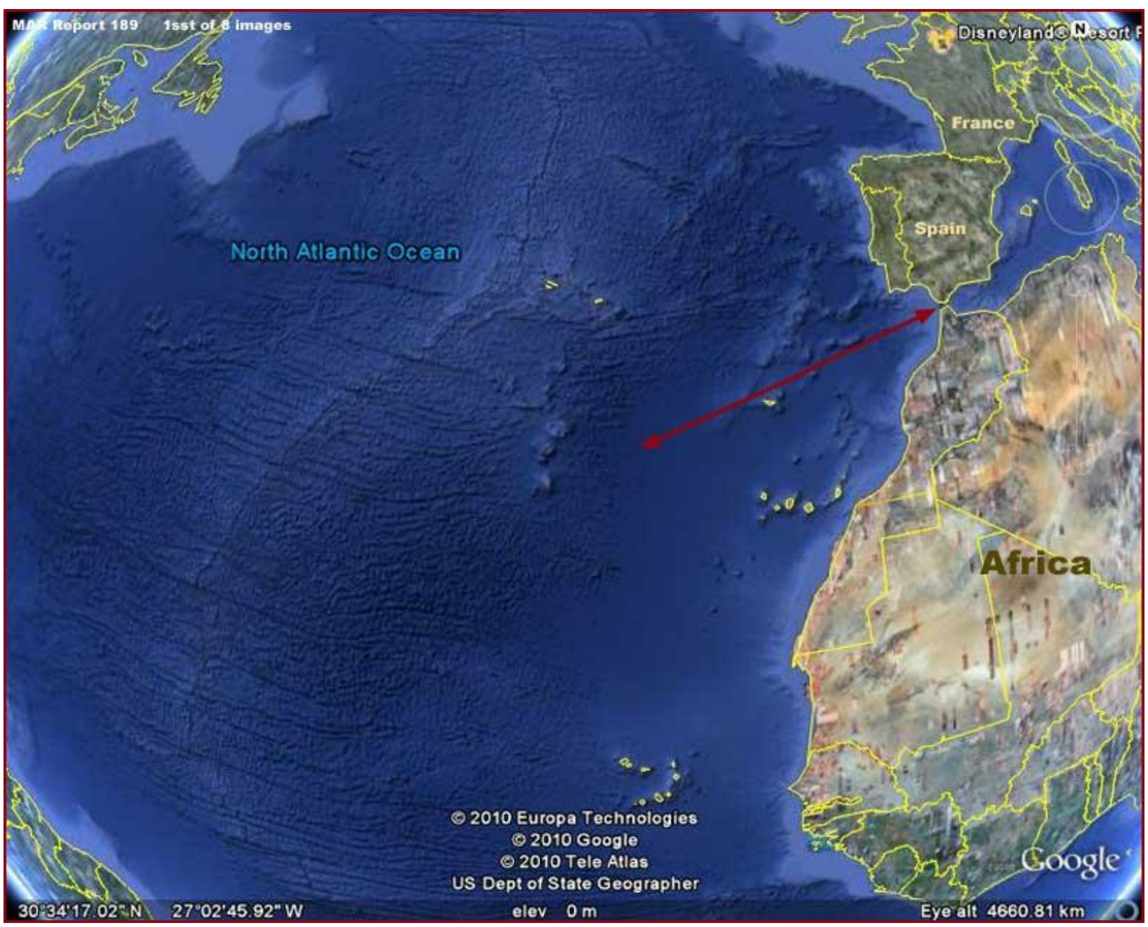
THE BIRTH OF THE ATLANTIC AIRLINER (1920-1940)

Part I, Starting Point

The unthinkable lightness of metal airliners

The Challenge

By the end of the nineteen-twenties aeroplanes capable of maintaining a *regular passenger service* across the Atlantic Ocean did not yet exist. Although by this time the Northern Atlantic had been crossed by airplanes several times from West to East and a few times from East to West, it had always been done by relatively small craft, making an incidental journey in the style of a record setting flight, taking off with a large extra supply of fuel in specially added tanks and carrying no more payload than a single mailbag. In these winged fuel containers, or *"bidons volants"* as the French called them, the weight of gasoline claimed *all* of the load carrying capacity of the airplane and there was none left for additional freight or passengers. The regular transportation of passengers in a sufficient number to be economic, had to wait until true *long range passenger aircraft* would be introduced, i.e. aircraft so large and efficient that they could carry passengers *as well as* the large amount of fuel required. One possible specification for such a class of airplanes is given on the next page, based on a seating capacity of 24 passengers and a crew of 6. No sleeping accommodation is considered, although flight times of 16 to 20 hours would be needed to cross non-stop the 4000 km of hostile ocean.



A SPECIFICATION FOR AN ATLANTIC AIRLINER ANNO 1928

Range:		**4000 km minimum**
passengers + crew: 30 =	30 x 75 =	2250kg
freight and mail:		750
oil:+ spare parts	4 x 100 =	400
total load (except fuel)	=	**3400kg**

true air speed: 300 km/h at sea level (minimum requirement, because of possible 50 km/h head winds)

Using Breguet's formula to check the implied requirements for the airliner:
Range=L/D x 270 x nprop/spec.fuel x (%% fuel) / (100 - 0.5 x %%fuel)

In which: **L/D** stands for aerodynamic efficiency or "finesse"; **nprop** stands for propeller efficiency; **spec.fuel** for specific fuel consumption (= kg fuel per pkhr); **%%fuel** stands for weight of fuel as a percentage of starting weight ("fuel load")

Try estimated values; most important: check if 35% fuel load is acceptable:
Range= 12 x 270 x 0.80 / 0.250 x **35**% / 82.5%
Range= 12 x 864 x 0.42 = 4350 km OK

Conclusion from above figures:
finesse L/D shall be at least **12** at cruising speed, indicating a streamlined monoplane with a minimal amount of external bracing.
propeller efficiency shall be **80%** or higher at cruise conditions
specific fuel consumption shall be **0.250 kg/hph** or less at cruise conditions

Weights and power required:
gross weight: **100%**
fuel weight: (see earlier) **35% of gross weight**
When furthermore is assumed an **empty weight of aircraft plus engines equal to 55% of gross weight**,
there remains for **payload** only: 100% - 35% - 55% =**10% of gross weight.**

From which follows: design **gross weight:** 10 x 3400 = **34000kg**
At a desired power load of 7 kg/hp, desired power = **4800hp**
Desired engines: 4 @ 1200hp, or **6 @ 800hp**, or 8 @ 600hp.

Check at cruise conditions:
Req'd power = drag x cruise speed / 75 / propellor efficiency
= 34000/12 x 300 / (3.6 x 75) / 0.80 = 3935hp = 82% of max power.
(This is acceptable at the beginning of the flight, when the tanks are full.)

Building passenger aircraft to cross the Atlantic Ocean had already been in the back of the minds of aircraft designers and entrepreneurs before World War One. By 1928 the time seemed right to actively start constructing such machines. In Altenrhein, Switzerland, Claudius Dornier worked at his Do-X and in Berlin, Adolf Rohrbach at his Ro-X.

Both designers favoured for this application a *flying boat* rather than a landplane, given the required large gross weight of the machine (34000 kg in our example). Heavy contemporary landplanes would have required large diameter wheels to operate on grass runways. To retract them in flight would be too complicated from a technical point of view, while to leave them extended (as had been the practice) an exceptional high air drag would result, making a sufficiently hight cruising speed unattainable. Also flying boats would be able to operate from “runways” which had a practically unlimited length and would have the theoretical possibility of landing on water in case of mid-way emergency..

The desired qualities of the Atlantic Airliner (in bold print on previous page) derive from practical experience with smaller aircraft, and can be taken as the objectives for the aerodynamic and structural design. In the year 1928 these particular objectives would have been very challinging indeed: not only the formidable size and weight of the aircraft is unheard of, but the objectives in themselves are in some ways contradictory. It will be very hard to find a way in which the large range can be combined with a high cruising speed. Yet high cruising speeds will be mandatory to enable the airliner to cross the ocean aganinst unfavourable head winds. Only at the completion of the actual aerodynamic and structural design phase will it become clear whether the ambitious objectives such as: L/D=12, an empty weight not exceeding 55% of gross weight, and a cruising speed of 300 km per hour, can be achieved. Indeed the final word will not have been spoken until the aircraft has been built and proven its actual capabilities in flight.

Sheer Size and Weight

In the nineteen twenties the design of aircraft in the proposed weight-class was a great challenge to the established aviation industry. There existed at least two reasons for this:

- there were few, if any, *engines* available which offered sufficient power and had proven reliability and endurance to propel giant airplanes over great distances;/
- nobody knew how to build truly large aircraft *structures* that combined the desired properties of size, strength and lightness. Indeed, some people had serious misgivings whether aircraft structures with such a combination of properties would ever be feasible. It was not until 1929, that Claudius Dornier proved conclusively with his *Do-X* (design gross weight: 48000kg), that large aircraft capable of flight could indeed be constructed. This particular aircraft, however, failed on the point of long distance performance.

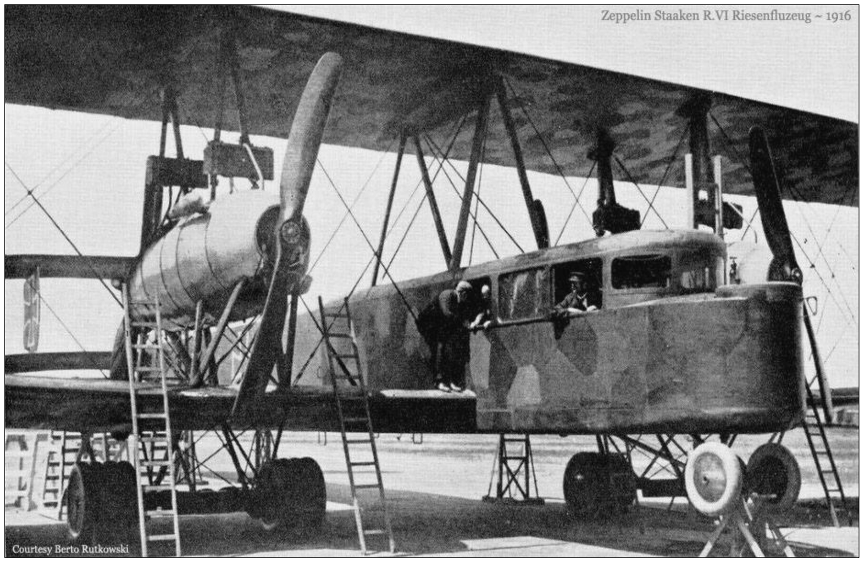
The largest aeroplanes built up to 1920 were the “giant” bombers and the large flying patrol boats of World War I. These planes were mostly biplanes. Russia set the trend in 1914 with the *Sikorsky Ilya Mourometz*, the largest aeroplane of its day with a starting weight of 5700 kilogram and a span of 21 meters. More than 70 of these large four-engine biplanes were pressed into service under harsh conditions at the Eastern front of World War I, where, surprisingly enough, only *one* machine was lost during very demanding military operations.

Sikorsky LeGrand (1913) 1

gor Sikorsky describes in his memoirs how the first versions of his S-22 bomber had an observation deck. The engines could be serviced during flight. He made an historic flight with the machine from his birth place Kiev in the Ukrain to St.Petersburg in Russia

Ilya M. with observation deck and ski landing gear

At the beginning of the First World War the German Graf von Zeppelin took the initiative of developing a special ("Riesen") class of giant aircraft with the purpose of bombing London. To be noted were the Gotha and Friedrichshafen bombers, which weighed up to 4000kg at a wingspan of some 24m. They made themselves notorious with the London population. The biggest of these German machines was the Zeppelin Staaken R.VI, whose 42 meter double wings could lift a gross weight of nearly 12000kg. A few of these aircraft were equipped with superchargers to operate at an altitude of 6000m (see illustration).



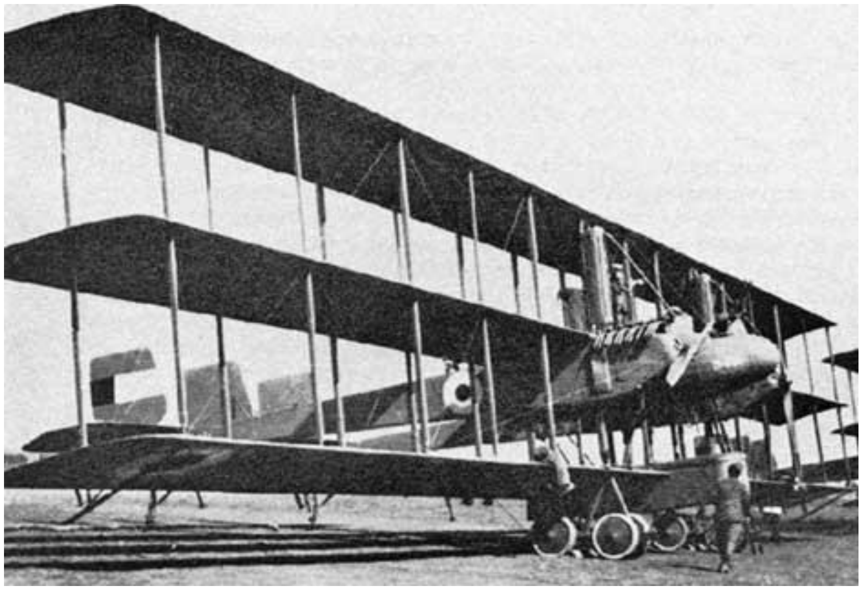
Zeppelin Staaken R-VI Riesen bomber (1917)

The Allies soon followed suit. Well known were the British *Handley Page 0/100* and *0/400* biplanes with starting weights exceeding 6000kg and a span of 31m. At the end of the war the Handley *Page V/1500* biplane appeared, with a gross weight of nearly 14000kg and a span of 38m. Later used as a commercial airliner for short distances, it could carry 40 passengers. An experimental super bomber designed to deliver 2000kg of bombs to Berlin was the *Tarrant Tabor*, a giant six-engine wooden tri-plane that weighed approximately 20,000kg when fully loaded. It crashed and killed its two pilots by flipping over at its first take-off in 1919.

Fully operational by the end of the war a more effective, compact machine was the two-engine Vickers Vimy biplane with a normal starting weight of 5670 kg and a wingspan of 21 meters. It was indeed the first machine to cross the Atlantic Ocean non-stop. Especially adapted to long disance flight, with extra fuel tanks mounted in its bomb bay, it carried in 1919 Alcock and Brown 3030 km from Newfoundland to Ireland in 16 hours (see illustration). It crash-landed in a swamp at the west coast of Ireland.

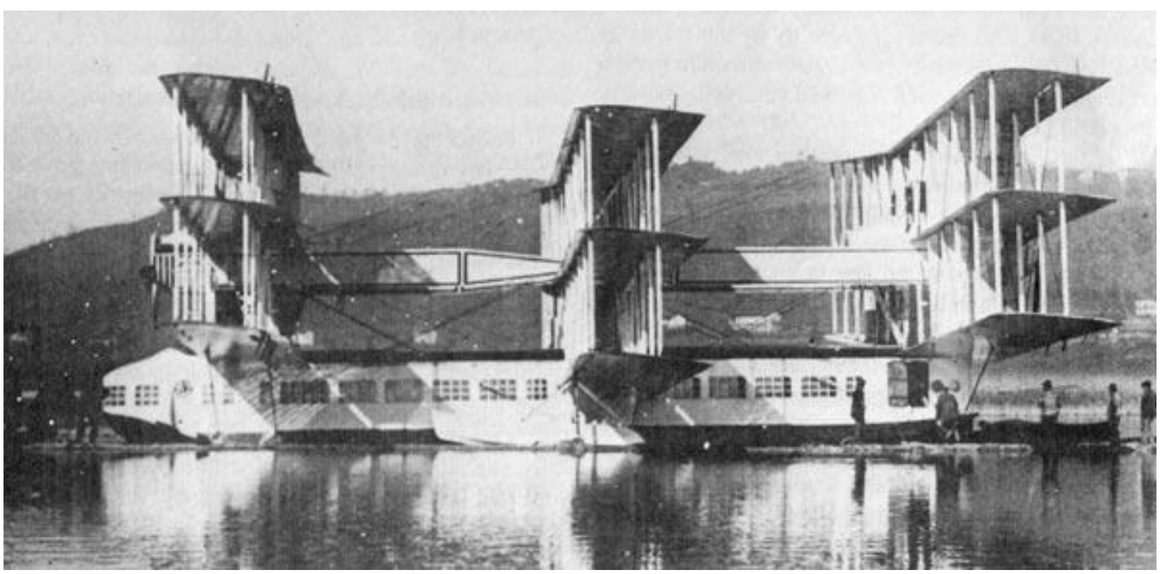
Vickers Vimy: the first Atlantic Crossin 1

Equally famous for large aircraft was the Italian designer Caproni who built a large number of triplane bombers such as the *Caproni Ca.33* (weight: 3800kg, span 22m) and the *Caproni Ca.46* (weight 5300kg, span 23m).



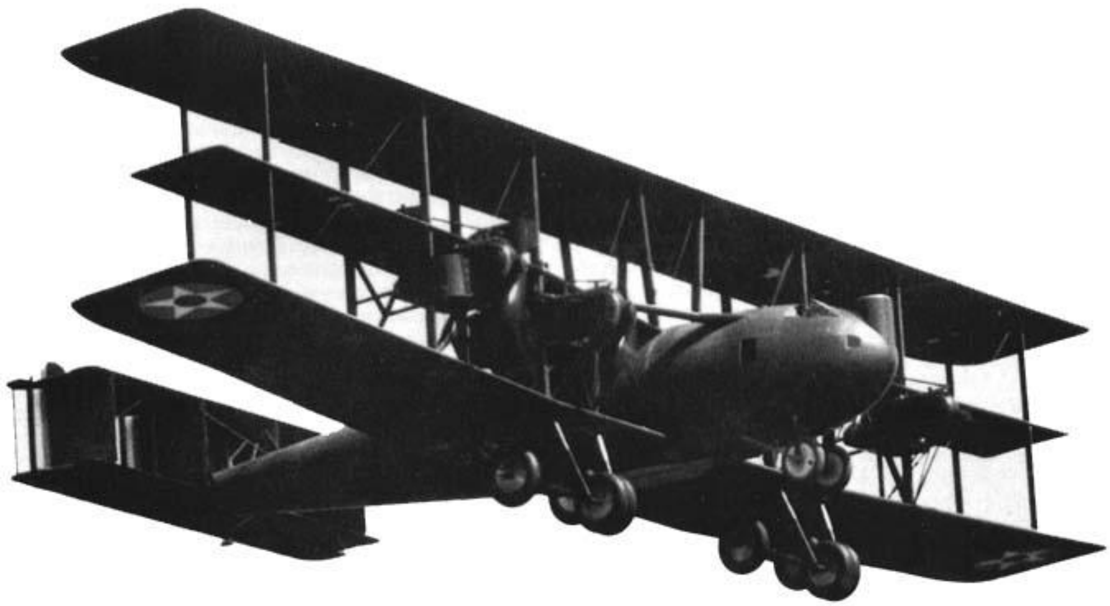
Caproni C-42 bomber

The model *Ca.42* was a triplane with a weight of 6700kg and a span of nearly 30 meters. According to one report Caproni manufactured altogether nearly one thousand aircraft of these various types. After the war he conceived and constructed the giant *Ca.60 Transaereo*, a monstrum with nine (!) 30m wings, eight 400hp engines and a starting weight of 26000kg. Built to carry one hundred passengers, it unfortunately, but not altogether unexpectedly, broke up during its first flight



Caproni Ca-60 Transaero

In the category of giant planes the U.S.Army ordered in 1921 from the Witteman-Lewis Corporation the prototype NBL-1 (Night Bomber Long-Range Type 1), an ungainly aeroplane very similar to the earlier mentioned British *Tarrant Tabor*, with three 36m wings and six engines. Designed by the same man responsible for the *Tabor*, Walter H.Barling, it was pretty soon referred to as *Barling's Bomber*. Although its test program was brought to a safe end, the oversized triplane was underpowered, much too slow and proven to be impractical in every respect. However, its surprisingly beautiful fuselage, shaped like a smooth aubergine (or was it a courgette?), was an outstanding early example of streamlined all-metal semi-monocoque construction.



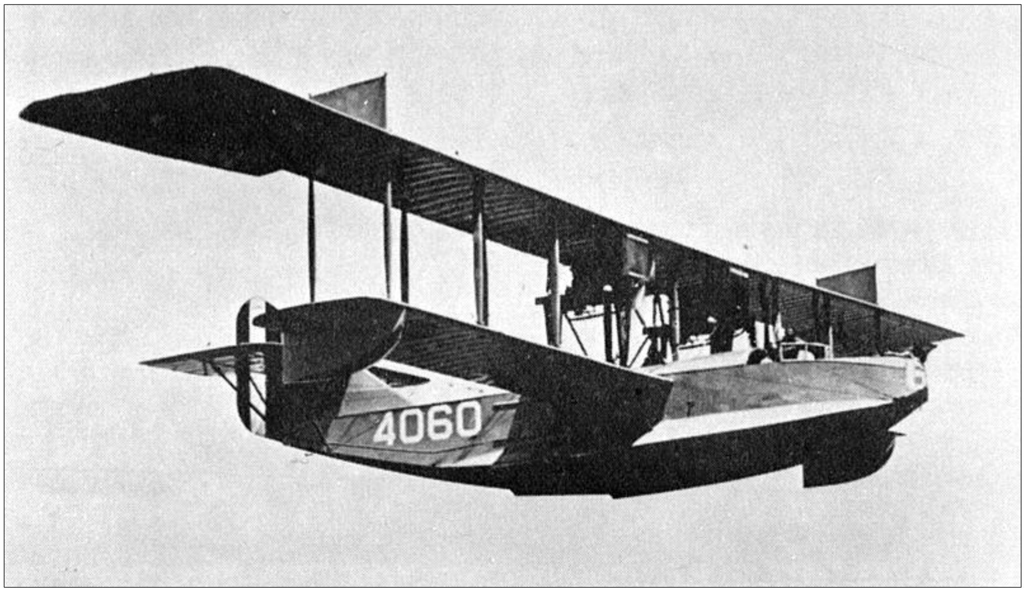
Barlings Bomber NBL-1

America's chief contribution to the development of large long-range aircraft came in the first place from flying patrol boats, such as the following creations of the Curtiss factory:

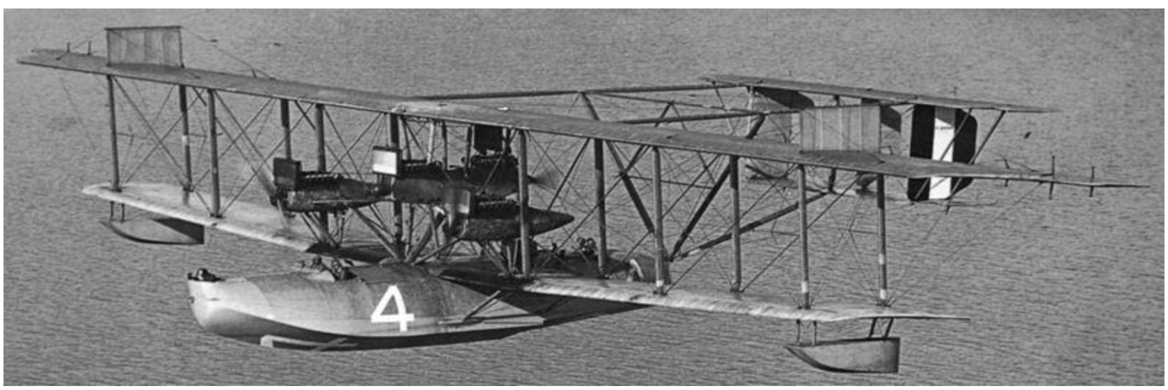
- the biplane H-4 “Small” America, built in 1914 to cross the Atlantic but never used in that capacity,
- the H-12 “Large” America used in some numbers during World War I by the British Navy and its successor:
- the H-16. The latter 'boat had a wingspan of 32m and a starting weight just under 6000kg.
- the NC patrol boats, of which the NC-4, completed the first West to East Atlantic crossing (in 19 days) in 1919.

One of the significant learning effects of the production of these flying boats was that they allowed both US and British manufacturers to gain experience in the hydrodynamic design of seaworthy hulls. The proper shape of the “planing” bottoms proved to be especially important not only for a successful take-off of a fully loaded 'boat in heavy seas, but also for being able to start from smooth, ripple-free watersurfaces.

Although during World War I the hulls were more often than not of an all-wood construction, the painstaking development of their shape served as the starting point for *all-metal* flying boat design practice in both countries during the twenties and thirties,.



Large Curtiss H-16 flying boat



The NC-4 flew across the Atlantic

After having seen these examples of early large airplanes, the question comes to mind how *heavy* they were.. A distinction has to be made between the total or "gross weight" of the airplane and its "own weight" of structure (airframe) plus engines. The gross weight determines the structural design and may also be taken as the maximum at which the airplane is supposed to take off.
Instead of "own weight" the term "empty weight" often comes up in comparisons. "Empty weight" comprises own or structural weight plus the weight of additional flight systems as well as the necessary fixtures for the passengers.
"Gross weight" is the maximum weight for which the aircraft is designed. It encompasses "empty weight" plus "load". Load may be seen as crew, passengers, fuel and provisions. The operator of an airplane is wise to see to it that the "take-off weight" does not exceed "gross weight".

As the following graph shows, the early airplane constructions had in general an empty weight which ran between 60 and 70 percent of gross weight, with exceptions at 50 percent (HandleyPage, 1918) and 83 percent (Sikorsky, 1913). The graph is based on data of actually built large airplanes in the period under discussion (see next Tabel).

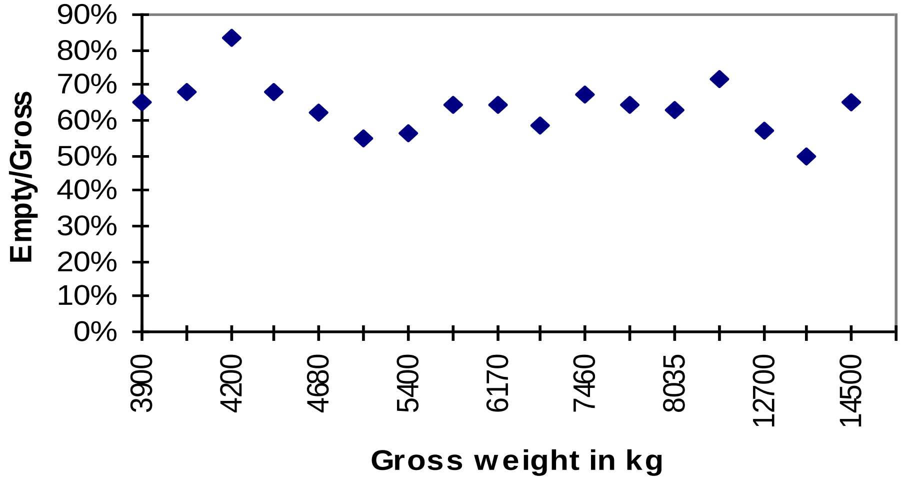


Fig.2 Empty weight vs Gross weight in %%

Table 1	type of plane	Gross weight kg	Empty weight kg	r: Relative weight: Empty/Gross
Gotha GIV	biplane	3900	2540	65%
Friedrichshafen GIII	bi	3930	2670	68%
Sikorsky Grand	bi	4200	3500	83%
Curtiss H-16	flyboat-bi	4620	3160	68%
Vickers Vimy	bi	4680	2920	62%
Sikorsky Mourometz	bi	5100	2800	55%
Farman Goliath	bi	5400	3030	56%
Short F-3 Felixstowe	flyboat-bi	5400	3470	64%
Curtiss F-5L	flyboat-bi	6170	3960	64%
HandleyP. 0/400	bi	6360	3720	58%
Sikorsky Mourometz E-2	bi	7460	5000	67%
Bristol Braemar	tri	7500	4830	64%
Caproni Ca.42	tri	8035	5040	63%
Zeppelin Staaken E.4/20	mono (metal)	8500	6070	71%
Navy-Curtiss NC	flyboat-bi	12700	7260	57%
HandleyPage V/1500	bi	13620?	6810?	50%
Zeppelin Staaken R.V	bi	14500	9450	65%

A lightness of 50 percent

The ratio (own-weight) **:** (gross-weight) is one of the more important design parameters of an aircraft - certainly if it is required to cover long distances. (Expressed as a percentage we are tempted to call it its *"lightness"*, but we are faced with the contradiction that the lightness will be maximal when the value of the ratio is at a minimum.) The objective of the designer is obviously to make the ratio as small as possible.

Own weight and empty weight are highly ambiguous terms, because it is not always clear how empty the airplane is at time of weighing. Sometimes empty weight indicates the weight of the bare structure of the aircraft, *without* the furnishings that are necessary to accommodate the passengers, such as chairs, upholstering, pantry, etc., but *with* inclusion of all technical installations required for safe flight such as hydraulic and electric systems, radio and air pressure systems. It is obvious that, as these additional systems were gradually added over the years, the “lightness” ratio of the aircraft became less and less favorable. More and more pressure was made to bear on the structural engineers to design lighter and lighter load bearing structures.

In some publications the term “empty weight” includes structure, systems, as well as the provisions for passenger transportation. The term “empty weight (equipped)” would then seem to be more appropriate.

The successful long-distance record setting airplanes built up to 1930 had an “own weight” or “empty weight” of approximately 50 percent of the 'maximum take-off weight”. In popular terms people would say: these airplanes could carry their own weight.

The *Fokker F-VIIb-3m* of Sir Kingsford Smith: *Southern Cross* (wingspan 22 m) could take off (in an overloaded condition) at 7000 kg, while her empty weight amounted to no more than about 3500 kg. Its lightness in this case was therefore 50 percent. The maximal non-stop stage on the Pacific flight proved to be 5070 kilometer and, as it happened, included navigating through an equatorial thunderstorm.

Fokker FVIIb-3m. The Australian Sir Kingsford Smith crossed the Pacific and later the Atlantic Ocean in this famous plane with a crew of four. (ca 1925)

The empty weight of the *Southern Cross* referred to the bare and empty airplane, augmented by the weight of three radio transmitters (no small matter in those days), the tare weight of an enormous extra fuel tank of 800 gallons capacity and two wicker chairs for the navigator and radio operator. The difference between empty weight and gross weight, (the loading capacity) of the airplane, was allocated to much fuel, some stores, a few mailbags and the crew of four.

In all, the Fokker F-7b-3m was a perky looking, well built airplane of mixed construction (see later), a very popular passenger transport for medium range distances, certainly not for the Atlantic. But modifying it, as “Smithy”did, into a *record setting airplane* worked exceedingly well. In the process he incidentally proved that landplanes could very well be used to fly oceanic routes. Anthony Fokker might have scaled the model up with scale factor 1,7, reaching a gross weight of 35000 kg and obtaining a true Atlantic Airliner. As he never was greatly interested in the Atlantic traffic however, he may have missed a chance. The 7b-3m carried unobtrusively one other great virtue with it: namely three new American 220 hp radial Wright Whirland engines. Wright radial engines, together with its Pratt and Whitney counterparts would set new standards for longevity and reliability, two properties direly needed for long distance airliners.

The same magic figure of *lightness of 50 percent* is also quoted for the *Davis-Douglas Cloudster* and the *Fokker T-2,* both airplanes equipped to fly non-stop across the United States in 1923. The list of examples can be easily extended. Lindbergh's *Spirit of St. Louis,* the *Junkers W-34* that crossed the Atlantic from East to West in 1928, the *Brequet XIV* that flew from Paris 6000 kilometers non-stop to Asia, all these airplanes had a lightness of 50 percent or less. Because they were so lightly constructed they could take aboard an extra large amount of fuel resulting in an exceptional range.

Now, faced with the challenge of designing a practical *Atlantic Airliner*, such as specified at the beginning of this chapter, the design strategy could be to make it just as light as the record setting airplanes, but obtain a higher aerodynamic efficiency in flight (with a "finesse", of say 12, compared with a finesse of 8-9 for the Southern Cross). A part of the fuel load could then be traded for passengers, without affecting the range of the airplane. The challenge for the structural engineers would be to design a larger plane that would possess a lightness close to the 50 percent mark of its (smaller) predecessors. Only then would it be possible to increase the payload capacity from a mere 5 percent to the required 10 percent or more for the *Atlantic Airliner*. However, many people believed in a spooky "limit-to-size" (see later) and predicted that the increase in bending moments and shear forces in the wing of such a large plane would necessitate a much heavier internal structure.