

THE BIRTH OF THE ATLANTIC AIRLINER

(1920-1940)

by Rit Staalman

Part IVa The Ultimate Propeller Airliner

SUMMING UP:

1. Required for an Atlantic Airliner: Low Own Weight (airframe + engines), High Load Capacity, Low Drag.
2. Suitable building material: Dur-Aluminum (favourable weight/strength + durability);
suitable construction method: Semi-monocoque, i.e. skin takes part of load.
3. Design:: make *wings as small as possible = high wing loads* (see earlier).
4. Small wings decrease weight, also lower drag. They require airplane to fly at high speed. (For the Atlantic this is good, because the plane often has to battle high head winds.) High air speed implies that good aerodynamic form is needed. It also implies that high power is needed, especially at take-off with full load.
5. Powerful,/light-weight engines become available in the 1930's (see appendix).
6. The various flight regimes (take-off, climbing, cruising with different weights) require propellers with adjustable blade angles. These also appear on the market in the same period.

So at the beginning of World War II all elements are available for the construction of practical Atlantic airliners.

1930: AMERICA GOES MONO AND METAL ¹

1. Boeing

Founded by millionaire *William Edward Boeing* (1881-1956) in 1916 in Seattle, the first aircraft produced by *Boeing Aircraft Co.* were two biplanes on floats. In 1929 Boeing became part of United Aircraft and Transport until 1934, when the U.S. government ruled that the combination of aircraft factories and airlines was against the anti-trust laws. *Claire Egtvedt* was chief engineer from the start. He had an engineering degree of U. of Washington. The company received its first Army order, for a pursuit plane, in 1923, followed in 1926 by a fighter making use of the new 'Wasp' engine. Next (1927) a fleet of 25 bi-planes was built, called the Model 40, for the new Boeing Air Transport company. The airline, with a government contract to carry mail, was an immediate success. By now, Egtvedt having been promoted to Vice president, the chief engineer was *Monty Monteith* and he designed a three-engined biplane, the Model 80, which could carry no less than 12 passengers

¹ Based on: Wayne Biddle: "Barons of the Sky"

(later 18) and a crew of three, including a registered nurse as stewardess. The Model 80 was of conventional, mixed design, meaning wooden wing, welded steel tube fuselage and fabric covered wing and body.

In 1929, so the story goes, Egtvedt and the chief pilot of Boeing Air, *Hubbard*, had the idea of building an all-metal plane. Egtvedt insisted it should be a clean unbraced monoplane with a pure cylindrical stressed-skin fuselage, tapering from large at the front to narrow at the tail. The wing had to be mounted low to accommodate a retractable undercarriage. Monteith got the task of designing it, although he had some misgivings about so much novelty all at once. Both the general geometry of the airplane as well as its time of development coincided with the Northrop Alpha. The Boeing Model 200 Monomail was first flown in 1930. It reached the unheard top speed of 254 km/h. In mastering the new trends in aircraft design – all metal mono-wings - no company made faster progress than Boeing. It delivered its first entry in the field, the the Model 221 *Monomail*, in 1930.



1930: Model 221 Monomail [source: Wiki]

A mailplane, with (later) an accomodation for 6 passengers, it had a wingspan of 18 meter, was powered by a 575 hp Hornet engine, could fly a maximum distance of ca.900 km at a cruisespeed of 210 km/h. It was of all metal construction with retractable landing gear. Apart from an adjustable propeller, all the elements for a truly modern airliner were present in the small airplane.

Boeing then entered the field for *bombers*. The *Monomail* was developed into a two-engined bomber, which was tested by the Army under the designation *Y1B-9A*. The plane was faster than any fighter plane of the day: it could reach a top speed of 300 km/h. To the great disappointment of Boeing the Army however dropped the design in favour of the *Martin B-10*.²⁾



Boeing 247 in flight

² Air Enthousiast 101, August 2002: The *B-9* had a similar stressed skin construction to the *Monomail*. The wings (identical to the *Monomail*) had ‘full length triangulated Warren spars’, which ran through the fuselage. The ribs were also trusses. The centre section of the wing was rectangular with no dihedral. The outer sections were tapered and had dihedral.

The *B-9* design was then transformed into the *Boeing Model 247* airliner, which first flew in 1933. It was this airplane, ordered by United Airlines, that started the industry-wide rush for modern all-metal stressed-skin airliners. Douglas and Lockheed joined the race with their *DC* series and *Electra* series respectively. The Boeing machine featured such refinements as NACA-cowlings and variable pitch propellers and of course retractable wheels.

In 1934 Boeing came into severe financial troubles because of the split up of United Aircraft. By this time work had started on the biggest aircraft of its day, the XB-15. Intended as a strategic bomber (although this term was cautiously avoided for political reasons) it was designed to a specification of the Army, calling for a range of 8000 km, or 5474km with a bombload of 1140kg.



Boeing XB-15 [source: Wiki]

The giant aircraft first flew in 1937. It had the following characteristics, but it is unknown if it met requirements. In particular the 8000km range is doubtful.

The following data can be found on Internet for a record flight:

XB-15: engines: 4 Pratt & Whitney R-1830-11 Twin Wasp = 4 x 850 hp; cruise speed: 265 km/h @ 1800 m
range: 5474km w. 1140kg bombs; max start weight: 32100kg
wingspan: 45m; wingload: 115 kg/m²; powerload: 8.7 kg/hp; own weight: 57%; fuel weight: 35%

The bomber had heavy defensive armament, a crew of 10 with comfortable resting quarters and small auxiliary engines for the electrical system. The wing was of conventional construction following the *Monomail* girder design. Aft of the second spar fabric skin was used to save weight. *The depth of the wing was such that the engines could be reached during flight by internal passageways* The span was so large that the aileron cables stretched when loaded. (compare: the Dornier's Do-X used control rods.) Despite the airplane's huge size the Boeing engineers had been able to control the net weight of the construction to a nominal 50% of its gross weight. An actual record flight showed that the resulting range was as required, approximately 5000km, but a 2000kg bomb load could not be reached. However, the four installed engines of 1000 hp each starting power could not propel the giant at sufficient cruising speed and no further developments took place.

At approximately the same time Boeing responded to another Army specification and developed the *Boeing B-17 Flying Fortress*. This aircraft was smaller and more practical. It first flew in 1935. Although it had excellent performance it was, for a complex of reasons, originally only ordered in limited numbers. All these reasons fell away when World War II started and during the conflict nearly 13000 *B-17's* were built.



1938: Boeing Model 307 Stratoliner (Wiki)

In the meantime the development work for the bombers was put to good use in the design of the *Boeing Model 307 Stratoliner*, of which 10 were built (1938/1939). These airplanes were equipped with a pressurized cabin (see Wiki). One of the prototypes crashed during a test flight by Dutch engineers, while the others earned their keep during the war on the Atlantic routes. (see Ency)

Model 307: 33m - 19050kg 4 x 900hp 354km/h @ 6095m 3846km range
 (1938) wingload 138 - powerload 5.3 - own weight 71% - (eng. 13%) - fuel wght yy%
 (DONALD, ENCY)

Boeing Model 314 Clipper

The Boeing policy of using the results of developments for the military for application in civil aircraft was also followed with the *XB-15* bomber. At the request for tender of Pan American Airways, Boeing submitted a proposal for a large flying boat, the *Boeing Model 314 Clipper* which PAA intended to use for its northern Atlantic route. At the strong suggestion of engineer *Wellwood Beall* (later VP) the wing design of the giant *XB-15* bomber was modified to fit the flying boat. The bomber wing was mounted on an enormous flatsided boat hull that had internally a layout with two-decks.

The engine power was increased to more than 6000 hp for take-off.

Calculations

B-314: 43m wingspan - start wght: 37400kg - 4 x 1500hp 282km/h @ 1655m = 4990km @ load: 10%?
 (1937) wingload 141 - powerload 6.2 - own weight 59% - (eng.10%) - fuel wght 31%?
 (fuel: 15898 ltr x 0.72 = 11447 kg = 31%; load = 3740kg) (source: vanSTEENDEREN)

The above source states (optimistically) that the range of 5000 km (3125 miles) could be reached with a payload of 40 passengers and 8 crew, which would have been largely sufficient for offering a transatlantic passenger service.

E. Davies writes in *Air Enthusiast* No.96 about the *empty weight of the flying boat*:

‘... the result of weighing came to within 0.5% of the calculated weight...43.840lbs = 19,900kg = 53%....’

This figure rather agrees with the relative weight of the *XB-15*. As we have shown increasing the cross-section of the hull does not increase necessarily the *relative* structural weight. So as we understand the 53% would indicate the structural weight of the 314, including all flight systems and engines, ready for test flight, but without passenger trimmings. This weight would be close to the weight of the bomber. The Davies article states that after testing the flying boat returned to Lake Washington ‘to be furnished’ for passenger travel.

As for the *fuel weight*: (E. Davis: tank capacity: wingstubs: 4x600; hull: 960; seawings: 2x1164 = total: 5688 USG - of which usable: 5448 USgals = 20,621 ltr x 0.72 = 14,850 kg = 39.7%
 Chapel uses fuel with a density of 5.85 lbs/USgal, which is 0.70kg/ltr
 the percentage fuel load would then be: 20,621 x 0.70 = 14,435 kg = 38.6%
 this would leave for *payload*: 100 - 53 - 38.6 = 8.4% ?? (= 3140kg, not much is it?))

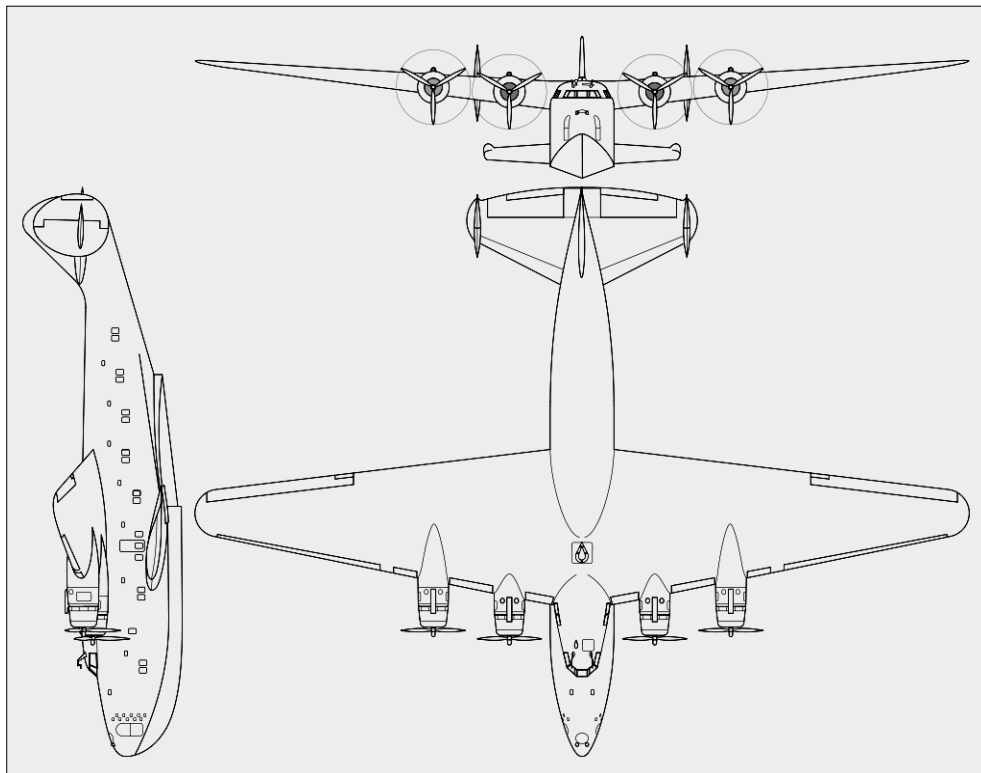
One other source: with respect to the improved model B-314A with more powerful engines:

provisional starting weight: 38100kg max true indicated a/s
B-314A: 46m 266m² 37400kg 4 x 1600hp 286km/h range: 5600km @ load: 8%
 (1941) AR 8 wngld 141 pwrld 5.8 - own wght 53% - (engine 10%) - fuel wght 39%
 (HANNAH, AIR ENTH 96)
 total gas: of which usable: 5448 USgals = 20,621 ltr x 0.70 = 14,435 kg = 39 % !
 total oil: 206 gals = 780ltr x 0.85 = 660kg
 pay load: 4900kg

Flight trials started at the end of May 1938. Extreme rolling movements in heavy seas caused delays in taking off for the first flight. At a certain moment one of the wings was so far submerged underneath the surface of the sea that the outboard propeller was in danger of going under. (People asked if Wellwood Beall was a sailor. He must have asked himself what he had gotten into.)

Once in the air, it proved very difficult to bring the huge single-tail airplane into a turn. This grave flying problem necessitated changing the tail section at considerable expense of time and money from a single rudder design to one with a double rudder, while finally the central vertical stabilizer was re-instated again resulting in an unique three-rudder design. The first passenger flight across the Atlantic had to wait until 20 May 1939. On the first flight: 22 passengers were carried. (See Air Enthousiast No.97, p4) This seems to confirm our above calculations.

Despite all teething troubles, the Atlantic service proved a succes.



Trans Oceanic flights

from: https://en.wikipedia.org/wiki/Boeing_314_Clipper:

Pacific route: The first 314 flight on the San Francisco-**Hong Kong** route left Alameda on February 23, 1939 with regular passenger and **Foreign Air Mail Route #14** service beginning on March 29. A one-way trip on this route took over six days to complete. Commercial passenger service lasted less than three years, ending when the United States entered **World War II** in December 1941.

At the outbreak of the war in the Pacific, the *Pacific Clipper* was en route to **New Zealand**. Rather than risk flying back to Honolulu and being shot down by Japanese fighters, it was decided to fly west to **New York**. Starting on December 8, 1941 at **Auckland**, New Zealand, the *Pacific Clipper* covered over 31,500 miles (50,694 km) via such exotic locales as **Surabaya**, **Karachi**, **Bahrain**, **Khartoum** and **Leopoldville**. The *Pacific Clipper* landed at Pan American's **LaGuardia Field** seaplane base at 7:12 on the morning of January 6, 1942.

Atlantic route: The *Yankee Clipper* flew across the Atlantic on a route from Southampton to Port Washington, New York with intermediate stops at Foynes, Ireland, Botwood, Newfoundland, and Shediac, New Brunswick. The inaugural trip occurred on June 24, 1939.



BOAC Clipper *Berwick* landing at Lagos, Nigeria

The war years

The *Clipper* fleet was pressed into military service during World War II, and the flying boats were used for ferrying personnel and equipment to the European and Pacific fronts. The aircraft were purchased by the War and Navy Departments and leased back to Pan Am for one dollar. Only the markings on the aircraft changed: the Clippers continued to be flown by their experienced Pan Am civilian crews. American military cargo was carried via Natal, Brazil to Liberia, to supply the British forces at Cairo and even the Russians, via Teheran. The Model 314 was then the only aircraft in the world that could make the 2,150-statute-mile (3,460 km) crossing

over water, and was given the military designation C-98. In 1943, President Franklin D. Roosevelt traveled to the Casablanca Conference in a Pan-Am crewed Boeing 314 *Dixie Clipper*.

The success of the six initial Clippers had led Pan Am to place an order for six improved 314A models to be delivered in 1941, with the goal of doubling the service on both Atlantic and Pacific routes. However, the fall of France in 1940 caused some doubt about whether the Atlantic service could continue; passenger numbers were already reduced due to the war, and if Spain or Portugal were to join the Axis, then the flights to Lisbon would be forced to stop. Pan Am began to consider reducing their order and, in August 1940, reached an agreement to sell three of the six under construction to the United Kingdom. The aircraft were to be operated by the British Overseas Airways Corporation and were primarily intended for the UK – West Africa route, as existing flying boats could not travel this route without stopping in Lisbon. The sale made a small net profit for Pan Am – priced at cost plus 5% – and provided a vital communications link for Britain, Winston Churchill himself later flew on the *Bristol* and *Berwick*, which he praised intensely, adding to the Clippers' fame during the war.



After the war, several Clippers were returned to Pan American hands. However, even before hostilities had ended, the Clipper had become obsolete. *The flying boat's advantage had been that it didn't require long concrete runways, but during the war a great many such runways were built for heavy bombers.* New long-range airliners such as the Lockheed Constellation and Douglas DC-4 were developed. The new landplanes were relatively easy to fly, and did not require the extensive pilot training programs mandated for seaplane operations. **One of the 314's most experienced pilots said: "We were indeed glad to change to DC-4s, and I argued daily for eliminating all flying boats. The landplanes were much safer. No one in the operations department... had any idea of the hazards of flying boat operations. The main problem now was lack of the very high level of experience and competence required of seaplane pilots".**

Retirement

The last Pan Am 314 to be retired, the *California Clipper* NC18602, in 1946, had accumulated more than a million flight miles. Of the 12 Boeing 314 Clippers built three were lost to accidents, although only one of those resulted in fatalities: 24 passengers and crew aboard the *Yankee Clipper* NC18603 lost their lives in a landing accident at *Cabo Ruivo Seaplane Base*, in *Lisbon, Portugal* on February 22, 1943.

Pan-Am's 314 was removed from scheduled service in 1946. BOAC's 314As were withdrawn from the Baltimore-to-Bermuda route in January 1948, replaced by Lockheed Constellations flying from New York and Baltimore to Bermuda.

Calculations

NORTH ATLANTIC CROSSING BY BOEING-314 CLIPPER									
units: km, kg									
range	distance		gross weight		own weight	total load			
5000	3196 km		38400		61%	39%		weight one passenger	
	1985 mile		mail	crew	oil			80	
			1000	800	600				
			2,6%	2,1%	1,6%				
condition:	L/D	nprop	c	Q		ff(approx)			
optimum	13	0,9	0,21	15043		0,29			
W-E	12	0,9	0,22	13255		0,32			
E-W wind	11	0,89	0,23	11493		0,36			
storm	11	0,88	0,23	11363		0,36			
condition:	ff	room for payload	crew+oil	cargo and mail	cargo and mail %	room for passngers	room for pass %	number	
optimum	28,3%	10,7%	3,6%	1000	2,6%	1717	4,5%	21	
W-E	31,4%	7,6%	3,6%	200	0,5%	1309	3,4%	16	
E-W wind	35,3%	3,7%	3,6%	0	0,0%	29	0,1%	0	
storm	35,6%	3,4%	3,6%	200	0,5%	-293	-0,8%	NOGO	

Table 4.1 : some calculations pertaining to the direct route, Foynes-Botwood

ff means: fraction of weight for fuel

Note: On the West to East run the number of passengers can be relatively high as well as a full load of mail can be carried. Returning to the States, there would be far less mail, as the English had their own postal service with air-tanked Short flying boats. Also the difficult wind situation would have to be taken into account. The aircraft would fly less efficiently and with greater fuel consumption. To make sure that the same safe range could be obtained, more fuel would be needed and less freight and passengers could be taken. The large range (5000km) compared with the distance (3200km) is necessary to allow for detours around severe storms and to allow for (frequent) changes of altitude to search for lower head winds.

Despite these limitations the Boeing 314 was the first truly operational Atlantic airliner. Within the limited time span of only ten years the American aircraft industry had built three generations of long distance flying boats. The Boeing ship was the ultimate product of this development. It surpassed everything that had taken to the air before. With an audacity and skill that left the others far behind, the Boeing Corporation had become the leader in the class of super great airplanes. They were now a major league by themselves.

2. Glenn Martin

The Martin Company had its own entry in the market for trans-oceanic flying boats. The *M-130* was built to a contract granted in 1932 to both Sikorsky and Martin. The *Sikorsky S-42* was the first result, delivered in 1934. The construction of the Martin airplane was subject to long delays but the airplane outperformed the Sikorsky in the end. Once again the aviation community was amazed by a daring creation, this time by a company that had been leading a relatively sleepy existence, well-known for its large bombers and patrol planes in the past, but not by any entries in the field of commercial aviation. The Martin company had been known as a supplier of Navy sea planes and patrol boats and had indeed edged Consolidated out of a production contract in this category in 1930. Few however suspected that this same firm would turn out an airliner that would beat every other airplane in its class. The *Martin M-130* flying boat appeared in 1935 and soon became the public's favourite *Clipper*. The all-metal (stressed-skin) *M-130* had an exceptional range and passenger capacity and was indeed the aircraft that Pan American Airways had been waiting for. Its weights were remarkable: empty 11100kg, while its starting weight was 23130kg. Its lightness was most surprising: 0.48.³



Glenn Martin M-130 Clipper

Its fuel capacity was much larger than needed for passenger service allowing extremely long exploratory flights with crew only. It also meant that in favourable circumstances starts with over-loads could be made.

The most striking aspect of the construction of the Martin-130 flying boat was its lightness of construction, allowing for fuel loads during regular service in the order of 35 to 40%.

In the following quote Spit and Oyens give some of the highlights of this successful design in which the stressed skin principle is being exploited to the fullest extent:

³ For more details see: <https://ritstaalman.files.wordpress.com/2018/05/atlair-martin1.pdf>

'...The all-metal airplane is of the semi-cantilever type [a very lightweight type of construction, GJS]...
...The four engines are positioned before the nose of the centre segment of the three-part wing. This segment is braced by supports to the sea-wings on either side of the hull; the two outer segments of the wing are free cantilevers (vrijdragend). The internal wing structure is simple: there are two spars, with the upper webs joined together by a wide corrugated metal strip, the corrugations running in the length-direction of the wing. On top of this strip the smooth outer skin of the wing is fastened, reaching from the leading edge to the rearward spar. Aft of this spar the wing is covered with fabric. Because the corrugated sheet absorbs a large part of the compression load during flight, the upper flange-areas of the spars can be very small. The bottom flanges have been dimensioned in such a way that they can bear the compression forces that occur during landing and inverted flight.

The tension forces that occur during normal flight in the lower part of the wing are mainly absorbed by the skin. The webs of the spars are of metal sheet, reinforced by riveted U-profiles. The ribs are built as trusses, with tubular vertical members and U-shaped diagonals...'

'...All stressed parts of the structure are made of Alclad. The wing profile is approximately Göttingen 398.

Wiki: https://en.wikipedia.org/wiki/Martin_M-130:

The **Martin M-130** was a commercial flying boat designed and built in 1935 by the Glenn Martin Co. in Baltimore, Maryland, for Pan American Airways. Three were built and mainly operated in the Pacific theatre: the *China Clipper*, the *Philippine Clipper* and the *Hawaii Clipper*. All three had crashed by 1945.

A similar flying boat, (the Martin 156), named *Russian Clipper*, built for the Soviet Union, had a larger wing (giving it greater range) and twin fins.



Martin M-130 China Clipper on launch pad (photo San Diego Air Museum via Wiki)

3. The Shape of Things to Come: the Focke-Wulf FW-200 Condor

On August 13, 1938, at the very time the flight trials of the *Boeing Model 314* were taking place at Seattle, a sleek four-engine landplane with the name *Condor* painted on its sides and a swastika on its rudder, landed at Floyd Bennett Field on Long Island. It was a *Focke-Wulf FW-200*, flown by Lufthansa Captain *Alfred Henke* and a crew of three. It came to deliver the mail from Berlin, Germany, after a non-stop flight of 6500km. After refueling, it set off for its return trip with a minimum of delay. The designer of the beautiful aircraft was *Kurt Tank*, a man who had started out as a design engineer for *Adolf Rohrbach* and who would become a legend in his lifetime.

The sensational flight was convincing proof that the choice for flying boats for trans-Atlantic passenger service was not as self-evident as many had thought.

The beautiful four-engined *FW-200 Condor* airliner had been created for Lufthansa in 1937 by *Kurt Tank*. It was the outstanding example of a land-based airliner of the late thirties, foreshadowing such later planes as the *Douglas DC-4*. Designed, built and tested (by Tank personally) in one year and eleven days, the *Condor* was meant to be a medium range airliner. Very soon, however, with special adaptations, it proved also very succesful on the long distance trajects of the world because of its light-weight, stressed skin construction.

Spit gives the following information on the standard *FW-200*:

FW-200 33m - 14800kg 4 x 760hp 365km/h @ 2100m 1500km @ load: 17%
(1938) wingload 123 - powerload 4.8 - own weight % - (engine %?) - fuel weight %
(SPIT+CONRADIS)

Note the low powerload and the light weight of an airplane designed to carry 25 passengers over medium distances. The powerload is low to facilitate take-off; remember that almost all *airfields* in this period of time were indeed fields (of grass).

Load fraction @ 75 kg/person = $(25 + 5 = 30 \times 75 = 2250 \text{ kg} + 250 \text{ kg mail} = 2500 \text{ kg load} = 17\%)$



1938: The FW-200 Condor ready for take off

'...The passengers are seated in two compartments, separated by a partition. This partition [bulkhead] contains the main spar of the wing, which runs through the fuselage and which can be passed via a pair of steps. The front cabin is reserved for smokers. By allowing people to smoke flying is made more pleasant [!]. There is room in total for 25 passengers. Behind the cabin there is a spacious toiletroom.

Because the wingspar runs through the fuselage, the fuselage itself can be kept low, with enough headroom to walk upright. The outside dimensions of the fuselage are consequently limited, which results in low drag and high speed (also: the outside hull is aerodynamically shaped, not just cylindrical, GJS, see dr Eckener.). Especially interesting is the wing construction *which uses only a single spar*. The stressed parts of the structure are made of duraluminium, including the skin of the wings as far as it contributes to the strength. The rear part of the wing is covered with fabric. An ingenious construction is used for the connection between wing and fuselage, where the various forces are transmitted with the aid of a heavy aluminium forging. The fuselage consists of a series of rings covered by metal skin. It is built in separate sections which are later connected. Where needed, special constructions have been chosen to concentrate the forces. At other points care has been taken to disperse them over a wide area...' (Spit)

The record machine that was used for special flights by Lufthansa to Tokio and Long Island carried a crew of four, no passengers and extra fuel to a total volume of approximately 10.000 liters. (Conradis). The non-stop trajet Berlin - New York was nearly 6400 km and was covered in nearly 25 hours against a considerable headwind. (There was about 1000 liter left remaining in the tanks, which is an equivalent weight of ten passengers). This would lead to the following data, assuming fuel weight was 7500 kg:

2000m

Conradis p.166: O->W 6400km, 24.9h; considerable headwind: av groundspeed: 256km/h

W->O 6600km, 20h; tailwind, 3000m 330

13000km 44.9h is average 290km/h

record

FW-200 33m - 18000kg 4 x 760hp 290km/h @ 2100m 7250km @ load: 4%?

(1938) wingload 150 - powerload 5.9- own weight 54% - (engine %?) - fuel weight 42(-4=38)%

(SPIT+CONRADIS+KLASSIKER 1/2004)

better: $290 \times 25 = L/D \times 270 \times 0.85/0.25 \times .38/.81$; $L/D = 7250/(918 \times 0.47) = 16,8!$

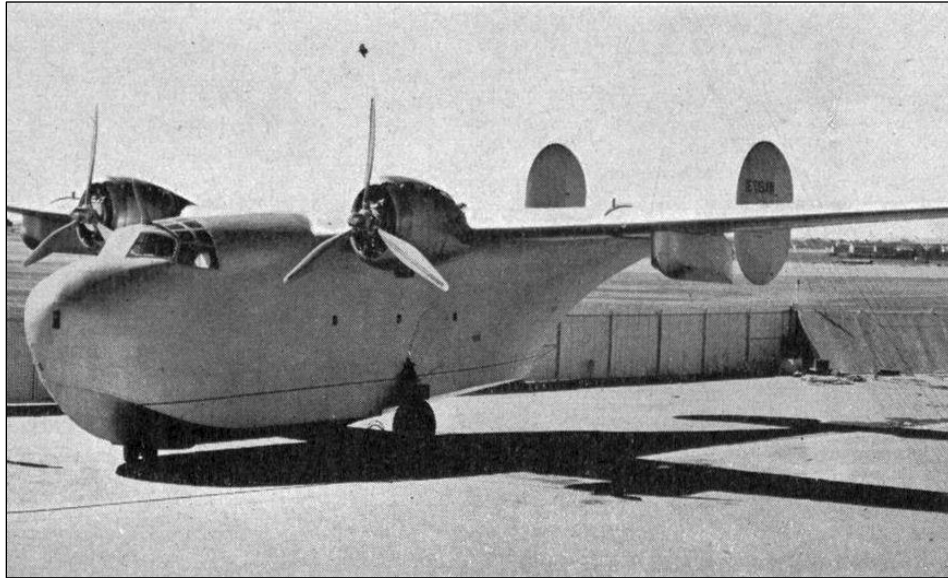
There is a hint of resemblance with the specifications of the Rorhbach Romar II trans-Atlantic flying boat (see earlier). Is there a continuous line of thinking in the mind of Kurt Tank? It would be interesting to compare the (single) spar wing designs of both machines.

The transAtlantic flight of the FW was a strong indication of the things that would come soon: trans Atlantic airliners that were simple four-engined land planes such as the Douglas C-54 (later: DC-4 and DC-6) and the Lockheed Constellation. During the war, another landplane, the C-87, (transport version of the B-24 Liverator) was also used to cross the ocean on a regular schedule.

1940: THE WAR WANTS LAND-PLANES

4. Consolidated

Prior to 1940 the Consolidated Aircraft Co. of San Diego was noted in principal as a builder of patrol flying boats for the navies of America and its allies. The most famous of these was the *PBY Catalina* of which 3300 were built. They flew at slow speed and were excellent protectors of wartime convoys of ships. A proposed successor, the Model 31 *P4Y Corrigedor*, had revolutionary wings, designed by *David R. Davies* for long range flight.



Consolidated P4Y Corrigedor (source Wiki)

When the army asked for a landbased bomber design, the resulting Model 32 *B-24 Liberator* inherited Corrigedor's wings, tricycle landing gear and bulky girth. The wings were slender and had a tear-drop cross section which together provided an exceptional long range. Approximately 11000 planes of this type were built by Consolidated itself, some of them in the form of the C-87, an airplane suitable for cargo and passengers.



1940: B-24 Liberator: trans-Atlantic capacity (note the slender wings)

Wiki writes on the B-24 wing design:

https://en.wikipedia.org/wiki/Consolidated_B-24_Liberator

“...The B-24 had a shoulder mounted high aspect ratio Davis wing. This wing was highly efficient allowing a relatively high airspeed and long range. Compared to the B-17 it had a 6-foot larger wingspan, but a lower wing area. This gave the B-24 a 35% higher wing loading. The relatively thick wing held the promise of increased tankage while delivering increased lift and speed, but became unpleasant to fly when committed to heavier loadings as experienced at high altitude and in bad weather. The Davis wing was also more susceptible to ice formation than contemporary designs, causing distortions of the aerofoil section and resulting in the loss of lift (unpleasant experiences drawing such comments as 'The Davis wing won't hold enough ice to chill your drink'.) The wing was also more susceptible to damage than the B-17's wing, making the aircraft less able to absorb battle damage. The wing carried four supercharged radial engines mounted in cowlings borrowed from the PBY Catalina (except being oval in cross-section, with oil coolers mounted on each side of the engine), turning 3-bladed variable-pitch propellers....”



1942: The Consolidated C-87 Liberator Express

source: http://axis-and-allies-paintworks.com/e107_plugins/forum/forum_viewtopic.php?356

The bombers for the European war theatre were routinely ferried across the North Atlantic. C-87's were used to maintain a regular communication route between the USA and Great Britain. As such they were pioneering the passenger services that would start immediately after the war. (The crossing was not always a pleasant voyage - the planes had no pressurized cabin and little heating. Over 10,000ft oxygen masks had to be used and the ride could be bumpy.)

After the war, Consolidated did not produce airliners for long distance travels. It did build a succesful medium range airliner, the Convair CV-240. As time went on, the company underwent various mergers and concentrated its production more and more on military equipment. Its most famous product in the line of piston engine bombers was in 1946 the truly gigantic *B-36 Peacemaker* of which a one only cargo version existed: the Convair XC-99 (1947).

This machine may be considered as the end product of piston engine airplane development. The giant Convair XC-99 is an intercontinental transport plane with an estimated payload capacity of 18 per cent when she is fuelled for the Atlantic run (maximum fuel load = 27 per cent). Its fuselage is lighter than that of a flying boat, but the weight of the landing gear is considerable (6,4 per cent).



1947: Consolidated XC-99 Cargo Plane. The ultimate in piston engine intercontinental aircraft design

The Convair XC-99 (1947, tow 134000kg) was derived from the successful intercontinental bomber B-36 and used the same wing and powerplant. The fuselage was re-designed and possessed two decks over the full length. Only a limited portion was pressurized. Only a single machine was constructed, that was used intensively over a period of eight years.⁴ The wing of the XC-99 had a span of 70m, while the fuselage's length was 56 m. The structural weight of wing plus fuselage plus tail was 30360kg, which figures out to about **23%** of total weight (this is state of the art 1947).

This may be compared with the figures for Dornier's Do-X (1929, 48000kg total weight): structural weight of wing (48m) plus hull (40m) plus tail: 17100kg or **36%** of total weight (this was state of the art anno 1927).

⁴ For Convair XC-99 see: Dennis R. Jenkins: "Convair B-36 Peacemaker" (Warbird Tech Series, 1999, ISBN 1-58007-019-1).

5. Lockheed, United Aircraft & Jack Northrop

John Knudsen "Jack" Northrop (1895-1981) was a self-taught engineer with little formal education whose talent for airplane design was recognized by all the great American airplane builders of the period. It would be impossible to write about the evolution of aircraft design in the United States without mentioning his revolutionnary contributions. At the firm of *Loughead* (later *Lockheed*), assisted by *Gerard F. Vultee*⁵, he built in 1927 the single engined *Vega* passenger/mail plane. He dared to construct the monocoque fuselage of *Vega* out of two laminated wood shell halves, which were hot-pressed in concrete bath-tub like molds. The wooden shell was fully monocoque, e.g. it had no bracing structure.

The high-wing airplane became famous for its speed and good looks.



1927: Lockheed Vega

The *Vega* was the cleanest looking airplane of its day, a true shocker, with a wooden unbraced high wing with plywood skin, like the Fokkers, and a perfectly streamlined body. Equipped with the unsurpassed *Wright Whirlwind* radial engine, housed in the newly developed *NACA* cowling, the *Vega* became an aeroplane sought after by millionaires, racing pilots, long distance adventurers and polar explorers. It spawned a family of Lockheed winners, both in wood and in metal, including Lindbergh's low-wing *Model 8 Sirius* (1929), Kingsford Smith's *Altair* (with retractable landing gear) and the *Orion* (1930).

The Lockheed *Model 8 Sirius* was a single-engined, propeller-driven monoplane designed and built by Northrop and Vultee in 1929, at the request of *Charles Lindbergh*. Two versions of the same basic design were built for the United States Air Force, one made largely of wood with a fixed landing gear, and one with a metal skin and retractable landing gear. Its basic role was intended to be as a utility transport.

Northrop himself went on to bigger things and started his own company, *Avion* in the spring of 1929. One of his objectives was to be free to work at his favourite project, *the flying wing*. (With some others, like *Donne* in England and *Hugo Junkers*, the *Horten* brothers and *dr. Lippisch* in Germany, he believed that an aircraft consisting of a wing only would be the most efficient airborne vehicle that could be envisaged.) At *Avion* he started on the road of realization of this dream by building an experimental flying wing of modest size (30ft span). He gained some valuable experience with it, among others in a *metal wing construction* which he called 'multicellular' (see *Douglas DC-1*). He then used this technique for the wings, fuselage and tail of a

⁵ *Gerard F. Vultee* was Lockheed's chief engineer in 1928 through 1931 and was involved in the designs of all the Lockheed variants of that time and specifically designed *Charles Lindbergh's Sirius*.

'conventional' airplane, his masterpiece of this period, the all-metal, low-wing *Alpha*. This awe-inspiring craft for airmail and six to eight passengers had a cylindrical fuselage with a gigantic cowling around its single Pratt and Whitney radial engine. It set a new industry-standard for speed and beauty.

(Actually, people did have extreme opinions about its looks. David Donald's caption below a photograph of the *Alpha* in his *Encyclopedia* reads: 'Despite its ungainly appearance and fixed landing gear, the 1930 *Alpha* may truly be regarded as the first "modern" airliner.')



1930 Northrop Alpha

In contrast, Wayne Biddle writes: "...With its gleaming silver skin and streamlined contours, the *Alpha* seemed to express far more than clever engineering, however. Like the *Vega* it looked the way an aircraft should look - not like an old-fashioned box kite, but almost like a Brancusi bird. Northrop even enclosed its fixed landing gear in smooth aluminium "trousers" to reduce the drag, completing the visual impact of a metallically feathered hawk. It was a breathtaking machine, radically different from the chunky steam locomotives and automobiles that were still the most familiar products of modern technology. To see the *Alpha*, let alone fly in it, was to discover a new possibility. This was Northrop's genius and great good fortune, that for a while he was able to translate aesthetic notions about flight into technical accomplishments."⁶

Whatever one thinks about its appearance, the aircraft was the turning point in American aircraft construction. The manner in which metal had been used in its construction was an example to all competitors. When Avion became, one year later, part of United Aircraft under the name of 'Northrop Aircraft Company', the *Alpha* was Northrop's main asset and it must have been intensely studied by everybody working on stressed-skin design, such as the Boeing engineers (also part of United) *Egtveldt* and *Monmouth* who had the *Monomail* on their drafting boards. (Or maybe Northrop also borrowed from Boeing?, because the *Alpha* and the *Monomail* really were contemporaries).

In a parallel development, some of Lockheed's wooden designs, such as the *Orion*, had been rebuilt by Detroit Aircraft Corporation (a sister company of Lockheed) with metal fuselages. [see: Wiki] The *Lockheed Model 9 Orion* was the last design using many identical elements from the Lockheed designs preceding it. It primarily used all the elements of the *Altair*, but included a forward top cockpit similar to the *Vega*, plus the NACA cowling introduced in the *Air Express*. The *Model 9 Orion* featured an enclosed cabin with seating for six passengers. The *Orion* received its Approved Type Certificate on May 6, 1931.

⁶ Wayne Biddle: "Barons of the Sky". page 178; Simon & Schuster, 1991, ISBN 0-671-66726-2



Lockheed Model 9c Orion of Swissair

The *Electra* was Lockheed's first all-metal and twin-engine design by *Lloyd Stearman* and *Hall Hibbard*. The name *Electra* came from a star in the Pleiades. The prototype made its first flight on February 23, 1934. Wind tunnel work on the *Electra* was undertaken at the University of Michigan. Much of the work was performed by a student assistant, *Clarence (Kelly) Johnson*. He suggested two changes be made to the design: changing the single tail to double tails (later a Lockheed trademark), and deleting oversized wing fillets. Both of these suggestions were incorporated into the production aircraft. Upon receiving his master's degree, Johnson joined Lockheed as a regular employee. By 1938 he had risen to chief engineer. He had the rare talent of picking the right man for every design job. His leadership ability first manifested itself with the *P-38 Lightning*. He then went on to design the *P-80 jet fighter* and the *Constellation* at the same time!"

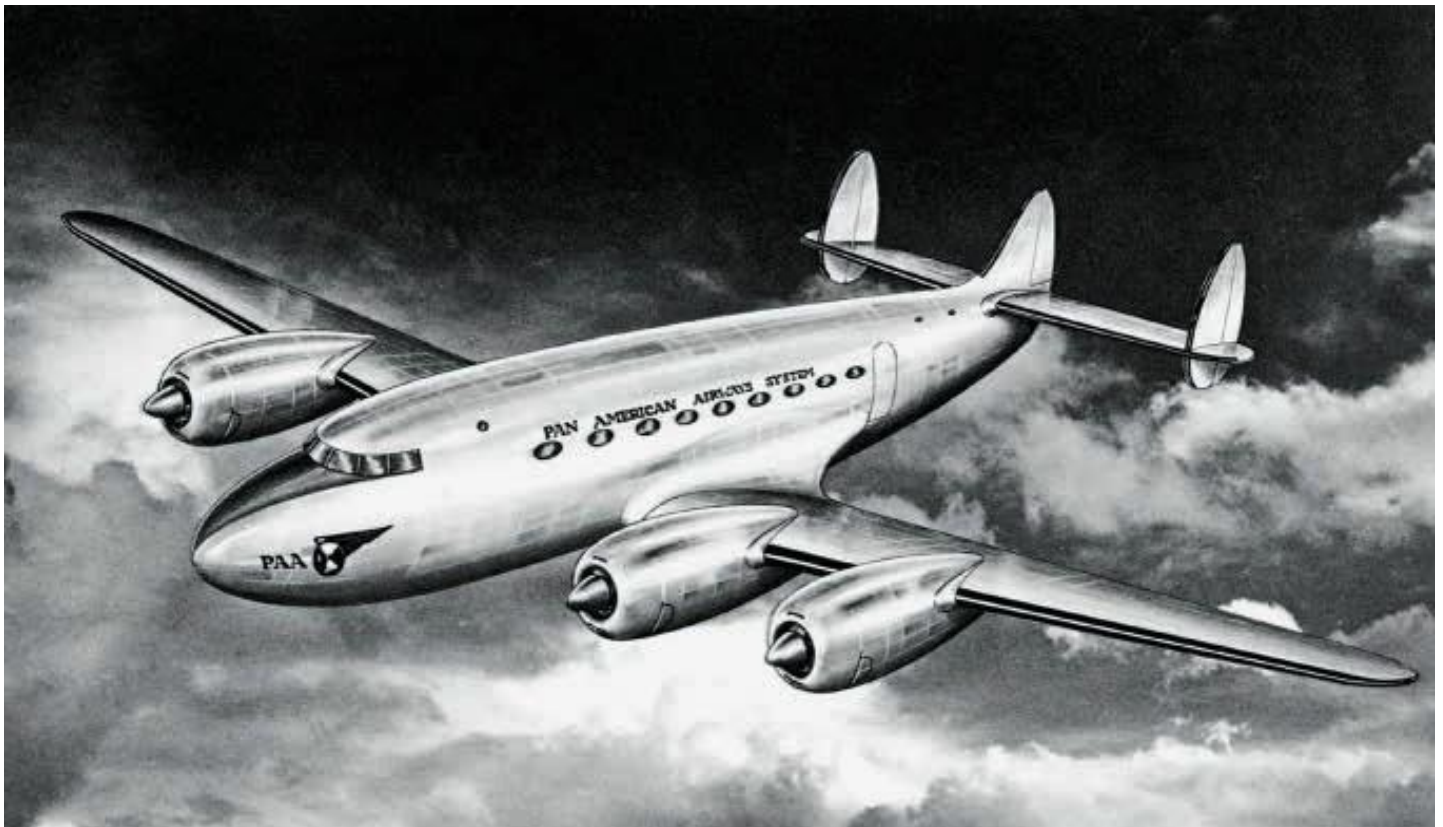


Lockheed Model 10 Electra

After October 1934 when the US government banned single-engined aircraft for use in carrying passengers or in night flying, Lockheed was perfectly placed in the market with its new Model 10 *Electra*. In addition to deliveries to US based airlines, several European operators added *Electras* to their prewar fleets.



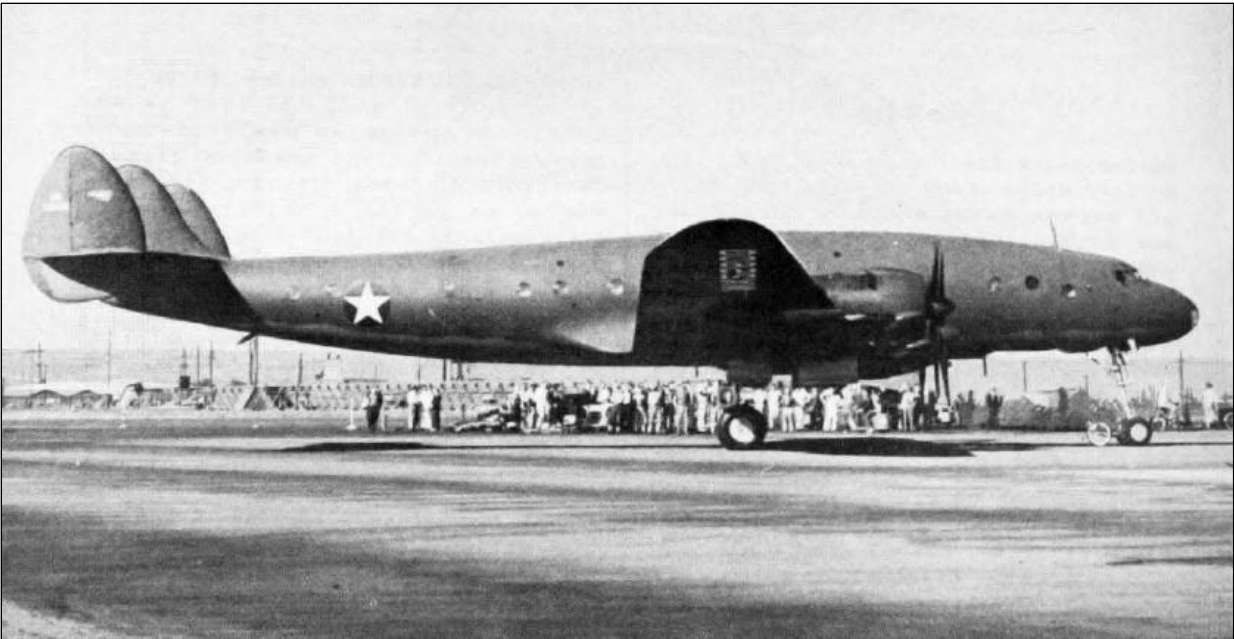
1937 Amelia Earhart's Model 10E Electra



1938: Model 44 Lockheed Excalibur (artist's impression)

Lockheed had been working on the *L-044 Excalibur*, a four-engine, pressurized airliner, since 1937. In 1939, Trans World Airlines, at the instigation of major stockholder *Howard Hughes*, requested a 40-passenger transcontinental airliner with a range of 3,500 mi (5,600 km) - well beyond the capabilities of the Excalibur design. TWA's requirements led to the **L-049 Constellation**, designed by Lockheed engineers including Kelly Johnson and Hall Hibbard. [see Wiki]

The Constellation's wing design was close to that of the P-38 Lightning, differing mostly in size. The triple tail kept the aircraft's height low enough to fit in existing hangars, while features included hydraulically boosted controls and a de-icing system used on wing and tail leading edges. The aircraft had a maximum speed of over 375 mph (600 km/h), faster than that of a Japanese Zero fighter, a cruise speed of 340 mph (550 km/h), and a service ceiling of 24,000 ft (7,300 m). According to Anthony Sampson in *Empires of the Sky*, Lockheed may have undertaken the intricate design, but Hughes' intercession in the design process drove the concept in shape, capabilities and appearance.



Jan 9, 1943: Rollout of first Lockheed C-69 Constellation for the Air Force

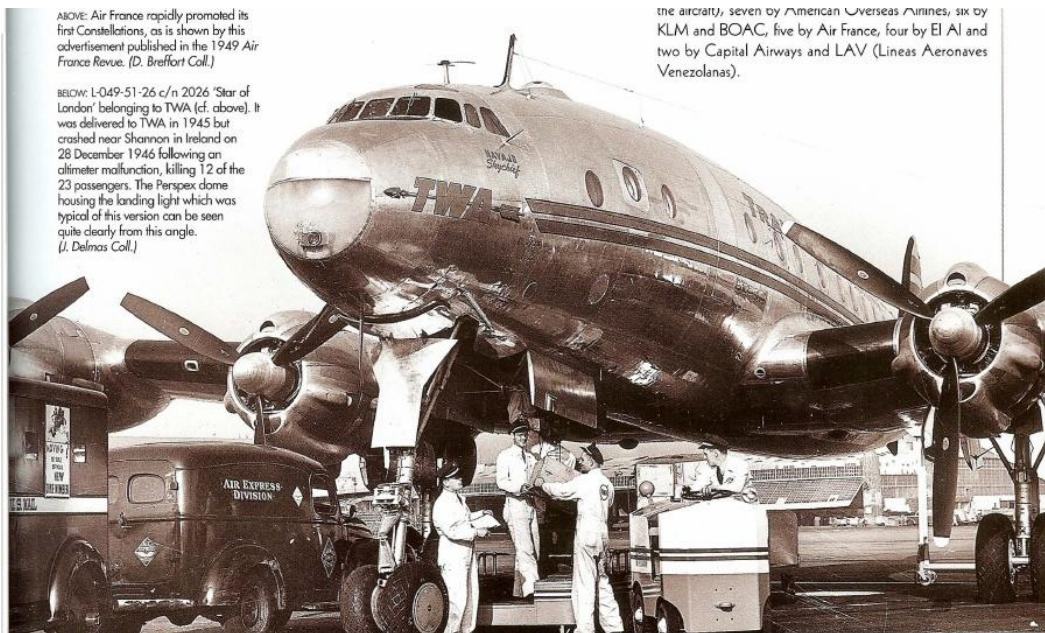
specs for airliner Lockheed L-049 (approximate data used)

		final wgt	start	cruise	
L-049:	37.5m 153m ²	- 43500kg*	4 x 2800hp ⁷	500km/h @ 7000m**	5000km @ payload: 14%
(1943)	AR 9.2	wngld 284 -	pwrlld 3.9 -	own wght 54% ?-	(eng. 13%) - fuel wght 32% ?

(my guesstimate: Atlantic payload= 40 pass+10 crew = 4500kg + 1500kg (mail+freight+food) = 6000kg = 14%)
(data from American Museum of Aviation)

From this beautiful site is thankfully quoted:

<https://www.scribd.com/doc/280054952/Lockheed-Constellation-From-Excalibur-to-Starliner>



On Feb. 5, 1946 the first international flight dubbed "The Star of Paris," a TWA Connie, lifted off from New York's LaGuardia Airport destined for Orly, Paris via Gander (Newfoundland, Canada) and Shannon (Ireland), 45 passenger travelled in 16 hours and 38 minutes.

* stage of development 1953 ** the airliner had a pressurized cabin

6. Douglas

By 1932, when Northrop severed the connection with United to embark on a joined enterprise with the Douglas company, the practice of stressed-skin design was spreading rapidly among the various American aircraft manufacturers. The *Alpha* gave rise to a line of successful derivatives, which had caught Douglas' interest, such as the *Gamma*, the *Delta* and the *Beta*. The *Gamma* was further developed into light attack bombers, the *A-17* for the Army and the *BT-2* for the US Navy, which ultimately led to the *Douglas Dauntless* (1938). Already by 1934, the Northrop company had been completely absorbed by Douglas.

Northrop's airplanes in this period had an all-metal construction which may well have been based on Rohrbach's ideas, although it is unknown if the two actually met during Rohrbach's stay in the USA to discuss for instance the design of the *Alpha*. Northrop had abandoned the pure shell idea of the *Vega* and embraced the stressed-skin concept. The outer skin of the fuselage was a light gauge smooth aluminium sheet, reinforced internally by circular rings ('frames') and longitudinal stringers. An assembly of this type is essentially different from the welded tubular structures that were used traditionally by builders like Fokker, Ford, Junkers or Vickers Wibault. Their airplanes had bodies with steel tubes carrying all the design loads. The tubular structure was covered up by plywood sheets, or canvas, or corrugated metal sheet, or even smooth metal skins, giving the airplane on the outside a more or less clean look. The distinctive feature was that these skins were tied to, or bolted on, or lightly riveted to the 'chassis' serving only as covers or panels to pacify the airstream and please the eye.

It was this Northrop approach to the design of metal airplanes that was used by Douglas under chief engineer *Arthur E. Raymond* to create that successful series of early Douglas airliners that became known as the DC (Douglas Commercial) series, from DC-1 to DC-7. For the initial entry of Douglas in this market Raymond c.s. followed the design lead given by Northrop in particular with the multicellular wing design.⁸

The DC-1 to DC-3 series development was started in the early thirties as a reaction to the ever growing interest of major airlines like TWA in metal airliners with two engines, like the Boeing 247 and the Lockheed Electra.. The resulting DST's, the DC-3's, the Dakotas and its military counterpart, the C-47 Skytrain, became the most popular medium transports of their time – a little heavy in the flesh, but almost indestructible. In all its variations, almost 16,000 were built around 1940.. Many survived the war and some are still flying to this day...

The success of the *DC-3* encouraged Douglas to go ahead with the design of a large four-engined passenger airliner. The specifications for this airplane were set in close consultation with five national airlines, who would be the future users. The airlines followed the project closely through the design and production stages and brought in a continuous stream of wishes and requirements. In the end this resulted in an aircraft which was much too complex and too heavy for economic use. (See Percy, Jane). After a period of testing by National Airlines the project was abandoned and the prototype was sold to Japan. It thereafter was referred to as the *DC-4E*.

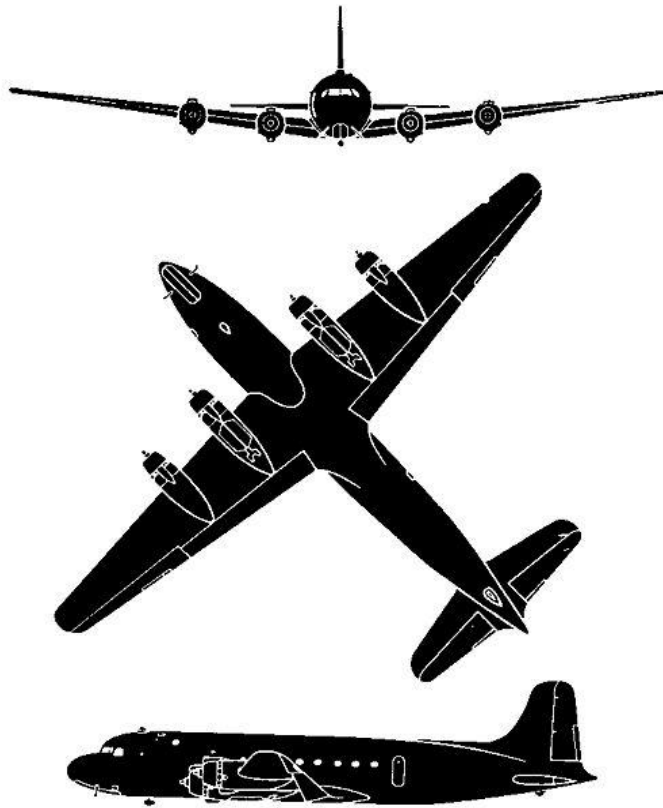
DC-4E: 42m - 30160kg 4 x 1450hp 322km/h @ ? m 3540km @ load: 14%?
(1938) wingload 151 - powerload 5.4 - own weight 64% - (engine 10%) - fuel weight 22%?
==== (Percy, Stroud)

Douglas then started at its own initiative the design of a much simpler four-engined transport, which became known as the *DC-4 Skymaster*, and its military variant, the *C-54*, which had a heavier floor designed for concentrated loads (see. Jane)

start
C-54A: 36m 136m² - 30900kg 4 x 1450hp 365km/h @ 3050m 4025km @ load: 14%
(1942) AR 9.5 wngld 227 - pwrld 5.3 - own wght 57%? - (eng. 10%) - fuel wght 29%?
(Percy, Ency)

(initial version with aux. cabin tanks, total: $USG \times 3.79 = 14023 \text{ ltr} \times 0.72 = 10100 \text{ kg}$ (Percy)
payload with this fuel: $9600 \text{ lb} \times 0.454 = 4360 \text{ kg} = 14\%$
 $4025 = L/D \times 998 \times 0.26/0.87$; $L/D = 4025 / 998 / 0.299 = 13.5$

⁸ see for a personal encounter with this wing: <https://earlyflightera.com/2014/12/06/1930s-light-metal-wings-ii>
/



By the end of the war Skymaster was without doubt the most succesful heavy transport that had ever flown and it may be called the *first modern Atlantic airliner*. The Douglas engineers really learned to control weight during their development of the DC family. For one thing they put overboard the multi-cellular wing construction á la Northrop with which they had started on the *DC-1 to DC-3* and returned to the more popular single box-type-spar wing, which turned out to be lighter. In the end they produced a large, light aircraft which possessed extremely good aerodynamic and structural characteristics based on a very simple geometry: cylindrical fuselage, slender wings with constant taper and a simple, relatively small single tail. (S.Jane)
[the wing had a NACA 23012 airfoil shape]



1942: The War Time Douglas C-54 Skymaster

This very simplicity proved the key to superior performance, although it made Skymaster at the same time a rather modest and unassuming looking aircraft. Having reached the ultimate, most logical form and construction for a low-wing transport, the end product of design somehow did not much to please the eye. It looked right, but not extremely beautiful. It was efficient, but did not trigger the imagination like the Catalina, the Martin Clipper, the Constellation or even the Dakota (not to mention the Handley Page Hannibal).



1946:Douglas DC-4: Easy to fly; Ready for Atlantic Service

Anecdote

Albert Plesman, President-director of KLM

On VE-day, May 5, 1945, *Dr. Albert Plesman*, president-director of *KLM Royal Dutch Airlines*, emerged from his wartime hideaway in the eastern part of the Netherlands and took the first possible flight to the USA. There he was able, with the financing of his government backing him, to arrange for the delivery of fourteen (now surplus) Douglas C-54A's.

On May 21 1946 KLM opened its all-new regular trans Atlantic twice-weekly service from Amsterdam to New York with the Douglas DC-4 Skymaster PH-TAR "Rotterdam" one of these rejuvenated airliners.

Youtube has a newsreel about the first flight. Watch the pipe smoking flightcrew in the cockpit!

<https://www.youtube.com/watch?v=Fys18X7I8YY>

7. Latécomers

After the war an effort was made to re-launch the luxurious giant flying boat, such as the Saro Princess and the Latécoère 631. These initiatives could not be brought to a success. Many years later two gigantic Martin Mars flying boats were still based on Victoria Island, Canada, as fire fighting machines to battle forest fires in the Canadian wilderness. As passenger transports however, the flying boats were passed out...

From "Hispano Suiza" Bulletin

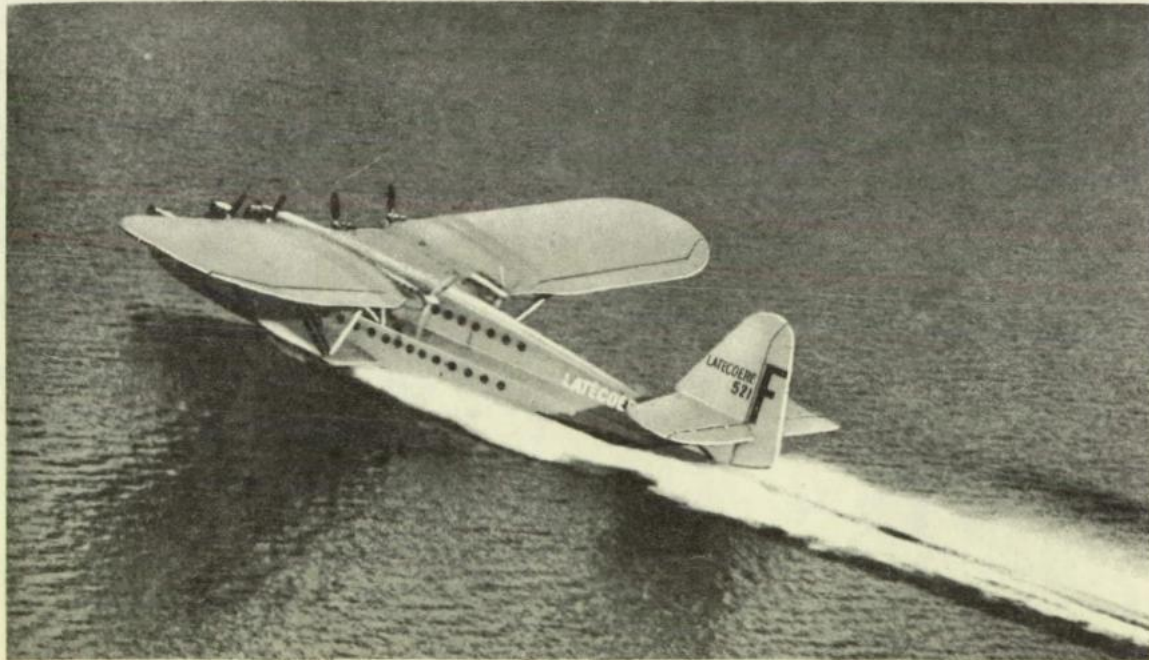


Figure 3.- The Latécoère 521 taxiing.



top: 1935: Latécoère 521; below: 1946: Latécoère 631: Troubled Beauty



Still, much later, 1952: the SARO Princess. The End of a Beautiful Vision.

Part IVb Summary and Conclusions

next page:

OVERVIEW OF IMPORTANT AIRPLANES IN THE HISTORY OF THE DEVELOPMENT OF ATLANTIC AIRLINERS

(in order of reported first flight)

YE R month)	BOEING	NORTHRO P	LOCKHEE D	MARTIN	CONSOLI- DATED	SIKORSK Y	OTHERS
1927		1) Vega monocoque wood fuselage hi-wing 1-eng 4-pass					
1928	8)Model 80 3-eng biplane all metal				?)Model 11 biplane Guardian XP-496 bomber mixed construction?		
1929		?)Flying Wing metal, cellular wings	11)8 Sirius Ch.Lindberg h low wing		1)XPY-1 (Commodore) metal/fabric on wings	?)S-38 amphibian wood/alum	all metal: 6)Dornier DoX ?)Rohrbach RoX
1930	5)Model 200 (Monomail) all metal	Alpha metal semi- monoc. body	9)8D Altair retr.landing gear				?)Junkers G- 38
1931	5)Model 215 (XB- 901=B9) metal bomber		?)9D Orion 4-6pas	P3M- 1=XPY-1 patrolboat, see Consolidate d		?)S-40 Clipper biplane all metal?	
		merger with DOUGLAS					
1932		?)Northrop Gamma Delta		7)XB-10 = B-10 all metal bomber	XBY1Fleetst er all metal 3)P2Y-1 (patrolboat)		
1932				11)Panam spec		11)Panam spec	
1933	2)Model 247 2-eng airliner	6)DC-1 ?)DC-2 all-metal; Northrop wing			?)P2Y-3		
1934		+ military offspring of Northrop designs	2)10A Electra 2-eng airliner all metal			3)S-42 Clipper hi- wing; 4- eng high wingload high AR	?)Breguet 530 Saigon
YE R mont	BOEING	NORTHRO P	LOCKHEE D	MARTIN	CONSOLI- DATED	SIKORSK Y	OTHERS

YE R month	BOEING	NORTHRO P	LOCKHEE D	MARTIN	CONSOLI- DATED	SIKORSK Y	OTHERS
1935	7)Model 299 YB-17 Flying Fortress	12)DC-3		1)130Clipp er (s. S-42);4- eng; low weight; all metal	3)XP3Y-1 (PBY Catalina) all metal patrol boat		1)Laté 521 (Fr.)6eng.met al hull; fabric covered wing
1936			6)12 Electra Jr				9)Blohm&Vo ss Ha-139 mail float plane
1937	10)XB-15 giant bomber		7)14 Super Electra		12)Model 29 XPB2Y-1 Coronado	8)XPBS-1 Excalibur? S-44	7)Focke Wulf Fw200 Condor 4eng landplane
1938	12)Model 307 Stratoliner 6)Model 314 Clipper	6)DC-4E					?)Junkers 90
1939		2)DC-5	9)18 Lodestar 1)P-38 Lightning	2)PBM-1 Mariner	5)Model 31 P4YCorregid or 12)XB-24 Liberator (Davis wings)		7)Short S26- G (Eng.) 24 pass for Atlantic 4x1400hp 33300kg
1940							9)Blohm&Vo ss BV-222 Viking flying boat
1941							
1942	9)XB-29 Superfortre ss	2)DC-4 (C-54) Skymaster		3)XPB2M- 1 Mars 65800kg			11)Laté 631 6 eng. 71400kg flying boat
1943			1)C-69 later: 049 Constellatio n				

Table 1 First Flights of significant airplanes

8 The End Situation With Regard to Weights

Loads are most clearly expressed as *fractions of design gross weight*. Inspection of a number of large aircraft around 1935 yield the data of Table 5. At this time the first flying boats were built in the US that, although not capable of transporting a large number of passengers across the Atlantic, would at least be able to operate a regular trans-ocean postal service. The approximate average weight distribution of these aircraft (Sikorsky S-42, Glenn Martin 140 and Consolidated PBY) is estimated as follows when the planes are fully loaded for take-off, setting out for maximum distance:

Table 5 Example weight distribution for Atlantic Airliner (1935)

design gross weight		100%
wing structure	13%	
hull,tail,systems	26%	
structure weight (airframe)		39%
Furnishings	6%	
own weight		45%
Engines	12%	
empty weight		57%
crew	2%	
fuel + oil (Atlantic run)	32%	
Subtotal		91%
left for payload		9%
starting weight		100%

These figures show the great influence of the empty weight. If careful design could reduce this item from 57% to 52% or less, either the fuel load or the payload may be upped by five per cent or more, which will have a significant effect on economic operation. (See analysis of weight of a successful Atlantic airliner such as Lockheed L-049)

By careful design and omission of all superfluous equipment some successful long-distance record-setting airplanes of the twenties could indeed lay claim to a minimal 'empty weight' of approximately 50% of the 'gross weight'. As the designers proudly proclaimed: the aircraft could carry 'their own weight'.

The *Fokker F-VIIb-3m* of Kingsford Smith 'Southern Cross' (1928), famous for its ocean crossings, had an empty weight of only 50%. It could take off (in an overloaded condition) at 7000 kg, while her empty weight came to no more than about 3500 kg. The term empty weight of the *Southern Cross* refers to the bare airplane, augmented by the weight of three radio transmitters (no light matter in those days), the tare weight of an enormous extra fuel tank of 800 gallons and two wicker chairs, one each for the navigator and the radio operator. The difference between empty weight and gross weight, constituting the maximum loading capacity of the airplane, was used for much fuel, some stores and oil, a few mailbags and a crew of four.

The same magic figure of 50% empty weight is also quoted for the *Davis-Douglas Cloudster* and the *Fokker T-2*, both planes meant 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-33* that crossed the Atlantic from East to West in 1928, the *Bréguet XIV* that flew from Paris 6000 kilometres non-stop to Asia. All these famous airplanes around 1930 had an empty weight of 50% or less. Because they were this light, they could take aboard an extra large amount of fuel, which resulted in an exceptional range.

These long-distance non-payload *record airplanes* (the French called them: 'bidons volants') set the benchmark for all structural designers working on long-distance *airliners* thereafter. The question that occupied them most of all was how to increase the size of the machine without making the own weight of the structure heavier than about 40 odd per cent of gross weight. If the predictions of early critics like **Melville**⁹ were right, this would be impossible. Melville c.s. held that the relative empty weight would increase prohibitively with increasing size.

⁹ see page 2 of THE BIRTH OF THE ATLANTIC AIRLINER, Part II Bigger Airplanes.

A rather threatening perspective, that had fortunately not come true by the end of 1929 when Claudius Dornier's giant Do-X (48000kg gross weight) took to the air from Lake Constanz. Also, as we have shown, in 1935 and following years, designers were very successful in keeping the structural weight in check, with great accomplishments during the Second World war and the years that followed. Table 6 shows the remarkable figures for the very large Convair XC-99, dating from 1947 (first flight). This giant transport plane was an adaptation of the B-36 long-range bomber and the largest propeller driven airplane that served in the US Air Force. Although not strictly an Atlantic Airliner, it demonstrates 'state of the art' lightweight construction for very large aircraft of that time. (Data shown is for the first (1947) version of the plane; at a later date the landing gear was upgraded and the total weight raised to 162000kg.)



Table 6 Structural weight Convair XC-99 transport plane (1947)

	kg		134000	tot wgt
Fuselage	11450	8,5%	<==	
Wing	16880	12,6%	<==	22,7%
Empennage	2120	1,6%	<==	
landing gear	8525	6,4%		
miscellaneous systems	3290	2,5%		
<i>subtotal structural weight</i>			31,5%	
furnishings (estimated)		7,5%		
<i>subtotal 'own' weight</i>	52260		39%	
engines+nacelles	19265	14,4% ¹⁰		
<i>subtotal 'empty' weight</i>	71525		53,5%	
crew plus stores		1,5%		
fuel plus oil (Atlantic run)		27%		
<i>subtotal so far</i>			82%	
<i>left for payload</i>			18%	
gross weight	134000		100%	

Comparing this with Table 5 it is striking that the weight of the airframe (fuselage, wing, tail) has come down considerably (from 39 to 23%). This has been achieved in a number of ways. Two of these have already been mentioned: careful design of the *wing shape* and increase of *wing-load*. Furthermore, in the years after 1935, *materials*, especially alloys of aluminium, were improved to withstand greater stresses. At the same time greater attention to the *shape* of the airframe resulted in a better distribution of the loads, avoiding unwanted stress concentrations.¹¹ The acceptance of so-called semi-monocoque or '*stressed skin*' design made for lighter constructions. The mathematical tools for *stress analysis* were perfected and became part of the education of engineers. Finally, a great deal of *empirical data* on stresses in light-metal building elements was amassed by

¹⁰ Nacelles included. These were of a special elaborate construction since the XC-99 had (six) pusher engines at the trailing edge of the wing.

¹¹ The *external shape* of the airplane also became more streamlined, resulting in lower fuel consumption and better long-range performance.

experiments in the aviation industry and by government institutions. These developments did of course require a certain period of time. Fortunately in the same period aviation *engines* improved steadily in performance and reliability, making possible a growth in size of the transatlantic airliner almost from year to year. At the outset the margin for success for a trans-Atlantic transport had been very slim indeed. If, still in 1935, only nine per cent of the gross weight of a ‘ship’ could be dedicated to passengers and mail, no excessive growth of structural weight could be tolerated at all. In this respect old Melville c.s. had been right. *In the end, however, after a proper learning period, there was no excess weight to keep the Atlantic-Airliner grounded.*

9. Showing the Evolution

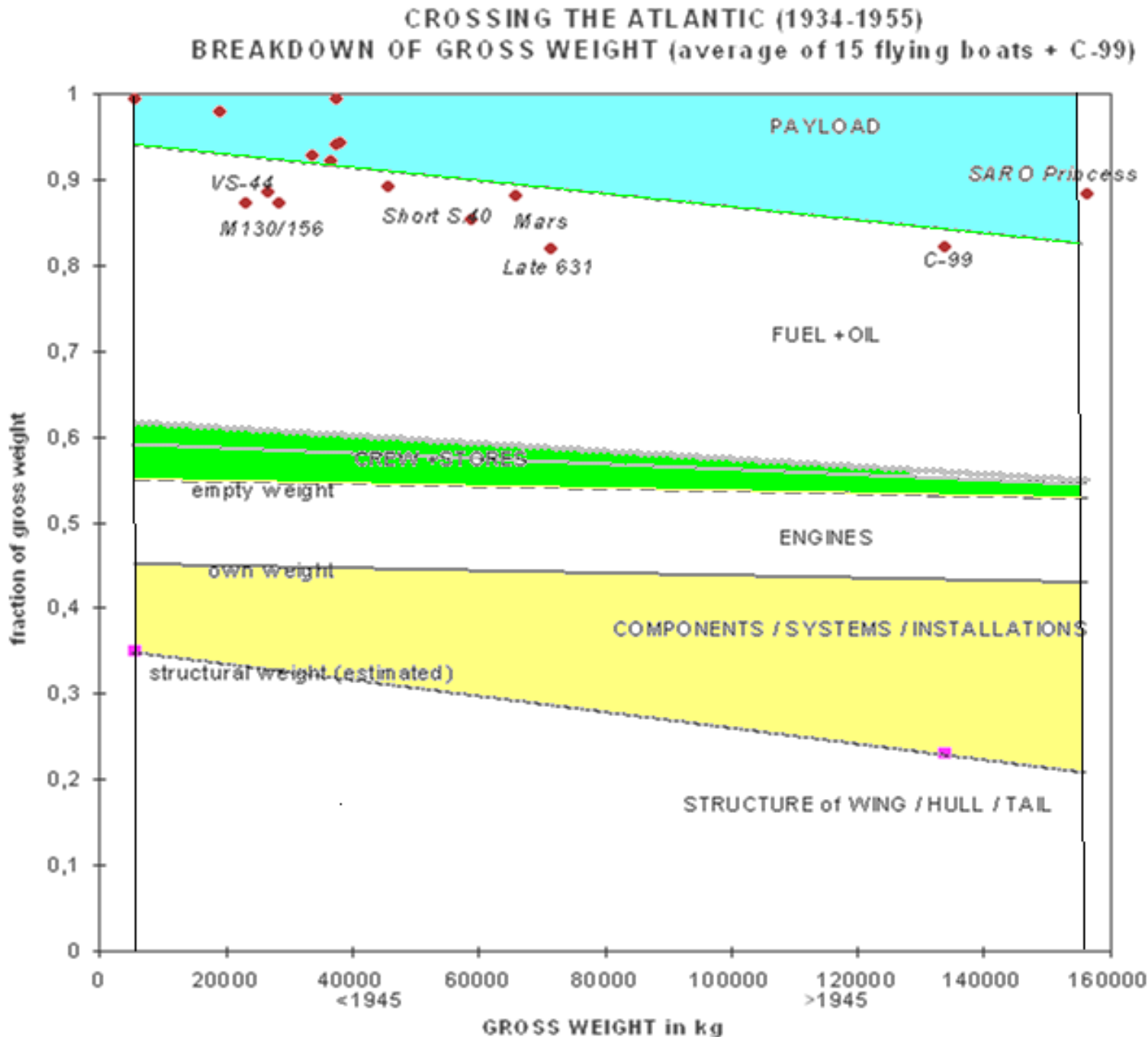


Figure 3: How the weights of Atlantic airliners developed over decades

Figure 3 shows the weight composition of sixteen transatlantic airplanes in the period 1934 - 1955

Y-AXIS An airplane (flying boat) starting out on a trans-Atlantic flight carries, in addition to his own weight, the weight of many objects, fluids and persons. These loads can be classed in various categories, whereby the weight of each category is most easily expressed as a fraction of 'total weight'. Certain categories are grouped together in named subtotals, like 'own weight' or 'empty weight'.

X-AXIS Total weight ranges 0 - 160.000kg. *Can also be considered to be time axis (1934 - 1955).* Generally speaking the light planes came first, then one after the other the heavier ones.

TREND LINES Of sixteen transatlantic airplanes of increasing size and total weight (see listing below) the relative weights per category are recorded and cumulated (empty weight = own weight + engines, etc.) In the graph, the results are not shown as points per airplane but rather as *linear trend lines for all planes*. (In the category Fuel Oil the points are shown as well).

CATEGORY STRUCTURE of WING/HULL/TAIL *It is remarkable to note that the trend line of structural weight comes down as total weight increases.* This is contrary to expectation (see THE BIRTH OF THE ATLANTIC AIRLINER, Part II Bigger Airplanes). In his review of construction history in the Journal of the Royal Aeronautical Society of January 1966, H.B.Howard accepts decrease as a recorded fact¹². Some reasons for the decrease are listed hereafter.

In the period considered there was:

- a continuous evolution of the basic layout of the airplanes (smaller wings, etc.)
- a perfection of stressed skin construction
- the use of lighter materials
- a cumulating of knowledge about stresses and deformations in light-metal parts,
- a better shaping of principal load carrying structures such as wing spars,
- weight saving production methods such as milling of box girders out of solid material.

Trend line *structural weight (estimated)*

CATEGORY COMPONENTS/SYSTEMS/INSTALLATIONS At the same time the complexity of airplanes increases with a growing weight of

- subassemblies (constant speed propellers, engine nacelles, landing gear/retractable floats)
- auxiliary power systems (electric, hydraulic, pneumatic)
- installations (anti-ice, fire control, heating, air conditioning, pressurization, drinking water)
- passenger comfort (seats, galley, toilets)

The total weight of these components and systems increases faster than the growth in total weight. When added to the weight of the category 'structure', the subtotal 'own weight' remains therefore about constant at 45% (see graph).

Trend line *own weight*

CATEGORY ENGINES. In this department the intensive efforts of engine builders begins to pay off: combustion engines get lighter per horsepower delivered. This makes that the subtotal 'empty weight' comes down from about 55% to an average of 50%, the benchmark figure that designers, historically speaking, aimed for.

Trend line *empty weight*

CATEGORY EQUIPMENT/SUPPLIES is taken together with **CATEGORY CREW**. As planes get larger the relative weight of these items diminishes,

Trend line *Crew + Stores*

CATEGORY FUEL + OIL. The quantity of fuel needed to cross the ocean (in a worst case situation such as flying with considerable headwinds from Ireland to Newfoundland) is decreasing as well with newer, larger aircraft. Their engines consume less, while the airplanes themselves have a better aerodynamic shape. This causes the uppermost trendline to come down.

Trend line *Fuel + Oil (dashed line, not labelled)*

¹² Figure 2 shown by Howard in his article 'Aircraft Structures' is based on the *actual weights of the structure* of a great number of British aircraft built in the first half of the last century. Journal of the Royal Aeronautical Society, Vol.70, January 1966, p.54

CATEGORY PAYLOAD. Since payload is the final item that closes the gap to 100 per cent, the capacity for payload increases when the trend line ‘Fuel + Oil’ comes down, as is the case during the period considered. In the beginning there was hardly any payload capacity; in the thirties it increases to 10 to 15 per cent maximum (Martin M-130/156, Vought Sikorsky VS-44, Martin Mars), while during the Second World War it reaches 20 per cent with the Latécoère 631. As a representative of a ‘modern’ land-plane, the giant Convair XC-99 (1947) is included, an intercontinental transport plane with an estimated payload capacity of 18 per cent when she is fuelled for the Atlantic run (fuel load = 27 per cent). Its fuselage is lighter than for a flying boat, but the weight of the landing gear is considerable (6,4 per cent).

LISTING OF THE SIXTEEN AIRPLANES CONSIDERED IN FIGURE 3

1)	Dornier Wal	(1922, 5700kg total weight), used for trend line structuralweight only
2)	Sikorsky S-42B	(1937, 19050kg),
3)	Glenn Martin M-130	(1935, 23130kg),
4)	Vought-Sikorsky VS-44	(1937, 26860kg),
5)	Glenn Martin M-156	(1937, 28600kg),
6)	Short S.26 G-class	(1939, 33800kg),
7)	Short S.45 Solent	(1949, 36800kg),
8)	Latécoère 522	(1937, 37400kg),
9)	Boeing 314	(1938, 37400kg),
10)	Boeing 314A	(1940, 38140kg),
11)	Blohm & Voss 222 Wiking	(1940, 45900kg),
12)	Short S.40 Shetland 2	(1947, 59000kg),
13)	Martin JRM-1 Mars	(1944, 65770kg)
14)	Latécoère 631	(1946, 71350kg),
15)	Convair XC-99	(1947, 134,000kg).
16)	Saunders Roe Princess	(1952, 156,500kg)

DATABASE FOR FIGURE 3, PAGE 30

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	(given data)	<i>trend</i> <i>line</i>	(given data)	<i>trend</i> <i>line</i>	add	<i>gives</i> <i>trend</i> <i>line</i>	add		add	<i>gives</i> <i>trend</i> <i>line</i>	add	<i>gives</i> <i>trend</i> <i>line</i>	%%	read graph
	gross wgt kg	struct ure wgt	own wgt kg	own wgt	eng- ine wgt %%	empt y wgt	eq.+ suppl wgt %%	eq+ suppl wgt	crew wgt %%	crew + stores wgt	fuel+ oil wgt %%	fuel+ oil wgt %%	left for pay- load	left for pay- load
Dornier Wal patrol boat	5700	0,35	2750	0,48	15%	0,64	0%	0,64	4%	0,67	32%	0,99	1%	0,01
Sikorsky S-42B passenger (Cochrane c.s.)	19051		8966	0,47	10%	0,57	5%	0,62	2%	0,65	33%	0,98	2%	0,02
Glenn.Martin 130 passenger	23130		8980	0,39	9%	0,48	4%	0,52	2%	0,54	33%	0,87	13%	0,13
Vought-Sikorsky VS-44 (Cochrane c.s.)	26860		10494	0,39	10%	0,49	3%	0,52	4%	0,56	33%	0,89	11%	0,11
Glenn.Martin 156 passenger	28600		11410	0,40	8%	0,48	3%	0,52	2%	0,54	33%	0,87	13%	0,13
Short S.26 G-class passenger (Jane's)	33800		13580	0,40	10%	0,51	7%	0,58	2%	0,60	33%	0,93	7%	0,07
Shorts S.45 Solent 4 passenger	36800		17940	0,49	12%	0,61	3%	0,63	2%	0,65	27%	0,92	8%	0,08
Latécoère 522 passenger (Internet)	37400		18810	0,50	7%	0,57	3%	0,60	2%	0,62	37%	0,99	1%	0,01
Boeing 314 passenger ††	37400		16360	0,44	9%	0,53	7%	0,60	3%	0,63	32%	0,94	6%	0,06
Boeing 314A passenger (Jane's)	38140		18130	0,48	10%	0,57	3%	0,60	3%	0,63	32%	0,94	6%	0,06
Blohm & Voss 222 transport (Jane's)	45900		23200	0,51	8%	0,58	2%	0,61	2%	0,62	27%	0,89	11%	0,11
Shorts S.40 Shetland 2 pass. (see Jane's 'operational empty wght'?)	59000		29240	0,50	9%	0,58	0%	0,58	0%	0,58	27%	0,85	15%	0,15
Martin JRM-1 Mars Transport	65772		30913	0,47	7%	0,54	6%	0,60	2%	0,61	27%	0,88	12%	0,12
Latécoère 631 passenger (Internet)	71350		26632	0,37	8%	0,45	8%	0,53	1%	0,55	27%	0,82	18%	0,18
Consolidated XC-99 transport(1947 version)	134000	0,23	52260	0,39	14%	0,53	1%	0,54	1%	0,55	27%	0,82	18%	0,18
Saunders Roe Princess passenger	156500		72256	0,46	9%	0,55	1%	0,56	1%	0,57	32%	0,88	12%	0,12
												aver age	9%	

NOTES ON THE DATA USED IN FIGURE 3

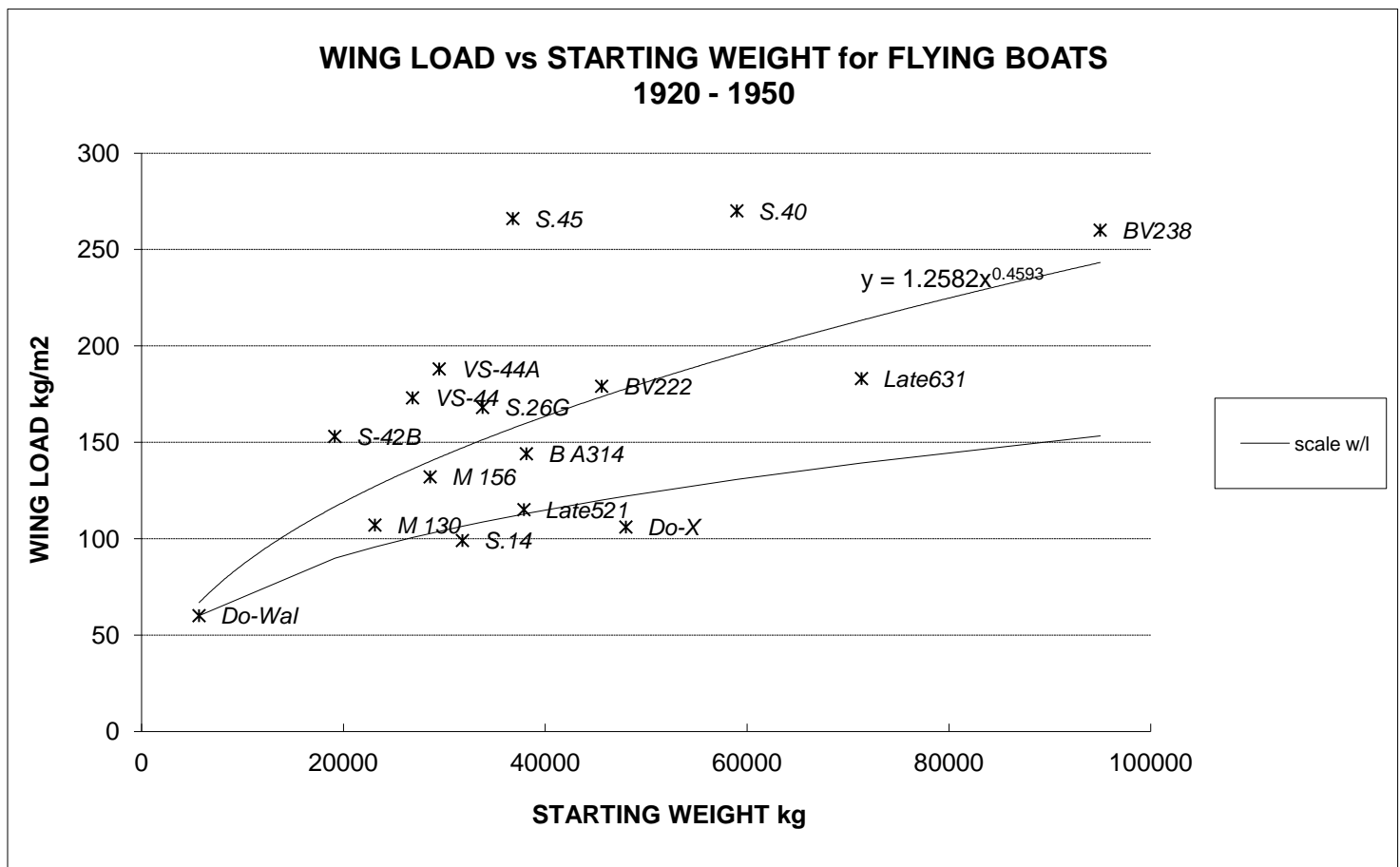
The Dornier Do-Wal was in fact incapable of making a non-stop Atlantic crossing, but has been used in the list as a starting point of the evolution of the all-metal flying boat. Its large relative, the Do-X, tour de force of Claudius Dornier, has been left out because its large weight (48000kg) was really an anachronism in 1929.¹³

The Convair XC-99 (1947, 134000kg) was derived from the successful intercontinental bomber B-36 and used the same wing and powerplant. The fuselage was re-designed and possessed two decks over the full length. Only a limited portion was pressurized. Only a single machine was constructed, that was used intensively over a period of eight years.¹⁴ The wing of the XC-99 had a span of 70m, while the fuselage's length was 56 m. The structural weight of wing plus fuselage plus tail was 30360kg, which figures out to about 23% of total weight (this is state of the art 1947).

This may be compared with the figures for Dornier's Do-X (1929, 48000kg total weight): structural weight of wing (48m) plus hull (40m) plus tail: 17100kg or 36% of total weight (this was state of the art anno 1927).

In the two decades leading up to World War II designers were becoming more and more conscious of the importance of wing design. Each year, heavier and heavier aircraft were built with, relatively speaking, smaller and smaller wings. In many cases the wingloads employed exceeded by far the simple linear requirement of geometric growth. (see illustration).

In the following graph, starting-weights and wingloads of actual planes are plotted. The top curve is calculated by regression analysis of the actual data and indicates the *trend of the designers to increase wingload as planes get heavier*. The bottom curve shows how wing loads would increase if the rules of geometric growth were strictly adhered to. Starting point is the Do-Wal with a weight of 5,700 kg and a wingload of 59 kg/m².



¹³ For Dornier Do-X see: "Grossflugschiff Dornier Do-X" (Motorbuch Verlag Stuttgart, 1982, ISBN 3-87943-659-2)

¹⁴ For Convair XC-99 see: Dennis R. Jenkins: "Convair B-36 Peacemaker" (Warbird Tech Series, 1999, ISBN 1-58007-019-1).

THE WEIGHTS OF AEROPLANES; DEFINITION OF TERMS

One must distinguish between the '*gross weight*' for which the aircraft has been designed and the actual weight with which it takes off for a certain flight. One certainly would expect in the beginning the Atlantic airliners to take off fully loaded, i.e. with a '*starting weight*' equal to the '*gross weight*', although in special cases the airplane may be allowed to take off in an '*overload*' condition.

Of special interest in our study is the '*empty weight*' of the airplane, meaning the weight of the *bare* airplane, e.g. the airframe ready to fly, complete with engines and technical systems, but without any operational furnishings such as chairs, pantry, and the like and without fuel, provisions and payload. Ideally, the '*empty weight*' may be taken as the weight of the bare, unfueled prototype ready for test flight, but without crew and measuring equipment and not yet outfitted for future customers. One may judge the quality of the structural design of a certain airplane by comparing his '*empty weight*' with that of other planes in the same category.

Unfortunately, when studying historical aircraft direct knowledge of the bare '*empty weight*' is often lacking and we are forced to employ the figure given in literature. More often than not the weight given applies to the *operational airplane* as it is standing on the tarmac (including seats and furnishings) before any loading is brought on board and before any fuel is pumped into its tanks. A third interpretation of the term may be '*empty weight*' equals '*gross weight minus disposables*'. If the furniture is reckoned to be part of the disposables empty weight is not the same as ready-weight-on-the-tarmac.

Aircraft specifications such as shown for instance by Jane's, usually include '*gross weight*' and '*empty weight*'. The maximum loading capacity of an airliner is the difference between the two:

$$\text{Maximum Loading Capacity} = \text{Gross weight} - \text{Empty weight}$$

As stated earlier, we shall assume that aircraft departing for *long-range* journeys are loaded to maximum capacity and that '*take-off weight*' equals '*gross weight*'.

As we have pointed out, the term '*empty weight*' as quoted in literature should be interpreted with caution as it may include not only the weight of the bare airplane, but also the weight of such additional items as upholstery, chairs and pantry in passenger planes and weaponry in military aircraft. Actually it is the *bare weight of the airframe* without additional provisions that interests us most, because it is an indication of the quality of the structural design of the aircraft. In certain rare cases we can find this exact data in the description of prototypes or the direct accounts of the designers concerned.

To come even closer to the bare structural weight we have introduced the notion of '*own weight*' to mean the empty weight of the aircraft minus the weight of the engines.

$$\text{Own weight} = \text{Empty (or Bare) weight} - \text{Weight of engines}$$

During operations the maximum loading capacity of an aircraft (see earlier) is put to use for different items.

The actual '*load*' carried in passenger planes consists of obligatory items such as crew (with luggage) and variable items such as: fuel plus engine oil and passengers (including luggage), cargo and mail. This leads to the following relationships for passenger planes:

$$\text{Load} = \{ \text{Crew} \} + \{ \text{Fuel plus Oil} \} + \{ \text{Passengers plus Cargo/Mail} \}$$

or in different terms:

$$\text{Load} = \{ \text{Crew} \} + \{ \text{Fuel plus Oil} \} + \{ \text{'Payload'} \}$$

In this formula the weight of stores such as food and drink is ignored (*however, maybe furniture must be included as one more term, depending on the definition of 'empty weight'*). The load shall be less than or equal to the *maximum loading capacity*. If the load exceeds the maximum loading capacity we speak of '*overload*', a condition that is only allowed under special circumstances only.

We assume the {crew} to be always present at take-off with a fixed weight. The variable amount of {fuel plus oil} is determined by the captain of the airplane and depends on the distance to be flown and flight conditions. Taking more fuel may imply taking fewer {pas-sengers} and/or less {cargo/mail}. This trade-off between fuel and payload is here indicated by the symbol $\langle \rangle$.

If the aeroplane is starting at a weight equal to its 'gross design weight', the maximum 'payload' that it can carry is determined by the loading capacity that remains after all other items are deducted from the 'maximum loading capacity'. So 'payload' in this case is the marginal item that remains after all other items (including 'empty weight') have been deducted from the 'gross weight'.

$$\text{Max. Payload} = \text{Maximum Loading Capacity} - \text{Crew} - [\text{Fuel} + \text{Oil}]$$

or:

$$\text{Max. Payload} = \text{Gross weight} - \text{Empty weight} - \text{Crew} - [\text{Fuel} + \text{Oil}]$$

As the amount of fuel determines to a large extent the distance that can be flown it is clear from above equation that for a destination at a maximum distance the 'payload' is at a minimum. In certain instances, such as an attempt to break the long- distance record, the choice may be made to carry as much fuel as possible (in additional tanks) and no 'payload' at all.

Similar considerations hold for military planes like bombers. The loading consists in this case of crew, oil, and bombs, ammunition, other supplies. This gives:

$$\text{Load} = \text{Crew} + [\text{Fuel plus Oil}] \quad \langle \rangle \quad [\text{Bombs plus other stuff}]$$

and:

$$\text{Max. 'Payload'} = \text{Gross weight} - \text{Empty weight} - \text{Crew} - [\text{Fuel plus Oil}]$$

It should be taken into account that the stated 'empty weight' may include or not include military furnishings such as machine guns, gun emplacements and the like.

10. Note on Engines: Gradually More Power (For Less Weight)

(this section based on NACA chronology)

The rate of evolution of long range airplanes was determined to a large extent by the rate engines of sufficient power and endurance could be developed by the engine industry. The following is a chronology of American developments, which in the Thirties culminated in bringing American engines at the top of the list worldwide. (source: NACA)

1920: New aircraft engines included the French Hispano Suiza design 180hp and 300hp by Wright; the Aeromarine 120 and 180; the Packard 300hp and 600hp types and the Lawrance 60hp and 200hp air-cooled engines. (Except Lawrance all in-line liquid cooled engines.)

1921, 700hp aircraft engine having 18 cylinders arranged in three banks of six, tested at Army Engineering Division, McCook Field.

1922, Completion of a 50-hour test of the Lawrance J-1, 200hp radial air-cooled engine, by the Aeronautical Engine Lab., Washington Navy Yard, foreshadowing successful use of radial engines in naval aircraft.

1922, Wright E-2 (Hispano-Suiza) engine operated continuously for 250 hrs at wide-open throttle, demonstrating improved durability of intake and exhaust valves; Navy Bureau of Aeronautics later increased engine suitability tests from 50 to 300 hours of endurance.

1922, Reversible propeller demonstrated by American Propeller Co., at Bolling Field, DC.

1923: Turbine-type supercharger with a gear drive under development at McCook Field.

1923: Navy Bureau of Aeronautics abandons water-cooled engines of less than 300hp with the development of the Lawrance direct air-cooled J-1, 200hp engine. Weight of water-cooling system was usually in excess of 25 percent of the total weight of the engine.

1923: Wright president Frederick Brant Rentschler (1887-1956) purchases the New York Lawrance Aero Engine Corp. and merges it with Wright Aeronautical Corp. and assumes production of their successful nine-cylinder J-1 radial engine. Successive improvements (by Heron?) result in the J-5, known as the Whirlwind, around which Bellanca designs his long-range aircraft.

End 1924 Frederick Rentschler resigns from the Wright Corporation to start his own firm, called Pratt & Whitney.

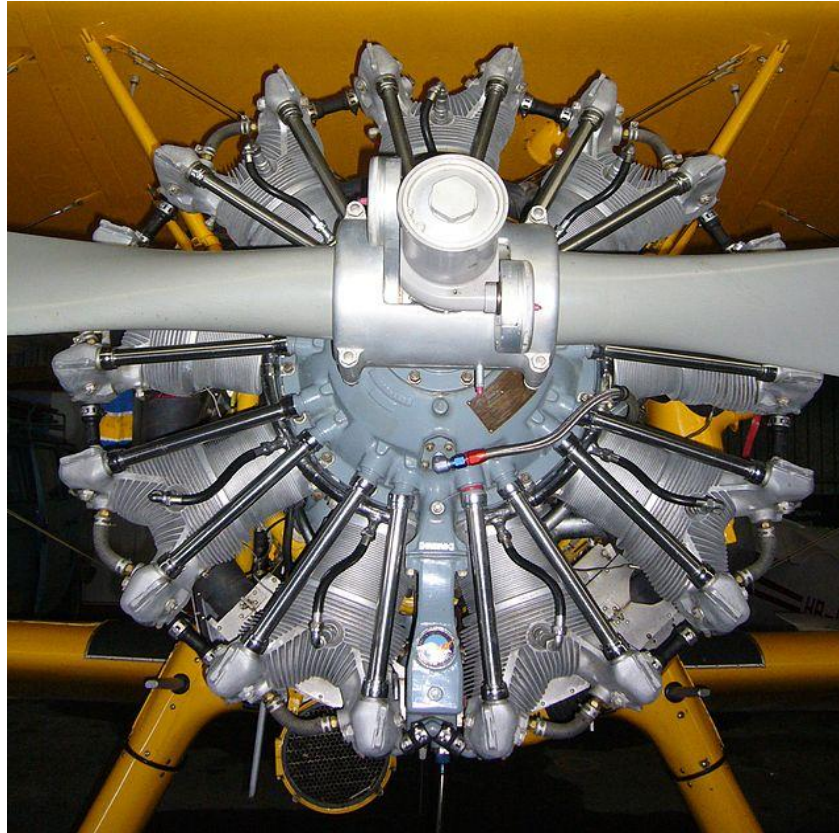
Rentschler was born in Ohio, the son of a German immigrant who owned a foundry. He attended Princeton(?) and during WWI inspected engine castings for Wright-Martin in Jersey. Rentschler stayed with the company after the war, it had been renamed Wright, and pushed for the production of advanced *air-cooled engines*. The company's board refused his suggestions and so in 1924 he left on sick leave to have 'an operation'. In truth he really spent his time seeking financial backing to start his own company. Finding it he resigned at the end of 1924 from Wright, snatching two of their best designers, George Mead and Andy Wilgoos. Together they produced a line of excellent radial engines, the *Wasp*, which soon competed with a sting with the Wright *Cyclone* (see above)... [Longyard]

1924: High-speed photography of sprays produced by fuel injection valves successfully developed and flight study of Roots-type supercharger with DH-4 and DT-2 aircraft conducted at Langley laboratory. Supercharging increased practical ceiling DH-4 from 14,500 to 31,000 ft and DT-2 from 18,500 to 28,000 ft.

1925, April: First trial flight of new *Wright Cyclone* 450hp air-cooled engine in *DT-6* torpedo plane, at Muchio's Field, NJ.

C.L.Lawrance becomes President of Wright Aeronautical Corp.

1926, Febr.: Pratt & Whitney produces first Wasp engine, a nine-cylinder radial air-cooled engine of about 400hp at 1800 rpm.



Pratt & Whitney R-985 AN-1 Wasp engine (source: Wiki)

1926, March: Inventor of sodium-filled valves for internal combustion engines, C.D.Heron, grants exclusive licence for manufacture to Rick Tool Co., later part of Eaton Manufacturing Co.

Sam.D. Heron was a leading air-cooled engine designer. During WWI he worked at the Royal Aircraft Factory in Britain trying to find a way to lighten air-cooled cylinders. With his associates he developed to a practical stage the use of steel liners placed in aluminium cylinders. When political pressure forced the RAF to cease its production capacity and concentrate on pure research, Heron transferred to Armstrong-Siddely and took with him an engine he had been developing. It became the Jaguar under that company's name (1922, 14 cyl. 300hp, see Giger). In the early 1920s he was persuaded to work for the US army at McCook Field. Within a few years he tired of his work for the American government. He found the same lethargy plaguing American military development that he had seen back in Britain, and he was known for snapping out at anyone or anything that delayed his work. In 1926 he joined the *Wright engine Company* where he put to use all the knowledge he had learned while at McCook, **to design the J-5 Whirlwind**, the engine that safely pulled Lindbergh to Paris. In fact, Heron personally checked all the parts that went into Lindbergh's engine. Heron was a mechanical engineer but he knew a great deal about chemistry. He invented the sodium cooled valve, which was an improvement on his earlier salt cooled valve. He pioneered the coating of valve seats with stellite, and helped to perfect the use of high octane leaded fuels. [Longyard]

1927: Air Corps sponsors development of Allison X-type engine of 24 cylinders expected to develop 1400hp. Navy flight-tests radial air-cooled Wright R-1750 and uses Pratt & Whitney Wasp in a number of aircraft.

1927: Superchargers pass from experimental development stage to active service use on radial air-cooled engines, while both Roots-type and centrifugal-type superchargers are being tested on water-cooled engines.

1928, May: Lt.C.C.Champion flies a *Wright Apache* equipped with *Pratt & Whitney Wasp* engine and NACA supercharger to new world altitude record for seaplanes of 33,455ft.

1928, May: First patent on sodium-filled valves for combustion engines issued to S.D.Heron, engineer of the Materiel Division at Wright Field. [see before]

1928, June: Successful tests of superchargers designed to give sea level pressure at 30,000ft at Wright Field. Lt.W.H.Bleakly in *XCO-5* makes flight to 36,509ft and remains there for 18 minutes.

1928: NACA develops cowling for radial air-cooled engines which increases speed of *Curtiss AT-5A* airplane from 118 to 137 mph, with no increase in engine horsepower. Fred E.Weick and associates contributes to the development.

Fred Ernest Weick (1899-1993) was born in Chicago and educated at the Armour Institute of Technology and at the U.of Illinois. His first job was as a draughtsman for the US Air Mail Service. After a stint with the Yackey Aircraft Company he went to work for the Bureau of Aeronautics. In 1925 he joined NACA where he discovered how to improve the cooling of radial engines while reducing their drag. To do this, he invented what became known as the NACA-cowl, which was announced in 1929. The cowl was so shaped as to be a round airfoil. As the propeller blast struck it, it actually created a forward pull. So effective was it that early examples of the cowl were known to pull themselves into the propeller disk! In the early 1930's he began to develop methods to make aircraft much safer. He was an early advocate of tricycle landing gear and tested this layout with the *W-1* light plane (designed and constructed at NACA Langley, 1933). This plane's success earned him an offer from ERCO in 1936 to develop a marketable light plane (*Ercoupe*). [Longyard; for the work of Weick and also Wood, see also Anderson]

1928: C.L.Lawrance becomes Vice President Engineering of Curtiss-Wright Corp, until 1930.

In 1929 Pratt & Whitney joins Boeing, Boeing Transport, Hamilton Standard (the propeller firm), Northrop, Sikorsky and Vought in the powerful holding United Aircraft and Transport. The deal was very profitable to Rentschler. To some of the participating aircraft builders, like Boeing and Sikorsky, the merger was beneficial, because they could share advanced engineering knowledge and contracts.

1929, Feb: Capt. Frank Hawks and O.E.Grubb establishes new non-stop transcontinental West-East record of 18 hrs 22 mins, in a single-engine *Lockheed Air Express*, the first practical application of NACA cowling for radial air-cooled engines.

1930: NACA makes confidential recommendations to industry and military services for best location of engine nacelles, with engines faired into leading edges of the wing, a report based on 1928 research of Donald H.Wood c.s. which influences design of all multi-engine aircraft thereafter.

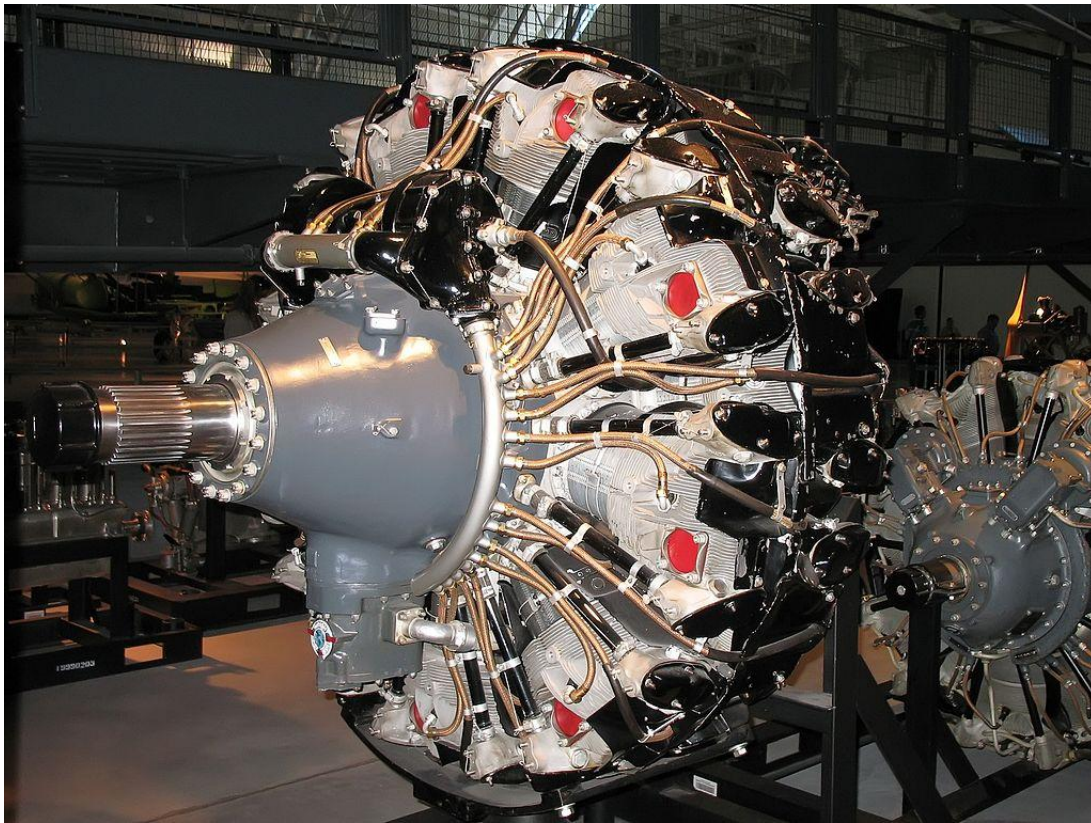
1930: Allison Division of General Motors begins development of V-1710 12-cylinder liquid-cooled engine, the only liquid-cooled engine of US design to be produced throughout WW II, with a power rating which increased in 17 years from 750hp to 2000hp.

1930: C.L.Lawrance resigns from Curtiss-Wright to form Lawrance Engineering and Research Corp. and Lawrance Aeronautical Corp.

1932: Control mechanism for variable-pitch propeller developed under the direction of Frank W. Caldwell, at Hamilton Standard Propeller Co. He receives for this the Collier Trophy of 1933, the propeller being in general use by then.

1939, Experiments with four-bladed controllable propeller on Curtiss *P-36* begin at Wright Field.

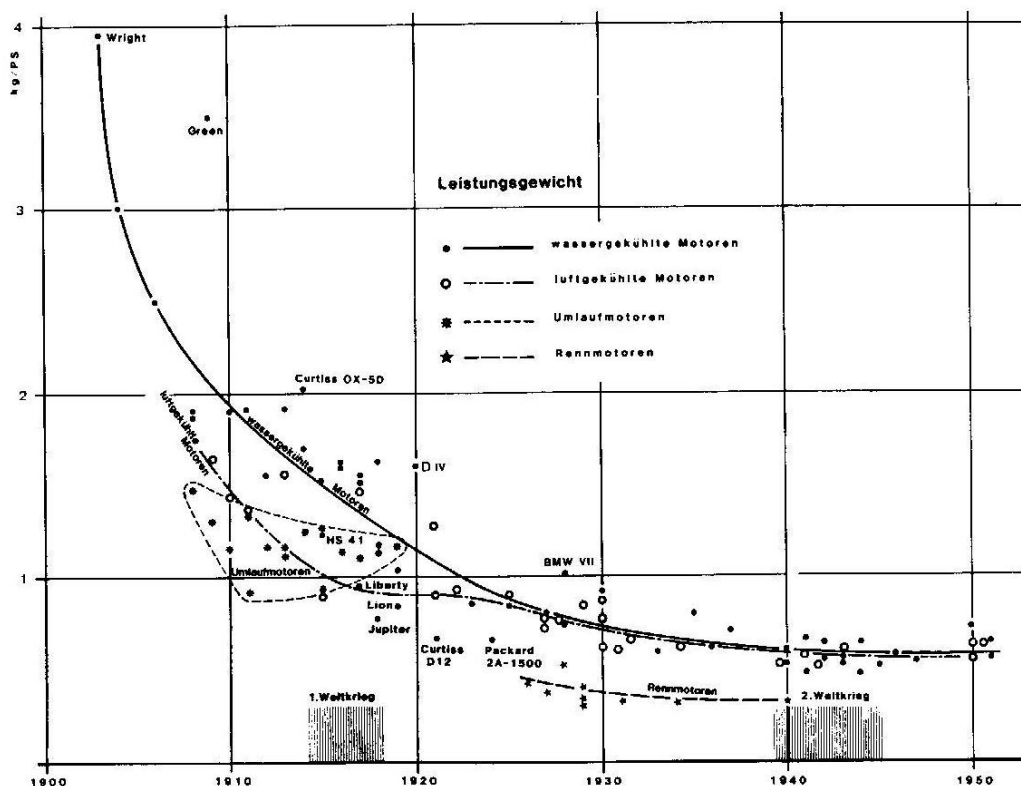
1941, First satisfactory spark plugs (ceramic insulated) for high performance US aircraft engines such as the P&W *R-2800* are ordered in mass production.



2200hp Wright R-3350 Cyclone: four of these masterful engines powered the Constellation

Performance data:

R-3350 Cyclone; Year: 1939; 18 cylinders of 156mm diam; total engine volume: 55 ltr; compr.ratio:6.8
 Start: 2200 hp @ 2800 rpm; Nominal: 2000 hp @ 2400 rpm; weight: 1212 kg; spec.weight: **0.61 kg/hp**

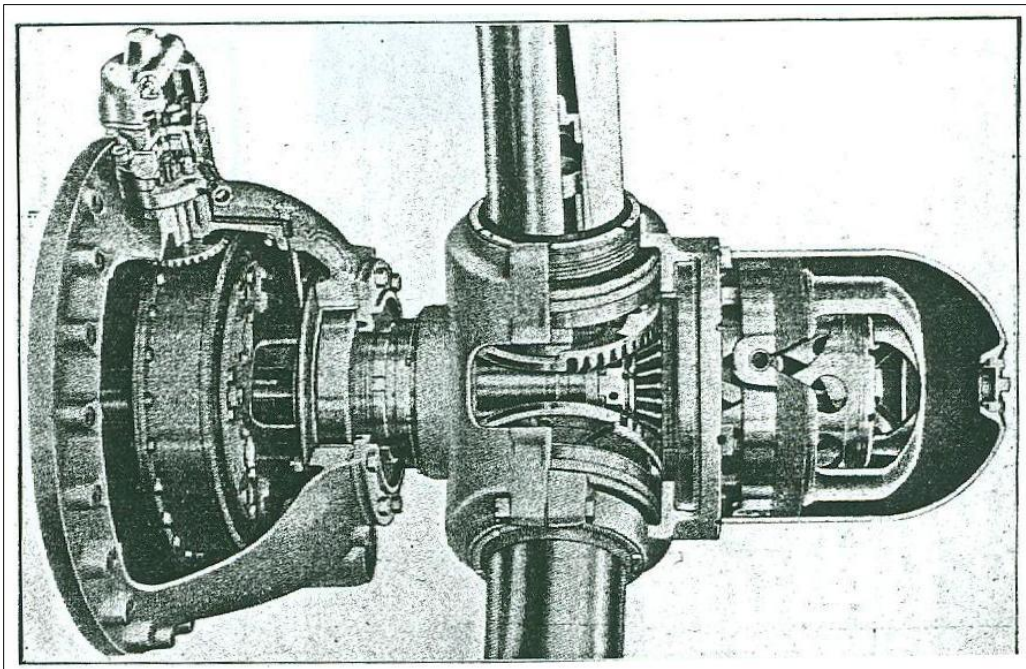


The decrease in 'Leistungsgewicht' (specific weight) from 4 to 0.6 kg/hp from 1903 to 1940 [Giger]

Technically there had been much progress in thirty years. The **radial air-cooled** engine had reached full maturity and dominated the field. There were now two major manufacturers in the United States: Curtiss-Wright and its spin-off Pratt and Whitney. Together they played a guiding role in world aviation. The two firms were locked in a close competition that expressed itself in an unprecedented flow to the market of engines, ever increasing in performance and reliability.

Truly remarkable of course is how powerful aviation engines had become: from a mere 200 hp in 1920 to more than ten times this power in the 1940's. This enormous boost in engine power was moreover delivered with ever lighter installations, as the graph on the previous page shows. The specific weight of the engine came down from 4 kg/hp in 1903 (Wright bros) to an astounding low of 0.6 kg/hp in 1940!. (source: Hans Giger))

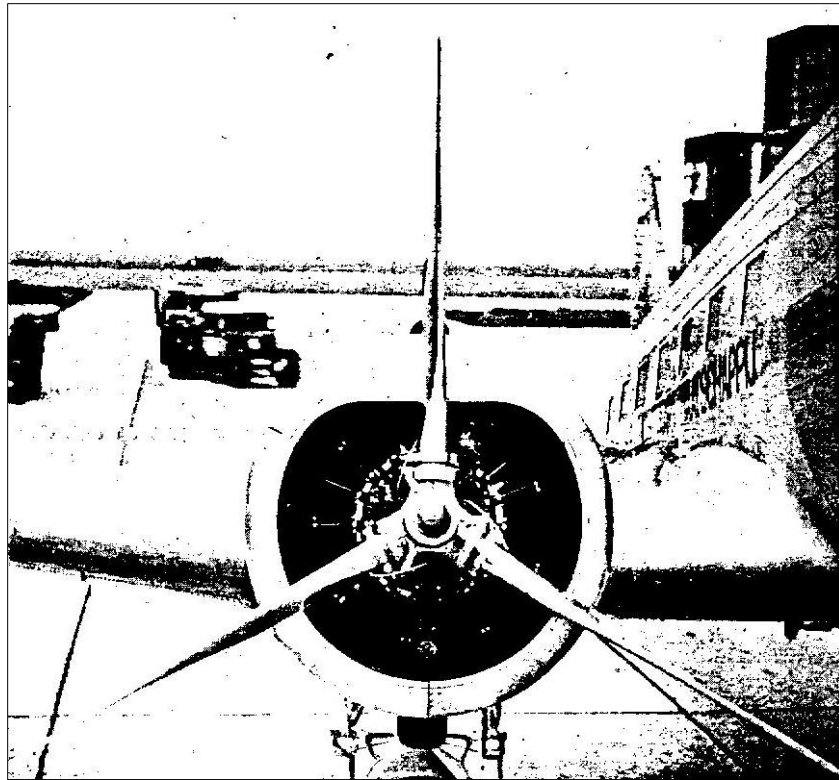
Of paramount importance to the feasibility of safe (long-range) airtravel was furthermore the introduction of *true controllable pitch propellers*, by Hamilton Standard in 1932. This engineering triumph pioneered by *Frank Caldwell*, meant that for the first time true efficiency and safety could be realized in multi-engined airplanes. Fuel economy was increased because the propulsion was delivered by propellers that could be adapted to all flight situations, from maximum at take-off to climbing, cruising and landing conditions.



1932: Hamilton Standard Controllable Pitch Propellers

The availability of powerful engines plus propellers boosted the development of long-range airliners. Important contributions came also from NACA. In 1929 the outcome of exhaustive research led to the definite form of the NACA *engine-cowling*, which was one more factor in establishing the supremacy of air-cooled engines for passenger airplanes. At approximately the same time, US airplane manufacturers were informed (confidentially) by NACA of the proven best location for engine-mounting: in the leading edge of the wing. From now on, also this aspect of airplane design had found its final form.

The picture on the next page shows the propeller of a Douglas DC-2 (of the same generation as the S-42 flying boat in 1932) in *feathered position*. This positioning of the blades made it possible to virtually stop the engine turning over during flight in case of malfunction. (Rigid propellers would continue rotating even when the engines were stopped with the danger of ruining the stopped engine or even causing fire. The windmilling airscrew would also add considering air resistance and make it more difficult to reach a distant airport.)



DC-2: propeller in feathered position; NACA cowling; engine in front of wing



Home at last at Schiphol, Amsterdam

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