SUSTAINABLE TRANSPORTATION: AIRSHIPS VERSUS JET AIRPLANES

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Introduction

The cloud that now surrounds the silver lining of jet airplanes is the smoke from their contrails. As the 21st century progresses, burning fossil fuels with abandon is coming to an end. This paper offers a definition of a sustainable transport system while outlining the need, presents information on jet airplane Greenhouse Gas (GHG) emissions and mitigation. This is followed by highlighting transport airships that could replace the most polluting older passenger jetliners that have been converted to cargo carriage. The paper concludes with some thoughts on the impact of transport airships in international trade.

Sustainable Transport System – The Need

There is no universally accepted definition of a sustainable transport system. Some definitions are listed below.

- **Transport Canada (1999) -** the goal of sustainable transportation is to ensure that environment, social and economic considerations are factored into decisions affecting transportation activity.

- **European Conference of Ministers of Transport (ECMT 2004) -** a sustainable transport system is one that is accessible, safe, environmentally-friendly, and affordable.

- **Transportation Research Board (TRB, 1997) -** sustainability is about how environmental, economic, and social systems interact to their mutual advantage or disadvantage at various space-based scales of operation.

An effective definition is offered - a sustainable transportation system is one in which fuel consumption, vehicle emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world [1].

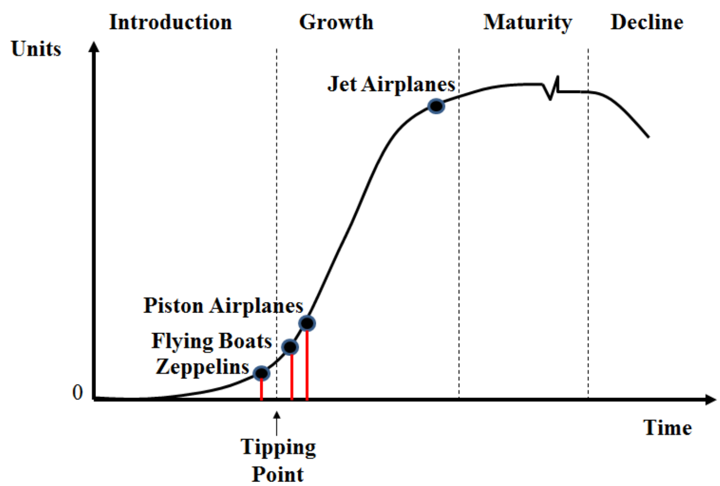
With this in mind attention now focuses on the issue of air cargo transportation needs and opportunities. Starting from 2009 world air cargo traffic is expected to triple over the next 20 years. This implies an average annual growth rate of 5.9 percent. The number of airplanes in the freighter fleet will increase by more than two thirds over the same period from 1,755 planes in 2009 to 2,967 by 2029. Cargo revenues represent on average 15 percent of the airlines income [2].This increase in planes, coupled with increases in passenger traffic, will place heavy demands on the atmosphere because of their GHG emissions. Transport of cargo by airship could help alleviate the pressures on the environment, but before we examine the state of this technology's return, it is useful to review its virtual demise.

The Jet Age

The Golden Age of Air Transport ended in 1939 with the outbreak of World War 2 (WW2). During this period, international air travel was the domain of flying boats, like the Boeing 314 and the giant Zeppelins. After the war, flying boats and Zeppelins were swept from the skies. Concrete runways had been built at all the major cities, which made wheeled airplanes more competitive than flying boats. However, airplanes with reciprocating engines were shortly to be made obsolete, too. The jet-powered airliner that was born as a child of WW2 would ultimately devour all passenger competition in the skies, seas (ocean liners) and over land (rail) to create the moniker that defined the modern world, the Jet Age.

Jet turbine engines created a sea change in air travel because they were lighter, more powerful and required less maintenance than reciprocating engines. Jet aircraft could fly twice as fast as propeller aircraft, and soar well above the weather, which made travel more comfortable, too [3]. Figure 1 presents an illustration of the product growth curve for jet airplanes versus its competitors and their exit date. Airships never made it past the tipping point before the war [4], but flying boats continued to be produced until the late 1940s. Piston engine airplanes, like the DC-6, had clearly reached the point of accelerating sales, until the introduction of the Comet (1949) and the Boeing 707 (1956) passenger jetliners.

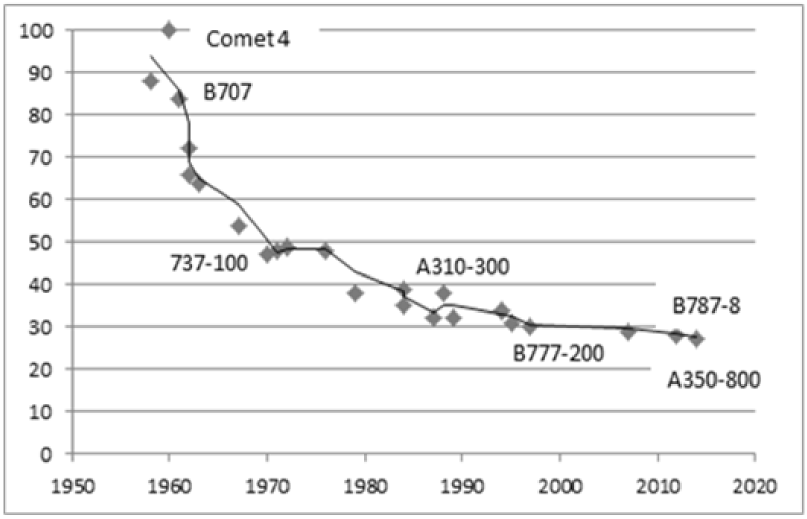
Figure 1 Air Technology Race, 1936-2016



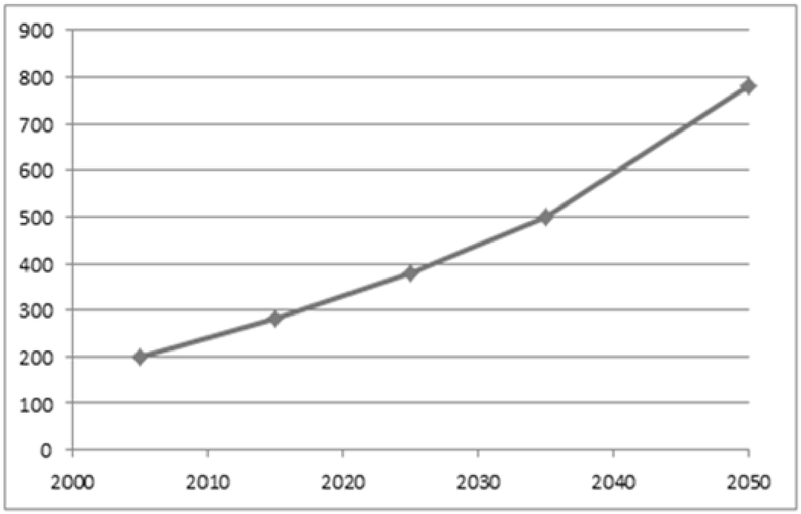
Passenger jetliners may now be approaching market maturity, but jet-powered aviation is still one of the fastest growing industries in the world and supports 8% of the world economic activity in terms of GDP [6]. Globally, air passenger traffic more than doubled from 1985 to 2000 and air cargo traffic grew even more quickly. Current forecasts assume a passenger growth rate of 4 to 5 percent to 2030 and beyond [5]. Air cargo is expected to grow even faster. The International Air Cargo Association (ICAO) states that air freight constitutes about 2% of world trade by volume, but 40% by value. Moreover, air cargo is projected to grow at 6.5% for the next 20 years [9]. The importance of airfreight in world trade means that cargo jetliners will continue to operate, but this spells a problem for the mitigation of climate change because global aviation contributes about 2% of total GHG emissions.

Aircraft CO_2 emissions are directly linked to fuel consumption. Each pound of fuel saved reduces CO_2 emissions by 3 pounds. The aviation industry’s goal is to reduce emissions by using more fuel efficient technologies. Current aircraft are far more fuel efficient than 40 years ago [7] as shown in figure 2. However, figure 2 also shows that CO_2 emissions arising from air transport will keep growing; ICAO forecasts that global aviation emissions will grow by 70% over existing levels by 2020. By 2050, that would be 4 times today’s levels [8]. New jetliner designs, like the Bombardier C-series and the Boeing 787, have been introduced that have lower fuel burn rates and greater efficiency, but much more is needed.

Figure 2 – Aviation Fuel Consumption Trends



Trends in Aircraft Fuel Efficiency Source: Peeters et al. [7]



Global Aircraft Fuel Burn Forecast Source: ICAO [8]

The major technical changes that are expected to contribute to aircraft fuel burn reduction in the future are [10]:

- Higher engine and aerodynamic efficiencies, which are expected to improve by 20% each and account for more than 70% of the fuel burn reduction over the next 50 years.

- Gradual reduction in aircraft structural weight of about 10% through use of composite materials. Aircraft structural weight has a reduction potential of up to 30% through full implementation of composite materials on the wings and fuselage.

Note, however, that it is likely to take many decades for the entire world fleet to reach the same level of these efficiency improvements and cost changes because of the time delay in technology uptake.

The international nature of aviation complicates GHG reductions. ICAO is the United Nations agency responsible for addressing international aircraft pollution. They are working with member countries to establish emission standards. However, their record is poor.

> "Over the last 18 years, ICAO has rejected in turn, efficiency standards, fuel taxes, emissions charges and global emissions trading. The carbon emissions standards now under consideration at ICAO barely bend the industry's steeply rising emission trend [11]."

By 2030, ICAO expects to have half the aviation GHG emissions offset by biofuels. The OECD (2015) considers the IACO goal to be "ambitious", and points out that biofuels are about twice the price of mineral kerosene. Unless there is some major technological breakthrough in biofuels, such as algae diesel, this method of offsetting jetliner GHG emissions is unrealistic [12].

The International Association of Air Transport (IATA) has praised the CO_2 efficiency standard that ICAO has adopted for new aircraft built after 2020 (defined as a maximum fuel burn per flight kilometre). From 2023 this standard also applies to existing aircraft designs still in manufacture at that date. Given the long life-cycle of commercial aircraft, this is unlikely to contribute much to the aspirational goal IATA has set for itself to reduce 2050 CO_2 emissions to 2005 levels [13]. Older airplanes will be contributing to CO_2 emissions throughout this period, especially the older passenger jetliners that have been converted to cargo carriage.

In July 2015, the U.S. Environmental Protection Agency (EPA) began to set aircraft pollution standards. As the world's greatest emitter of aviation GHGs, the regulatory actions by the U.S. EPA in its domestic market will have a direct impact on global aviation emissions. Jetliner manufacturers can continue to improve fuel efficiency through reductions in aircraft weight, improved aerodynamics to reduce drag and greater engine efficiency, but more serious measures will be needed to discourage the growth of demand in order to have any reduction in GHGs [14]. IATA's hopes of avoiding more serious pricing of carbon emissions seem unrealistic.

> "Even if all the mitigation-measures currently on the table were to be successfully implemented, it is doubtful that a reduction in civil aviation's overall absolute CO_2 emissions could be achieved if forecast traffic-growth in the sector is realised. The gap between traffic growth-rates and emissions reduction-rates will remain, unless it can be closed through behaviour change to reduce demand for air-travel [14]."

Changing travel behavior generally means raising prices to recognize the negative externality created by jetliner GHGs. The two options are Carbon Taxes or some Cap and Trade system. ICAO favours the Cap and Trade approach, but carbon offsets are difficult to monitor and less reliable to the extent that they may not be permanent. Carbon pricing will increase pressure for a transportation innovation to replace jetliners for cargo carriage as the direct and indirect costs of operating airplanes are passed on to the consumers. It seems impossible to envision a day with fewer passenger jetliners, but the time could be soon at hand when old jetliners that have been converted to cargo carriage could be replaced by the revival of an alternative greener technology – hydrogen-powered cargo airships.

Transport Airships

In 2002, Manchester Metropolitan University's (MMU) Centre for Aviation Transport and the Environment carried out a feasibility study of the potential environmental and operational benefits of airships for freight conveyance. The study concluded that using airships to carry freight has the potential to significantly reduce the fuel consumed per FTK. In addition to the associated reduction in actual emissions, the lower cruise altitude of airships confers substantial climate change benefits, with greenhouse gas emissions reduced by over 80% [15].

In 2010 the International Air Transport Association (IATA), the trade association of airlines, caused uproar from Airbus and Boeing by calling for the airfreight industry to change to airships rather than conventional aircraft as a way to meet targets on greenhouse gases emissions.

“Lighter-than-air airships have much higher fuel efficiency than heavier-than-air aircraft,” said an IATA spokesman, Jean Baptiste Meusnier. “This makes them ideal for the use of cargo, as seen with some of the super-heavy lifters already in operation.”

“An airship produces 80 to 90 per cent fewer emissions than conventional aircraft,” explained Meusnier. “They also fly at the lower altitude of 4,000 feet instead of 35,000 feet, which means their water vapour trails contribute almost nothing to global warming [16].”

Professor Sir David King of University of Oxford, the former UK government’s chief scientific adviser, also supports the use of airships for air freight. Few cargos need to travel at 800 kph, with the possible exception of organ transplants. However, he does not believe airships would replace conventional air freighters completely – due to their far slower speed of 125kph (78mph) – but instead would become a viable option between airfreight and ocean. With airships using only a fraction of the fuel of conventional jetliners taking off and landing and with some of the heavier varieties being able to carry twice the load as a 747, their cost benefit would be attractive to certain operators, shippers and cargoes [16].

Prentice and Yip [17] use a conceptual model of the trans-oceanic market to examine the potential share of airships in the transoceanic markets from Hong Kong. The sheer weight of cargo is the only limitation of a transport airship because their large cargo bays can accommodate very low density freight. The Prentice-Yip value-density pyramid is reproduced below. Figure 3A presents the current speed and conceptual divisions of the Hong Kong trade lanes. Sea-air transport is freight that travels first in ocean containers then is transshipped to cargo jetliners for final delivery. An example is SAL Albatros that operates a sea-air service out of Dubai. They claim that they can deliver freight to Europe in 14 days from China and at 45% of the GHG emissions of pure jet shipment [17].

Figure 3 Value-Density Cargo Shipping Pyramid

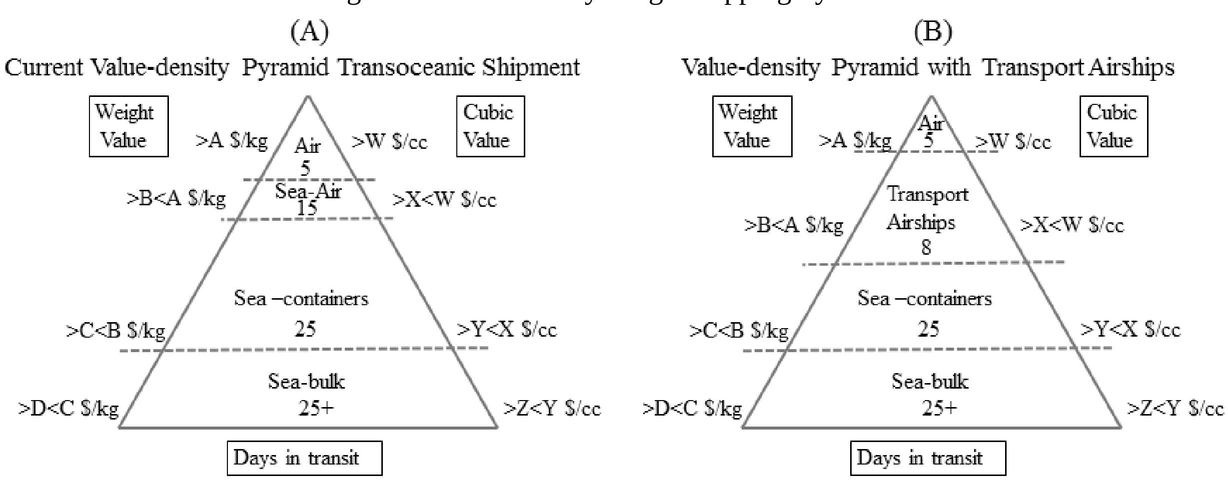


Figure 3B illustrates the transoceanic shipping market with transport airships. The airships would take over all the sea-air market. As suggested by King [17], transport airships would eat into the lower part of the existing dedicated cargo-jet-plane market. Many freight shippers would be happy to wait three or four days longer if the price were significantly lower. Transport airships would not compete with air cargo moving in the belly holds of passenger airplanes. This is a by-product that is priced to fill the available space.

Transport airships could attract the higher value goods moving by ocean containers. Ocean shipping times from Asia to Europe or North America are at least 30 to 40 days from dispatch to receipt. This is long time for inventory-in-transit, but products that do not have the value to density ratio required to be shipped economically by jet aircraft have only the sea-air choice. A significant market should exist for transport that could offer 5 to 10 day service, even if the cost is double or triple container shipping rates.

A third component of the transoceanic freight market for transport airships is cargo that is attracted by the opportunity of a faster, low cost shipping method. It is reasonable to expect that transport airships would induce larger volumes of some trade goods, and open entirely new markets for others. For example, the types and volumes of perishable food products that move between Southeast Asia, Europe and North America are very limited. Similarly, fully assembled upholstered furniture and large pieces of molded plastic are seldom moved long distances. These and other goods could become as widely traded intercontinentally, as they are continently traded.

Transport Airship Development

Unlike the 1980s when the investment in airship research dried up with the collapse of oil prices, demand in the 21st century continues despite the decline in energy prices. The emissions of transportation are gaining attention because the threat of climate change is becoming clearer every year. Airships are not only fuel efficient, they can easily burn alternative fuels, such as methane and hydrogen. A hydrocarbon-hydrogen gas mixture, called blaugas, was used to power the *Graf Zeppelin* and could be used again.

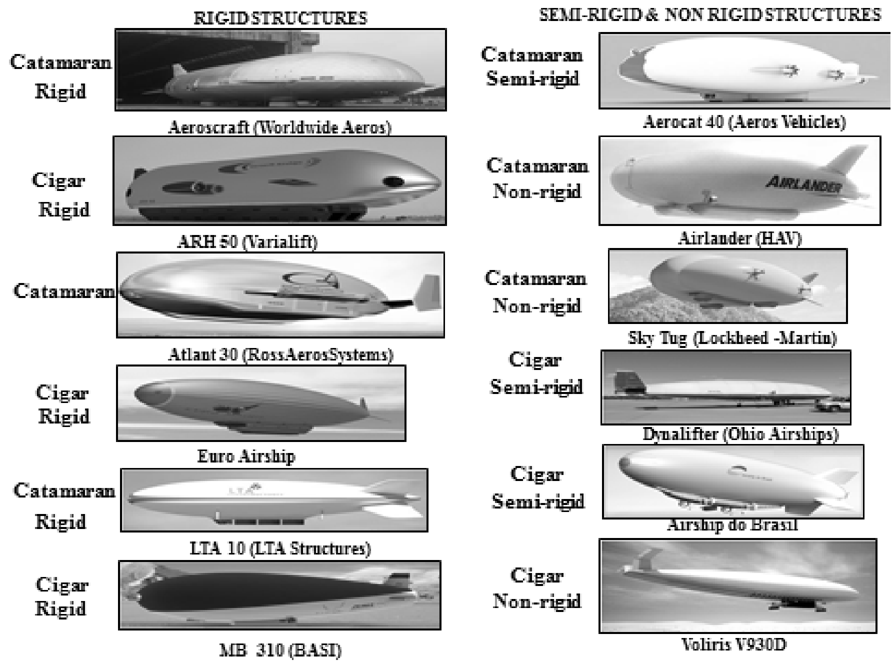
In addition to using hydrogen for fuel, the use of hydrogen as a lifting gas has been raised in many airship conferences. Supply problems and economic issues have prompted one airship manufacturer to consider exploring phlegmatizing additives in hydrogen as a replacement for helium [20]. In any case, the ban on the use of hydrogen as a lifting gas was never based on any engineering or scientific research. As Van Treuren reports:

> "At no time had anyone ever demonstrated that hydrogen gas worsened those gasoline fires following the crashes, nor were tests arranged that showed how a gasoline fire in the car spreading to the flammable envelope would have been affected by a big bubble of hydrogen escaping upward as soon as the bag burned through." [21]

A survey of global airship activity addressing development projects and operations shows that limited but viable world-wide activity is taking place. A number of companies are designing heavy lift transport airships, but only a few demonstration models have been and flown. The only full-scale transport airship is the HAV AirLander that is scheduled to fly in spring 2016. Most designs are at a conceptual stage; if investment was available, a prototype could be flown within two years, and certified within three years. Figure 4 shows pictures of the cargo airships currently under consideration [14].

The competition for the dominant design of a transport airship is producing many different variants. The structural issues revolve around whether the airship has a rigid or semi-rigid structure, or an inflatable non-rigid envelope. Each design has its merits as well as drawbacks. For example, the rigid structure is heavier such that the airship must be bigger to carry the same weight, but it is also more robust and less sensitive to temperature changes. The other advantage of the rigid airship is that the lifting gas is contained at atmospheric pressure, whereas the non-rigid (blimps) are pressurized. Consequently, the non-rigid airships leak more than the rigid designs.

Figure 4 – Illustrations of Transport Airships Under Development



Airships can also be categorized by shape. Traditional airships are cigar shapes, while new catamaran shapes have emerged as "hybrids". The catamaran designs are heavier than air when empty, so in theory, they can drop a cargo and return without the need to take on new cargo or ballast. Some others use a combination of lifting gas compression and ballast to offset the change in buoyancy. Again, each design presents trade-offs. The "hybrids" consume more fuel, while the need for ballast means the airship must have water or other material available at its destination to offset its cargo load. Systems using gas compression require more on-board equipment and energy.

Ground-handling methods for exchanging cargo loads are another area in which multiple solutions are being put forward. Although a dominant design has yet to emerge the many ideas stimulated by the opportunity to transport freight by airship suggests that one soon will provide the direction. Subsequently, the rest of the airship industry will follow.

Conclusions

Technological innovations in transportation diminish the barriers of time and distance. When the costs of transportation fall, trade volumes increase and entirely new industries can be created that drive economic growth and employment. The massive public investment in airplane technologically during the WW2 led to significant advances in speed, safety and cost reduction. In the Jet Age that, the masses could afford holidays in exotic locations, multi-national business organizations operate globally and high value goods were air freighted to serve inter-continental trade demands.

At the time that jet-powered aircraft were being adopted, no one was concerned about the by-products of burning such vast quantities of carbon-fuels, like Jet-A (kerosene). For over 60 years, the Jet Age has shaped the nature of passenger transport and the international trade. Now that the real costs of GHG emissions from jet airplanes are being recognized, air transport is scrambling to devise plans to reduce fuel consumption and find alternative fuels, or effective GHG offsets. It seems inevitable however that some form of carbon tax will be imposed, and this will raise the costs of jetliner transport.

Without question, jet airplanes used for dedicated freight transportation are the most polluting segment of the aviation industry. These are typically the oldest and least fuel efficient jetliners, but they are also the segment of air transport that might be replaced most easily. Transport airships are being designed and tested that could reduce GHG emissions greatly. Potentially transport airships could use hydrogen gas as a fuel and offer zero-carbon emission air transport. A world-wide competition is emerging to develop transport airships, and with the added incentives of carbon taxes, it is only a matter of time before this new technology begins to be employed commercially.

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