Aluminum Alloy vs Carbon Fiber for rigid airship frame

Table of Contents

In the golden age of airships, the frames of the rigid airships used Duralumin or even Alclad (2000 series alloys). In the present day, the internal frame of the **Zeppelin NT** uses Aluminum Alloy (AA) girders, Carbon Fiber (CF) trusses and Kevlar cables. However, the structure is hermetically enclosed in a helium envelope, in a “semi-rigid” layout. **Pathfinder 1**, a true rigid, uses CF tubes joined in a geodetic frame by titanium hubs. **Flying Whales** plans to use a CF frame made of triangular truss girders. The clear objective is to build an aircraft with the lowest possible mass, but that modern approach comes with new challenges.

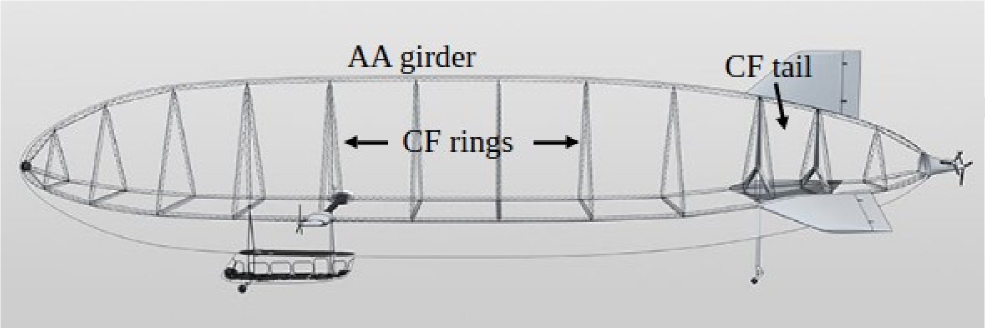

Figure 1: Zeppelin NT has three main AA girders, CF “rings”, Kevlar cables and a CF reinforced tail section

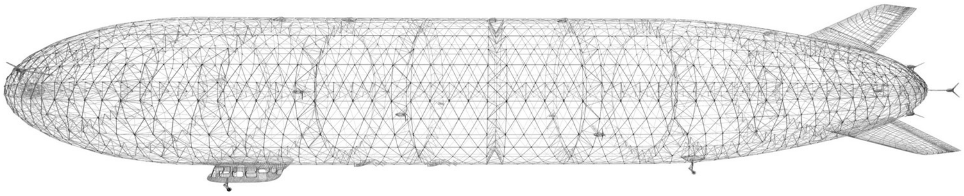

Figure 2: Pathfinder 1 is made of CF tubes joined by Titanium hubs

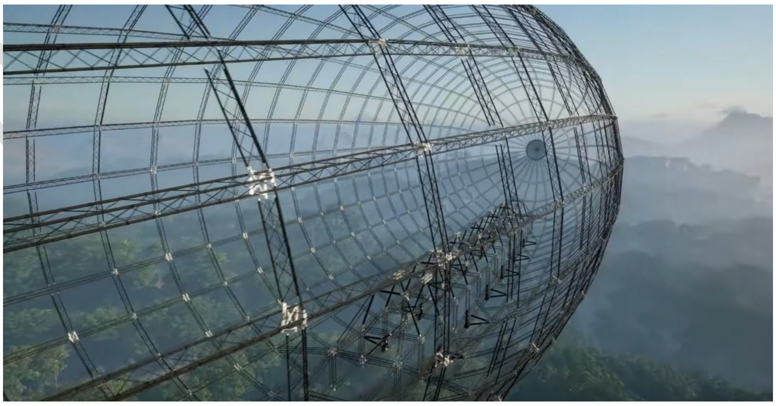

Figure 3: Flying Whales aims for an all-CF truss structure

Weight reduction

Compared to AA, CF generally has a 2-4 times higher strength-to-weight ratio and a 2-3 times higher stiffness-to-weight ratio. The technology emerged in the 1950's and 60's and sounds like *the* straightforward improvement for modern airships, on a par with Mylar / Nylon / Tedlar replacing goldbeater' skin for gas bags.

Fibers orientation

AA properties are defined from the start by the chosen type of alloy (2xxx series, 7xxx series, …). The alloy is isotropic and calculations are straightforward: the thicker, the greater the strength and stiffness. Sourcing is also straightforward.

A CF material is always custom-made for a particular purpose. The structural engineer must discuss his need with the CF manufacturer, for example to choose the correct fibers orientation of a multi-ply CF skin. The resulting strength and stiffness of the material depend on that orientation. Also, it is possible to design the CF material in regards to expected load and reduce its weight further.

In the case of an airship frame, the longitudinal girders must participate in the bending moment and resist shear and bending forces from the airship payload and buoyancy, all of that in the vertical plane. But they must also resist the radial pressure from the gas bags and the dynamic forces met in flight. It seems difficult to orient their fibers in a specific way. The same goes for rings, which must work in compression to stiffen the hull, but also receive forces from the gas bags: radial again from gas pressure, lateral from the longitudinal movement of gas bags during the flight…

In other words, it would be safer to have most of those CF elements behave in a quasi-isotropic way. This is particularly true due the lack of real-life experience and existing data. Note that for a triangular truss girder made of CF, the struts working in tension/compression may still be optimized. Composites may also be used efficiently in lieu of historical steel tension cables, indeed CF is at its best under tensile loads. Zeppelin NT chose that option, with aramid cables. In that case, those tension elements (tubes or cables) can be optimized with a "0 degree" angle of the fibers.

Practical weight reduction

According to literature, the weight reduction to be expected using CF compared to AA is in practice around 30%, up to 40% (examples: car components, rotor blades, wing…). On top of that, the structure stiffness is easily doubled: at equivalent weight, CF is 2 to 5 times stiffer than AA. Better stiffness improves buckling resistance and further reduces the need for cross-cables and fittings.

As shown in the table below, the weight gain from CF could correspond to a **~2.5 multiple** in payload for a Hindenburg class airship. We can consider that modern design techniques (CAD) could already improve the weight of the historical frame through better design and sizing of components. The total weight gain from CF then decreases proportionally. However, without any fundamental change in shape, the order of magnitude remains probably around a potential +100% / +150% payload increase.

Table 1: Payload increase using Carbon Fiber

	Hindenburg airship	**Hindenburg with CF frame**
Volume and total lift	Theoretical lift at sea level: 200.000m^3 H_2 => 228.4 t (Literature indicates ~235 t)	Similar volume of 200.000m^3 => similar ~230 t total lift
Frame weight, without fuel, useful load and payload, but including gas cell weight, cables, gondola, tail…	Knut Eckener says: **130.1 t** - 4 x Engines DB602 = - 8.8 t - Gas cells estimate = - 2 t - Cover estimate = - 9 t Total: **110.3 t structure**	Assuming a conservative 30% weight reduction: **110.3 x 70% = 77.21 t**
Take-off weight	Knut Eckener: 242.4 t Literature: 215 t	Similar aim
Payload	**24.3 t** including: 8.3 t for 55 passengers 12.7 t for mail 3.3 t humidity	Extra payload allowed: 110.3 - 77.21 = **+33.1 t** Total practical payload becomes: 24.3 + 33.1 = 57.4 t **=> a 136% increase**

Durability

Corrosion

CF composites are inert and immune to corrosion from moisture or chemicals. However, they act as a cathode when coupled with metals in the presence of an electrolyte, promoting galvanic corrosion in the metal (acting as anode). For example, in contact with aluminum, CF accelerates severe pitting and material loss due to Al’s high anodic activity, especially in moist or saline environments. Proper insulation, coatings, or sealants are essential to mitigate galvanic corrosion. Titanium (Ti) is more resistant than AA due to its stable oxide layer, and only experiences minimal galvanic corrosion when paired with CF. Note: Ti also compares favorably to CF in tensile strength and elasticity. If not for the cost, Ti is the ideal metal for structural components joining CF elements.

On the other hand, AA are prone to corrosion due to their reactive nature, but they naturally form a protective oxide layer that enhances resistance to atmospheric corrosion, moisture, and mild chemicals. In harsh conditions like saltwater or acidic environments, if the oxide layer is compromised, Al alloys can experience pitting, crevice corrosion, etc. For aerospace applications, AA require coatings or anodizing to improve corrosion resistance.

UV resistance

AA are by nature UV-resistant. In contrast, UV exposure degrades CF composites by affecting the polymer matrix (typically epoxy). Prolonged UV radiation breaks down the epoxy’s molecular bonds, causing surface resin degradation, micro-cracking, and yellowing. This reduces surface strength and stiffness slightly but does not significantly affect the carbon fibers themselves, which are UV-resistant. In the case of an airship frame, the CF main frame would be enclosed in the Tedlar envelope. Pigmented Tedlar is UV opaque and UV-resistant, removing the need to coat the CF. Of course the external structure, in particular the control surfaces, would need to be protected, but the focus of this document is really the main ellipsoid structure.

Thermal management

Aerospace-grade CF composites, typically using high-performance epoxy or polyimide matrices, have moderate heat resistance and are inferior to AA in this regard. Standard aerospace CF with epoxy matrices degrades above 120–200°C, with the matrix softening or breaking down, even if the carbon fibers remain stable up to ~1000°C in inert conditions. Advanced polyimide-based CF extends heat tolerance to ~300–400°C. In aerospace applications, CF is suited for moderate temperature environments but requires thermal barriers or coatings near high-heat sources like engines. Compared to aluminum alloys, which soften above ~400°C, the heat resistance of CF is limited by its matrix.

In practice, for an airship frame, common epoxy satisfies thermal management criteria (the case of fire is treated below). Concerning critical areas, the turbofans of Airbus planes are housed in nacelles made up of 60% CF. Certainly, the engines areas of an airship can safely use custom CF components, either in-hull or outboard.

Fatigue

CF outperforms AA in fatigue resistance for aerospace applications, thanks to its high stiffness (~140–230 GPa vs. AA’s ~70 Gpa). CF with multi-angled layers resists crack propagation longer. It can endure millions of cycles at high stress without failure, while AA develops micro-cracks earlier, especially in high-strength grades.

The fatigue behaviour of CF is complex since composites fail by a collection of damage mechanisms including; fiber breakage, matrix cracking, fiber-matrix debonding, delamination and the effect of shear-induced diffuse damage. CF’s fatigue life depends on matrix integrity and layup; delamination can occur under impact or poor design. AA, being isotropic, is more predictable but requires thicker sections to match CF’s fatigue performance, increasing weight.

On first approach, fatigue concerns in airships are significantly less severe than in airplanes due to lower cyclic loading and structural demands. An airship never really lands, it hovers, and the cabin is not pressurized. It remains at low altitude, and moves comparatively slowly through atmospheric changes in temperature, humidity, etc. As a consequence, the stress on its structure does not see a dramatic deviation from median stress like in aircraft.

The Airbus A350, with over 50% CF, undergoes full structural inspections every 12 years, compared to 8 years for the mostly AA-built A380. The service life is 20–25 years in both cases. CF provides here a significant advantage for the A350. However, as said, rigid airships experience far less structural stress. They may not require full inspections before decommissioning. In practice, fatigue knowledge and evaluation is also based on experience, “*The service history of airplanes of similar structural design*” (FAR 25.571). This knowledge is still lacking for rigid airships.

Fire safety

In the event of a fire, composite materials react in a very different way compared to metals:

- **Thermal Behavior**: CF composites have lower thermal conductivity (~0.5-10 W/m·K) than AA's (~150-200 W/m·K), slowing heat transfer and retaining heat longer in localized areas. Epoxy-based CF degrades at ~120–200°C, with matrix breakdown releasing smoke and toxic gases (e.g., carbon monoxide, hydrogen cyanide). Polyimide matrices extend tolerance to ~300–400°C. Metals like AA melt at ~660°C but conduct heat away, avoiding localized hot spots.
- **Fire Response**: CF composites char and burn layer-by-layer, losing structural integrity gradually. The matrix combusts, weakening the fiber network, while AA maintains strength until melting. Composites may release fibrous debris, complicating fire suppression, unlike metals, which deform or melt uniformly. The matrix (and some fibers) may be prone to combustion, smoldering, and re-ignition even after the initial fire is extinguished.
- **Safety Implications**: Composites require fire-resistant coatings or intumescent layers to delay burning in aircraft. Metals, while heavier, provide predictable failure modes in fires, aiding design for evacuation and containment.

Crash landing

This fire behaviour has a big implication on large airships design. FAR 25.xxx rules do not cover those airships-specific scenarii yet, we must use common sense.

During a crash, the CF structure above and around the passenger area, located in the keel, would certainly collapse, “caging” the cabin. Also that structure – a large portion of the total airframe - would require flame retardant resin. If the crew is further spread around the ship, specific areas require compliant CF or separate fire-proof shelters. In the case of the Hindenburg disaster, the occupants were prevented from fleeing the scene by the burning fuel spread around the wreckage. A few had to find a way through the collapsed Duralumin structure, Cpt. Max Pruss comes to mind. No doubt a destroyed airframe can block an exit route, see picture below.

Crash dynamics is very different with airship vs. airplane. Due to low speeds and static lift, many occupants can survive a hull loss. Crash survivors should not have to go through a burning CF wreckage or be stuck in such a wreckage releasing toxic fumes. Note that even an all-AA structure, which does not burn or release fumes, would still “cage” the cabin and create panic. Solutions must be found to evacuate passengers safely.

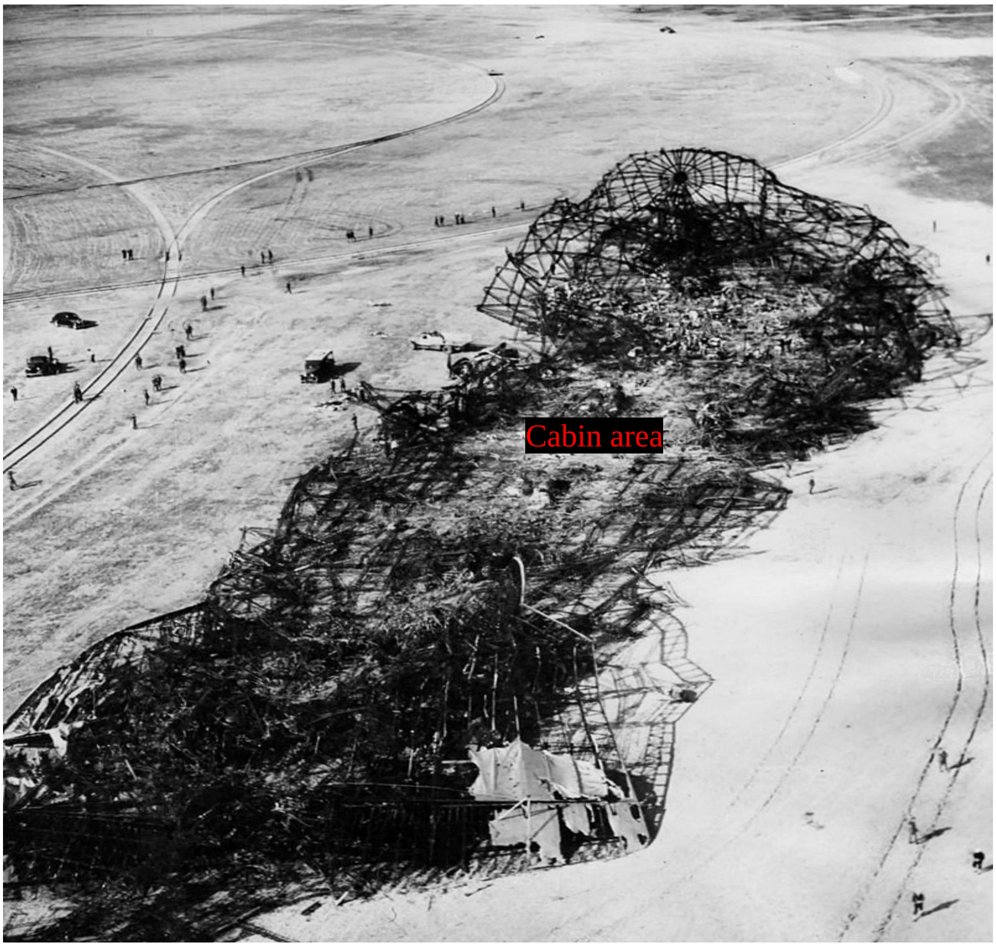

Figure 4: Wreckage of LZ-129 at Lakehurst in 1937, cabin area at center

Fuel system

In large airships, the fuel is distributed along the entire keel, with numerous fuel lines. Here again, all the surrounding CF structure probably classifies as *fire zone* and should be compliant to FAR 25.865:

Essential flight controls, [...], and ***other flight structures*** *located in designated fire zones or in adjacent areas which would be subjected to the effects of fire in the fire zone must be constructed of* ***fireproof material*** *or shielded so that they are capable of withstanding the effects of fire.*

Hydrogen as a lifting gas

When talking about fire, the elephant in the room is of course the possible use of H_2 as a lifting gas. How would CF react to a hydrogen fire? H_2 ignites at approximately 200–250°C and its flames can reach 1000-2000°C due to hydrogen's high combustion energy. In the case of the LZ-129, the H_2 burnt in ~30-37 seconds, moving along the longitudinal axis at 7- 8 m/s. The gas released by the aft cells left upwards, but the ship immediately tilted backwards. The gas of the midships cells burnt through the front cells. The Duralumin frame either melted away, bent, or kept its integrity until the ground contact, where it collapsed under its own weight after a while.

Figure 6: After ground contact, the front structure is mostly intact

A CF frame would face the same gradient of fire effects. CF produces more dramatic consequences than AA though. For composite elements facing intense heat, over 1000° for several seconds, even the best resins vaporize and release toxic fumes. The carbon fibers themselves can oxidize. For less intense heat, the resin can fail without vaporizing, and broken pieces of composite would fly around and fall on the ground. Some pieces would be burning, smoldering, or not catch fire at all. Contrary to the Hindenburg catastrophe, a lot of toxic fumes would be released:

- **Carbon Monoxide (CO)**: Binds to hemoglobin, reducing oxygen transport. Inhalation causes headaches, dizziness, confusion, and, at high concentrations (>1000 ppm), unconsciousness or death within minutes.
- **Hydrogen Cyanide (HCN)**: Disrupts cellular oxygen use. Low exposure (50–100 ppm) causes nausea, dizziness, and breathing difficulty; higher levels (>200 ppm) can be fatal in minutes due to respiratory failure.
- **Volatile Organic Compounds (VOCs)**: Cause irritation to eyes, nose, and throat, and prolonged exposure may lead to neurological or organ damage, though less immediately lethal.

Besides fire, gas bags can leak. In which case, a flammable gas would be in direct contact with the CF frame. It's unclear if we want the entire structure to be declared as *fire zone*, as fire zones do include areas in which "flammable gas can leak". Then, the entire composite frame would need to use coating or flame-retardant resins, adding consequent weight to the structure.

Lightning

Historically, the large airships flew through storms, even if the captains tried to avoid them. In a 1960 interview, Max Pruss states that on trips to South America airships were **regularly** struck by lightning, but remained unharmed. Crews of military airships (WW1) also reported numerous strike events. We must assume that flying below cumulonimbi with a massive 250m airship attracts lightning leaders like there is no tomorrow. But thanks to their Duralumin frames, and the outer cover doped with Aluminum and bonded to the frame, the large airships were in practice a Faraday cage. A lightning bolt would simply hit the ship and continue safely towards the ground.

CF’s conductivity is nowhere close to metal’s. For that reason, lightning strikes are a serious concern for CF components in aircraft and wind turbines. Several solutions are currently in use by the CF industry. They consist more or less in adding some metal to the CF elements. This spreads the electrical charge and leads it away. It comes at the cost of added weight and new issues.

Lightning regulation

The regulation is common sense and would apply to airships as is. **FAR 25.581** regarding Lightning protection states:

(a) The airplane must be protected against catastrophic effects from lightning.

[...]

(c) For nonmetallic components, compliance with paragraph (a) of this section may be shown by—

(1) Designing the components to minimize the effect of a strike; or

(2) Incorporating acceptable means of diverting the resulting electrical current so as not to endanger the airplane.

Airbus case study

Airbus is one of the most knowledgeable company when it comes to CF in aircraft, with R&D teams working on the subject for years. The A350 now includes 50% of CF parts. But the company still faces CF-related problems. For example, the paint on the A350 fuselages cracks, peels, or blisters, exposing the underlying expanded copper foil mesh designed for lightning protection. This was first noticed in 2020 when a Qatar Airways’ A350 was stripped for a new World Cup livery. Qatar Airways then sued Airbus for $ 618 million plus $ 4 million/day per grounded jet. The issue now seems resolved, but is shows that the CF technology is still young. Even well-funded companies with expert knowledge can still make costly mistakes. In any case, it’s not because the problem is getting solved for airplanes that it is solved for airships.

Airplanes present large rigid surfaces, be the wings or the monocoque cabin. When lightning strikes a CF wing with electrical protection (e.g., embedded copper or aluminum mesh, as used in the Airbus A350), the electricity is diffused over a **large conductive area**. It prevents damage and ensure safety. The size of this diffusion area depends on the Lightning Protection System (LPS), strike intensity, and wing design. Specific details for the A350 are as follows:

- **Typical Diffusion Area**: For a lightning strike (~200,000 amps, Zone 1A or 2A per **FAR 25.581**, see figure below), the current spreads through the conductive mesh (e.g., Heavy Expanded Copper Foil, HECF, or Perforated Copper Foil, PCF) over an area typically ranging from 1–5 m^2 on the wing surface. This is based on the mesh's conductivity (~10^6 S/m for copper) and the need to dissipate energy without arcing or overheating the CF.

- **Airbus A350 Design**: The A350's CF wings (>50% CF) use aluminum or copper mesh (e.g., Hexcel's IWWF or Cytec's Surface Master) to conduct lightning current across the wing skin, preventing localized damage. The diffusion area is engineered to cover large panels (e.g., upper/lower wing covers, ~32 m x 6 m). But the effective current spread is localized to ~1–3 m^2 around the strike point, depending on mesh density and bonding.
- **Factors Affecting Area**:
  - **Strike Zone**: High-energy zones (e.g., wingtips, Zone 1A) require denser mesh, spreading current over smaller areas (~1 m^2) to avoid burn-through. Lower-energy zones (e.g., mid-wing, Zone 2A) allow broader diffusion (~3–5 m^2).
  - **Mesh Design**: A350's HECF/PCF ensures low resistance, spreading current efficiently. Improperly installed mesh (e.g., 13 A350s in EASA AD) may reduce diffusion, risking fuel tank ignition if near fasteners.
  - **Inspection Post-Strike**: Damage (e.g., pitting, burns) is typically confined to ~0.1–0.5 m^2 at the strike point, but inspections cover larger areas (~2–5 m^2) using drones, ultrasound or thermography to check for delamination or mesh damage.

From this precise information, we note that a lightning strike diffuses on a flat (circular) surface which is **at least 1 m^2, up to 5 m^2**. Neither the truss structure of Flying Whales nor the tube structure of the Pathfinder 1 present such circular strike surfaces. Airship don't even have properly defined "lighting zones", which serve as a reference for the design of lightning protection systems.

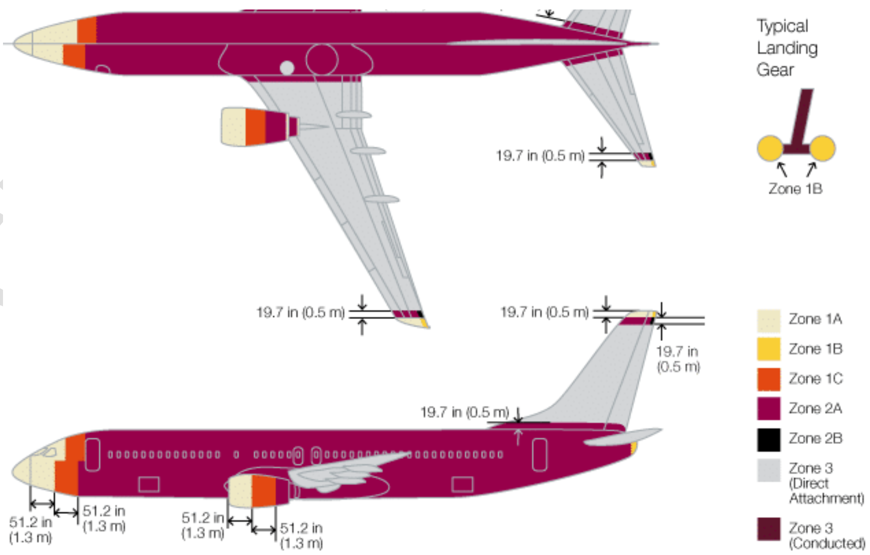

Figure 7: Common lightning zones on airplanes

LTAR case study

The rigid structure of the Pathfinder 1 can be divided into different areas:

- A small nose cone, made of aramid and carbon fibers.
- The rest of the geodetic structure, made of 10.000 CF tubes joined by 3.000 Titanium hubs.
- The gondola and the tail fins, made respectively of glass and carbon fibers.

By comparison to airplanes, we can expect the ship to be hit by lightning at the **nose**, or generally around the bow. At an altitude of 300 m, an airship is more likely to encounter cloud-to-ground lightning channels. Generally, we can expect lightning to strike on the **upper bow** area, as it happened historically. If we look at close-up pictures of the Pathfinder 1, it seems to have some antennas in that area. The author does not know if those are antennas (favored opinion) or lightning rods. It is always possible to add many rods on the ship, at the cost of a drag increase.

Strike on the nose

The Kevlar nose is sufficiently large and can integrate a typical LPS. There is no difference with an aircraft nose, a well-defined zone 1A (high initial current with low sweep). A lightning entry point is unlikely to create any serious structural damage. But contrary to airplanes, the electrical charge can not be conducted away “along the cabin”. What happens then is unclear to the author. The cone may be bonded to other elements, for example a cable, to conduct the lightning away from the ship. The gondola, which would channel ground-to-cloud strikes, presents the exact same issue.

Strike on a CF tube

In this scenario, the strike hits one of the 10.000 CF tubes. Pathfinder 1 uses roll-wrapped tubes made of “aerospace-grade” CF prepregs. The meaning of *aerospace-grade* is unclear though, as it does not say if the tubes integrate a LPS wiring or not. LPS meshes must come as **a top layer** of surfaces made of multi-ply CF. Technically, the roll-wrapping process **does not allow** for adding such a protective layer. Neither does filament winding, which is the planned carbon fiber technology for the successor of the Pathfinder 1. Adding a proper LPS to the tubes may be possible through never-done-before R&D. The author believes that, currently, the tubes of Pathfinder 1 are left bare, without LPS.

Historically, extensive lightning tests have been conducted for **flat**, bare, CF surfaces, typically wings. Those large surfaces are either non structural (wing skin) or would resist a strike due to their size and design. Here, the tubes are **narrow structural** elements, 3” in diameter and 12 feet (3.65 m) long at best. Even protected, they **don’t allow** for a diffusion area of 1 m²: since a 3” tube has a circumference of 25 cm, a cylindrical surface of 1 m² would require a 13.1 feet length (4 m). Even then, the elongated shape does not prevent heat concentration. On top of that, the tube acts as a container, trapping the air inside. That air can undergo dramatic pressure changes due to lightning heat, resulting in an explosion. This is a known phenomenon with antennas, fishing rods, etc.

Figure 8: Lightning strike on a CF fishing rod

Geodetic designs are resilient, and Pathfinder 1 may afford one, or a few, damaged tubes. The ship would still need grounding and immediate inspection. Inspection is key to find entrance and exit points, pinholes, delamination, etc. Of course, it is no easy task to climb up the CF frame and check each tube with ultrasound. The author believes that those issues are avoided by restricting minimum weather to a *sky clear of clouds*, which has of course a huge operational impact.

Strike on a Titanium hub

A strike on a Titanium hub may be even worse than a tube strike. The issue is again the small dimensions of the component. The extreme heat of a lightning strike will try to diffuse towards the CF tubes through the adhesive joints (see figures below). The difference of conductivity between Ti and CF, even lightning protected CF, almost guarantees arcing in the micro-gaps created by the adhesive. Arcing may extend around the hub, and we must remember that those come in direct contact with the gas cells :

- Tube ends (several per hub) may suffer damages **hidden** under the Ti slot: debonding of the adhesive, CF delamination, etc. Those damages would be very hard to find and inspect. It's unclear to the author if for example sonography would work through the Titanium layer.
- A tube end may simply smolder and break, endangering structural integrity.
- Again, the air trapped in the CF tube may heat up violently, this time locally contained by both the Titanium slot and the CF. This may result in an explosion more powerful than a mid-tube overpressure.

Lightning does not always produce thunder. Since the gondola is located under its belly, the ship could be struck without anyone noticing. Should the 3000 hubs be regularly inspected for hidden damages? Also, how to inspect the carbon fiber inserted in the hub slots? Replacing a tube is not as straightforward as removing rivets on an AA girder. The author does not know how LTAR has planned to solve those problems.

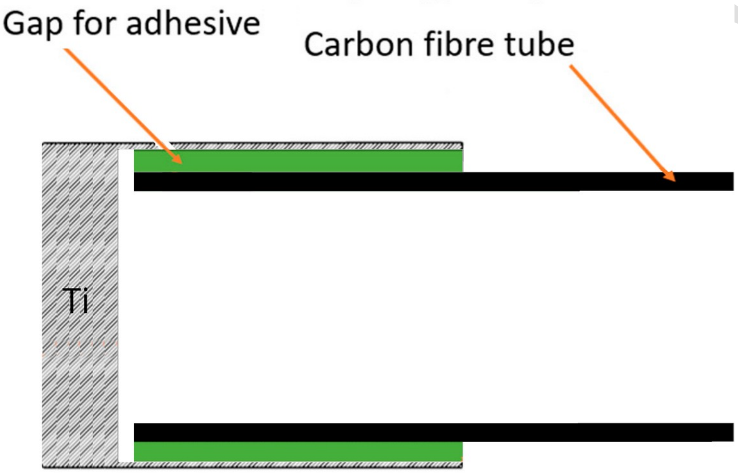

Figure 9: A Titanium hub / Carbon fiber tube joint

Figure 10: Tube inserted into a Titanium hub (compositesworld)

Note

The focus of this paper is the “main frame” of a rigid airship. The numerous engines of the Pathfinder 1, its tail fins, and other protruding elements present separate problems.

Sustainability

At present, airships don't exist as a mean of transportation. The few blimps flying around the world have zero impact on the environment, and a few rigid airships would not change the equation. Only **mass production** would make a significant impact on the environment.

Still, we may have a quick look at the sustainability of Aluminum Alloy vs Carbon Fiber. Potential investors may be attracted by the "green" factor of airships. On the customer side, the Millennials generation is particularly worried by its impact on the environment.

Simply said, AA wins easily:

- The CF manufacturing process is very energy intensive: ~20–30 kg CO_2/kg compared to half that number for AA, at ~10–15 kg CO_2/kg.
- CF manufacturing produces more pollutants than aluminum mining and refining, including long-lasting pollutant and micro-plastics. Meanwhile, new techniques and a more mature AA industry is constantly reducing its waste output, in particular the infamous Red Mud.
- AA has a much larger supply chain, and its production is more efficient by economy of scale. Currently, CF simply does not scale, it remains a handcrafted process.
- AA can be recycled at around 95%, at 5% of the original energy cost, without generating novel pollution. None only could a frame be recycled at end-of-life, as it happened for almost all historical airships, but the necessary aluminum could be sourced as recycled aluminum to start with! Recycled AA has the same characteristics than the original AA. On the other hand, CF recycling exists only at rate of 7 – 10%, and has a different meaning. The process aims at retrieving the fibers by burning the resin, which generates pollutants, or at grinding the CF into filling material. CF is downcycled, meaning only lower quality products can be produced from the recycled material.

Costs

Producing a 100 t airship frame using aluminum alloy (AA) versus carbon fiber (CF) involves significant cost differences. For AA (e.g., 7075), material costs are ~$3–6/kg, totaling say ~$ 600,000 for 100 t. Specialized labor, including machining and welding, adds ~25% of production cost ($ 150,000), with total costs around $ 750,000.

For CF, material costs are ~$20–50/kg (projected to rise 10–20% by 2030 due to increasing demand in aerospace and automotive), totaling say ~$ 5 million. Labor, requiring specialized layup and autoclave curing, contributes ~40% (~$ 2 million), yielding total costs of $ 7 million.

This first principles approach shows that a CF frame would be an order of magnitude more expensive than an AA frame. But from a previous paragraph, the weight reduction of CF allows double the payload (2x to 2.5x factor). A quick and naive projection, below, shows that over a 20 years period, the weight reduction from CF easily compensates the initial capital cost.

Table 2: Aluminum Alloy vs Carbon Fiber costs

	AA frame	**CF frame**
Capital cost of airship	$91 m	$100 m
Including rigid frame cost of	$1 m	$10 m
Projected revenues, CF weight gain factor = **2.2**	100 passengers * $20 k Revenue per year: 10 trips/y = $20 m	220 passengers * $20 k Revenue per year: 10 trips/y = $44 m
Time to break-even, assuming 25% profit	91/20 * 1/.25 = 18.2 years	100/44 * 1/.25 = 9.1 years

Maintenance costs

As noticed before, superior fatigue resistance of CF decreases the *need* for maintenance. In the same time, it increases the *complexity* of maintenance, in particular in case of accident or suspected incident. For example, AA cracks are visible with the naked eye while CF delamination requires equipment and more complicated processes. At low scale of production, without any economy of scale, those factors probably cancel each other.

Let’s make a quick and naive estimation of maintenance costs, to find an order of magnitude. Maintenance costs of a regular airliner (A321) are 25% of the production cost. Keeping this 4:1 ratio and the numbers of the table above, the maintenance of the CF frame could cost $ 2.5 m over lifetime, while the AA frame maintenance would cost $ 250.000. Again, this difference is not significant compared to the weight advantage of CF and associated revenues.

Conclusion

If the choice between Aluminum Alloy and Carbon Fiber was easy, the structure of the A350 would not have a roughly equal split of each. Neither would jet fighters have a mix of CF, AA, Titanium, and glass fiber.

The table 3 below shows that Carbon Fiber is generally more complex and presents yet-to-solve safety issues. It shines first and foremost with its weight advantage, at equivalent mechanical properties. In the end, the airship structure must be considered in the general business case.

The payload is often the most important factor of air transport, but it’s not systematic. For example, CF would allow an increase of passenger capacity, but each passenger would then have less space. If the airship is intended for luxury cruises, the idea is certainly not to revive the “sardines in a can” feeling of airliners. In a luxury context, empty space is valuable, as it is for private jets.

When it comes to cargo transport, a company like Flying Whales obviously wants to carry as much cargo as possible. They chose an all-CF truss structure to maximize the weight advantage, but we can observe some realities:

Table 3: Sum-up Aluminum Alloy vs. Carbon Fiber for a rigid airship structure

	Aluminum Alloy	**Carbon Fiber**
Weight gain		✅ Weight saving that doubles the payload.
Durability – Corrosion	Mature industry with well-known solutions (anodization, coating).	Excellent corrosion resistance. The issue is the junction metal/CF (galvanic corrosion), requiring the use of expensive Titanium.
Durability – UV	No factor	Would be protected by the UV resistant hull envelope.
Durability – Thermal	No factor	No factor
Durability – Fatigue	Nowhere as relevant as airliner fatigue, which is well understood.	Excellent fatigue resistance but complex inspection.
Fire – Crash, Fire zones, H_2	✅ Well understood behavior, yields by bending before fracture, does not add "fuel to the fire".	Requires expensive high-grade flame-retardant resins, breaks suddenly, adds to the fire (toxic fumes…)
Fire – Lightning	✅ Naturally immune	Requires Lightning Protection meshes, which add weight back in. Implies smart design to avoid concentration effects. Not mature.
Sustainability	✅ Clear winner, but sustainability is irrelevant outside mass production.	The CF manufacturing and recycling industry has a long way to go. Better fatigue resistance may improve components lifetime.
Costs	✅ 10X cheaper if we consider only the rigid structure.	Expensive processes.
Generally	Has the advantages of a mature technology and good natural behavior in case of accident.	Has the huge advantages of better strength-to-weight and stiffness-to-weight ratios.

- they propose to use "CF winding" for their structure, which can only mean a structure made of CF wound tubes. To the author's knowledge, LPS do not exist to protect such tubes.
- After 13 years and $ 312 m invested, FW does not have any flying ship. They are currently planning a fourth round of $ 150 m to go to production.

Cargo operation does not easily allow to evade bad weather. Flying Whale's technical video shows a truss structure made of CF tubes, which brings the same concerns than the tubes of the Pathfinder 1, in case of lightning strike. The business case of the Pathfinder 1 remains unclear, even if LTAR advertises a disaster relief operation. As of today, the Pathfinder 1 prototype has been equipped with a passenger gondola, not a cargo bay.

The Zeppelin-NT gives a hint on an elegant design which, like the A350, tries to harness the best of both worlds. The three main girders are made of AA, easy to produce and by nature lightning resistant. The blimp’s “rings”, in fact 12 triangular segments, are made of CF with Titanium hubs. Those rings work in tension together with aramid bracing cables, which is the ideal load for composite materials. The tail area is reinforced by another composite structure, again ideal in this scenario. The gondola is made of insulating glass fiber, protecting the passengers against lightning effects. Finally, the fins are also made of composite, in which case the CF know-how is well established in the aerospace industry. Despite the apparent complexity of mixing all those technologies, a prototype was produced within five years. Even if, 25 years later, the Zeppelin-NT is not a business success, it still flies. However, tourists have noticed that it only flies in clear-of-clouds weather, with many last minutes cancellation from the company side.

For a larger airship (Hindenburg class), the economy of scale would make a AA/CF mix more viable. The ominous “Safety First” principles would hint at girders made of AA, creating a Faraday cage, and everything else made of composite. However, other solutions could exist, like an envelope made of yet-to-be-created ultra thin CF integrating lightning protection, etc. Creative engineers will find a way. One of the first steps would be to actually have a large prototype flying and **start gathering data**. As the regulation points out, design must be based on “experience of similar aircraft”, and prototypes do not require optimized payload or extensive safety measures.

Online sources

Many sources are from my own library of technical papers. Online resources are plenty and AI does a good job at finding them (Grok was used extensively). Comments of Youtube videos from carbon fibers manufacturers are often very interesting.

https://www.youtube.com/@RockWestComposites

https://www.youtube.com/@DarkAeroInc

https://www.youtube.com/@flyingwhales7543

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