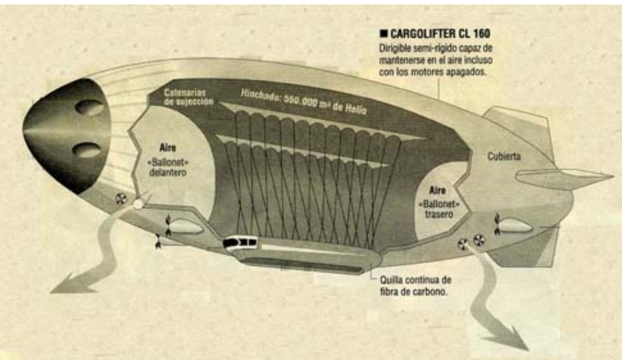

Fig. 18. The inner suspension in Cargolifter airship

7. SEMI-RIGIDS WITH INTERNAL TRIANGULAR CROSS-SECTION KEEL

7.1. Torres Quevedo's semi-rigids: 1902, 1914, and 1919

Three out of all four Torres Quevedo's patents on airships were devoted to different systems of semi-rigid dirigible balloons, although only the 1906 *autorigid* system was finally built [9] [10].

Once he had solved the 'problem of Flight' with his trilobed airships, and while *Astra* was selling the first units, Torres Quevedo devoted himself to a new field: Automatics. In 1912 he presented his first *automatic chess-player*, and wrote his *Essay on Automatics*, a theoretical treatise where he created the scientific discipline which still today bears that name [5] [19].

Nevertheless, during those years Don Leonardo's skills were even wanted by countries like Mexico. In June 1913 they requested that he work on an airship specifically adapted for flights at between 2000 and 4000m. The project led to a new patent, granted on the 2nd March 1914 for a system of 'cylindrical collapsible balloons', semi-rigid airships of variable volume for variable relationships between atmospheric pressure, density and temperature [10].

That what in 1902 was a semi-rigid keel, made up of a combination of rope and metal cables and longerons, was simplified in 1914 through a new rigid triangular cross-section hull, all along inside the bottom of the gas bag, 'suspended' from one upper catenary belt thorough non-rigid suspension cables.

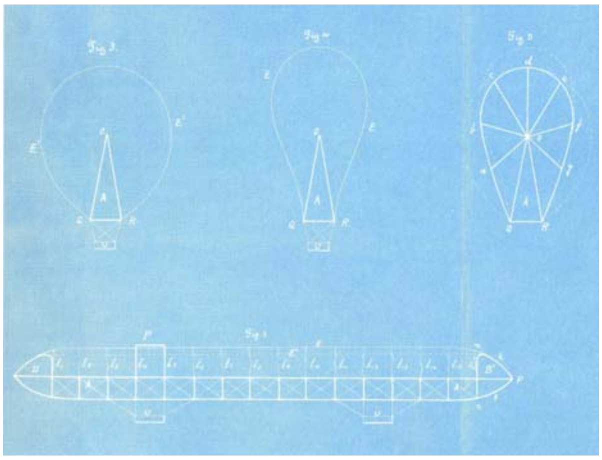

Fig. 19. Inner triangular structure in Torres' 1914 patent

In 1919 Torres Quevedo introduced the patent for a new semi-rigid airship: the 'Hispania'. Again, it was an evolution from his 1902 patent, with a new inner rigid triangular framework [10].

7.2. Italian and French 'bilobed' semi-rigids

The first semi-rigid airships were those built in France by the Lebaudy Brothers according to Henri Julliot's designs. After trials with 'Le Jaune' in 1903, the company manufactured several units for the French Army: 'Patrie' (1906), 'République' (1908), 'Liberté' (1909), etc. They also built one in 1910 for the British Army, after public subscription coordinated from the *Morning Post* newpaper [3] [4] [17].

But it was in Italy were more semi-rigids were developed. The first ones, in 1909, following Julliot-Lebaudy's ideas, were the 'Da Schio's 'Italia', Forlanini-Dal Fabbro 'Leonardo Da Vinci', and Crocco-Ricaldoni 'N.1bis'. All of them had extended articulated keel frames running along the bottom of the gas-bag to distribute suspension loads and allow lower envelope pressures than in blimps [3] [18].

Nevertheless, it was after taking recourse to another of the solutions present in Torres Quevedo's 1902 patent when the most significant and skilled semi-rigid airships in the world were constructed during World War I. The key for the improvement was the use of internal vertical rigging joining the envelope and the internal keel of triangular steel components. In so doing, the internal 'hull' would provide the necessary stability. At the same time, the gas-bag would adopt a bi-lobed form, as can be seen in Forlanini's 'F-5', Class 'M', etc., the better known units being Humberto Nobile's 'Norge' (1926) and 'Italia' (1928) [18].

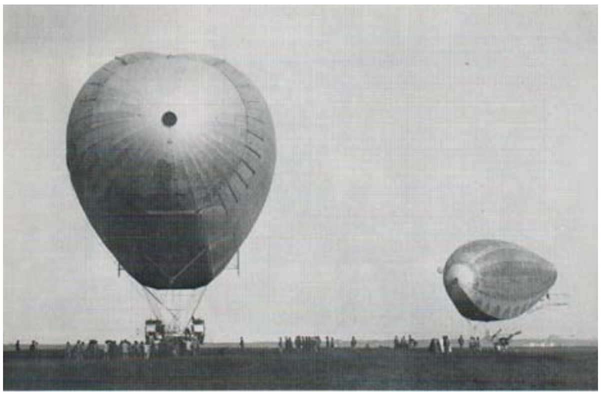

Fig. 20. Italian Clase M semi-rigid airship

At the beginning of the thirties, in an international context dominated by rigid models based on the Zeppelin' system, a French company, now the *Société Zodiac* (better known later for their rubber dinghies) again took on the construction of semi-rigid airships. It started in 1930 with the small 1,100 m³ 'Vedette' 'V-10'; followed by two big semi-rigid models in 1931, the 10,170 m³ Eclaurieurs 'E-8' and 'E-9'. All of them had the typical bi-lobed appearance due to the vertical suspension of the keel [3] [13].

Fig. 21. French Zodiac bi-lobed airship "E-8"

Fig. 22. Triangular frames and longerons in Zeppelin NT

7.3. The semi-rigid airship Zeppelin NT

During the last decade of past Century, *Zeppelin Luftschifftechnik GmbH* was founded with the aim of continuing the legacy of Count Von Zeppelin. As it has being widely recognized, the team in charge of developing the project, headed by Klaus Hagenlocher, analyzed several patents throughout the world; among them, patents which included triangular structure for inner frameworks [I].

Airships manufactured since 1997 by Z*eppelin NT* (*Zeppelin Neue Technologie*) are of the semi-rigid type. Cabin, empennage and engines are mounted on an inner rigid framework which "comprises triangular carbon-fibre frames and three aluminium longerons", held together by aramid wires.

Only the design team could determine the extent of the 'debts', if any, *Zeppelin NT* has with Torres Quevedo's contributions as included in his 1902, 1906, 1914 and 1919 patents, where we find rigid, semi-rigid and auto-rigid triangular frameworks, metal and rope longerons, etc.

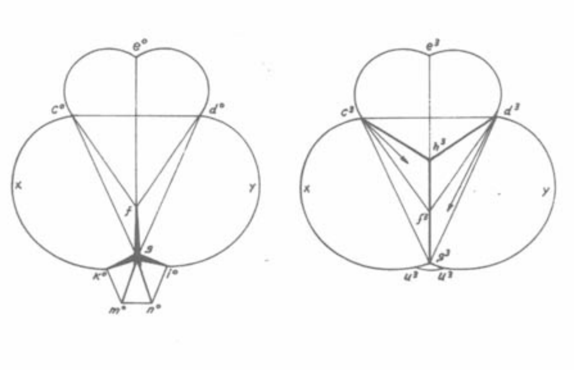

Fig. 23. Rope triangles and metal longerons, 1902

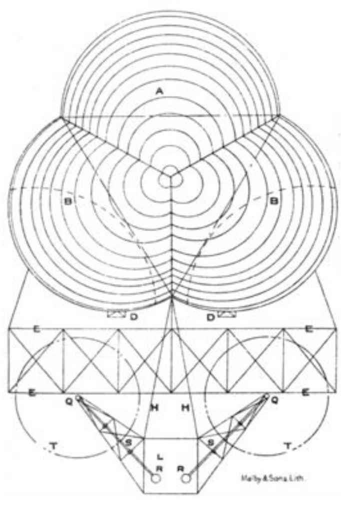

Fig. 24. Rope triangles and longerons in autorigid airships

Again, plausible use of Torresquevedian solutions, if any, could be traced in such impressive airships as hybrid 'Skycat', Lookheed Martin 'P-791', Aeros 'ML866', etc. But it would be their design teams those who could give the most accurate approach.

8. FINAL REMARK

For reasons of historical acknowledgment, one final remark can be formulated in the form of two open questions: 1) Should we admit that resemblances of Torres Quevedo's conceptions can be traced more than 100 years after his original 1902 patent? 2) Should we also concede that he laid in 1902 the foundations for 100 years of airship designs?

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