Stratobus-30:

Business Case and Market Analysis

Version 1

Strato-2C demonstrator. Credit: Grob Aircraft

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Executive Summary

The Stratobus-30 is a proposed 30-seater passenger aircraft to be developed from the Strato-2C experimental platform. The aircraft is to be powered by a combination of hydrogen fuel cells (supplying high energy) and electric batteries (supplying high power). Due to its high lift/drag ratio (as a consequence of the large wing aspect ratio), the aircraft would have a low installed power/mass ratio. This, in turn, leads to a low overall energetic consumption. The major advantages of this feature are the low resulting operating cost and reduced hydrogen infrastructure complexity, as the hydrogen can be stored onboard the aircraft in gaseous form.

The first part of the analysis reported in this document (Paragraph 3) discusses different operational scenarios for the envisaged aircraft, both existent/well-proven scenarios and completely new modes of operation – e.g. train-like operation. For each scenario, the potential market is evaluated, to the extent of the available data. For the train-like operation, the implementation of this operational mode in Romania is discussed in more detail. The choice is not random, as the Romanian government is considering the development of a strategy for internal air transport that could incorporate this type of air operations.

The second part of the report (Paragraph 4) identifies the global companies (and associated projects) active in the ecosystem that develops hydrogen technologies for aeronautical applications. Powertrain and aircraft OEMs are identified and briefly discussed. The aircraft OEMs that plan to develop vehicles prone to represent competition for the Stratobus-30 are discussed more in depth.

The third part of the report (Paragraph 5) deals with cost-related aspects. First, an estimation of the total cost of one commercially-available Stratobus-30 is produced (as a target objective), by comparison with existing aircraft. The cost amortization is further discussed. Finally, an estimation of the cost of energy per seat-km is produced for the Stratbus-30. This projected cost seems to be ~3 times lower than the current cost of fuel per seat-km for the Dornier 328.

The final part of the report (Paragraph 6) contains a set of market-driven requirements for the aircraft. These are requirements stemming from the different modes of operation discussed in Paragraph 3. The extent of the market captured by the Stratobus-30 is in direct correlation with the capacity of the design to meet all (or a large number) of these requirements.

The report is concluded with a paragraph dedicated to conclusions.

The Stratobus-30 does not exist today. It is hoped that the material included in this report raises awareness about the commercial potential of such an aircraft. If this is the case, the next step would be, in the author’s vision, the creation of an international consortium and initiation of an R&D project for the maturation of technologies required for the Stratobus-30. This project would culminate with the development of a flight demonstrator. The next phase would be the industrialization of the development, on a purely commercial basis.

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1 Introduction

The problem to be approached in this analysis: is there a need for a new zero-emission aircraft with a capacity between 20 and 40 passengers, with mission ranges up to 2000 km? Only if a need is identified, the development of such an aircraft ca be financially justified.

From a technological point of view, the currently available options for a true zero-emission passenger aircraft are extremely limited: battery-electric, hydrogen-electric, hydrogen combustion or any combination of these three options. We will discuss only about the hydrogen-electric and battery-electric options, as for 20-40 pax aircraft, these options seem to be the most appropriate.

The aircraft around which the analysis is performed is a new zero-emission aircraft, fully electric, powered by gaseous hydrogen (+ fuel cells) and electric batteries. The proposed aircraft is an evolution of an existing platform – the Strato-2C experimental aircraft. The experimental aircraft was developed in 1992-1997 under a German research grant. The new envisaged aircraft, labeled Stratobus-30, incorporates a series of technological innovations that ensure its competitivity against any similar development.

One will discuss next how such an aircraft can both fulfill an existing market need and also create completely new markets, usually not addressed by the aeronautical industry. These new markets have the potential to increase exponentially in a relatively short time, as they serve directly the end user – the regular traveler. The aircraft starts fulfilling a need that is natural to all humans – the need to travel fast, comfortable, safe and in 100% sustainable manner.

2 The need for sustainability

Despite the tremendous efforts for incremental technological improvement, the aviation industry is highly pollutant. Modern gas turbine-based propulsion systems are, in some cases, up to 50% cleaner than the first generations of jet engines, turbofans and turboprops. The aerodynamic characteristics of the aircraft have much improved over the years. Commercial operations have been optimized. But, despite all this, commercial aviation is responsible for, depending on the source, 2% to 3% of the total amount of CO2 emitted annually worldwide. With the number of commercial aircraft projected to increase, this percent can only go up – see Figure 1.

In the past years, the western society has started to perceive aviation as a direct path to environmental destruction. Flying, if not fulfilling an obvious, immediate necessity, is associated with the traveler's ignorance towards the environment. Airlines are struggling to change this perception. This struggle originates both in the need to comply with more stringent emission-related regulations and in the need to attract more clients, to maintain the air transport business viable. Among the methods considered for alleviating the negative environmental impact of aviation, one can distinguish:

- Development of new propulsive systems, making more use of electricity and hydrogen
- Usage of Sustainable Aviation Fuels (SAFs) in greater and greater proportions
- The implementation of carbon offset schemes
- The optimization of Air Traffic Control

All methods are challenging and have negative impact on the industry, by significantly increasing the cost of operations. While the first method concerns mostly the OEMs, the last three methods are implemented directly by the airlines. The SAFs are much more expensive than regular Jet-A fuel, their availability is limited and the environmental impact is debatable. The net-zero CO2 concept is far from being clean.

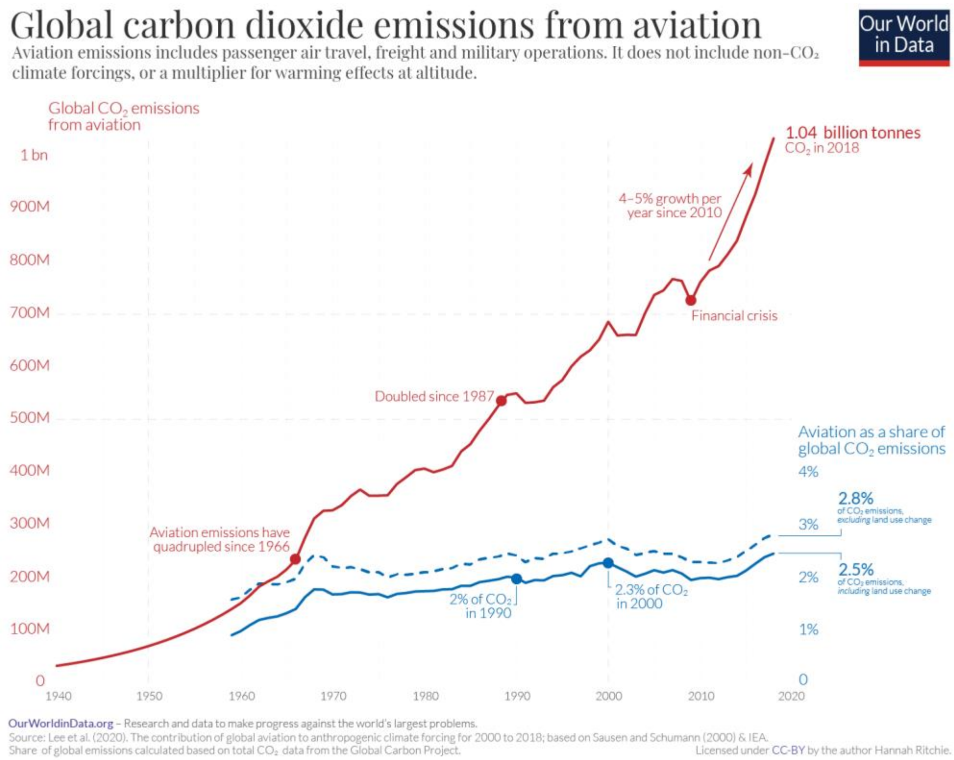

Figure 1 - Time series of global emissions from aviation since 1940 [1.1]

The carbon offset schemes, as described in [2.1], are even more debatable than SAFs. Basically, this is a mechanism by which airlines pay (per tonne of emitted CO2) for the implementation of various projects with positive environmental impact (e.g. reforestation). Nevertheless, as carbon trading has become a profitable business, one could easily argue that the usefulness of the so-called "positive" projects is highly exaggerated. Evidence for supporting this claim is provided in [2.2]. Therefore, the carbon-offset scheme, although relying on good intentions, is not more than a greenwashing process, in which much more CO2 is being emitted than captured.

In the absence of radically different solutions, with immediate and profound positive impact on the aviation industry, air transport will gradually diminish. People are now encouraged to use the train for short travels, as an alternative to air transport. But what if the train is not available? In many countries around the world, the rail infrastructure is not as developed as to allow replacement of air transport. Moreover, in certain cases, the landscape of a region or country simply does not allow the development of a rail network, even with significant financial effort.

It seems obvious that the approach on air travel needs to change. The change is impossible with existing technologies, as these have been designed for the current mode of operation. There is an acute need for a revolutionary type of aircraft that can satisfy the requirements of a modern and sustainable aviation, **without increasing the costs of travel and without overly-complexifying operations**. Moreover, the new type of aircraft needs to allow operation in complementarity with other means of transportation (train, car, boat), creating synergies between different transport infrastructures.

The Stratobus-30 is the first aircraft that can address all these problems. The innovative aircraft design allows the continuous development of air travel, on completely sustainable bases.

3 Potential markets

When the commercial viability of a new product is assessed for the first time, one needs to investigate two potential directions:

- The product as a replacement of an existing situation/system/process. This implies the product is better suited to comply with all societal requirements. Consequently, the product can capture a certain share of the existing market, following its release.
- The product can fulfil new needs, that were dormant until now. The release of the new product allows these needs to resurrect, thus creating a completely new market.

We follow the same approach for the Stratobus-30. First, we investigate potential markets in which the new aircraft can replace existing ones and fulfill (roughly) the same missions. The second direction is the development of new operational modes which is prone to create significant demand provided enough flexibility is embedded into these modes. It will be shown that the newly created market is directly influenced by the characteristics of the aircraft, both performance and cost-wise.

3.1 Drop-in replacement of existing short-range, low-capacity aircraft

Assuming the Stratobus-30 becomes available tomorrow (certified and ready for commercial operations), what is the market the aircraft can engage on? What is already there on this market, how and when can the new aircraft penetrate it?

One performed a non-exhaustive analysis of existing airlines that operate at least two of the following aircraft:

- Avions de Transport Regional ATR-42
- British Aerospace Jetstream 41
- Cessna 208
- Cessna 408 SkyCourier
- De Havilland Canada DHC-6
- De Havilland Canada DHC-8-100
- Dornier 328
- Embraer EMB120
- Fokker 50
- Saab 340

Some characteristics of each aircraft type are provided in Annex 1 (section 1.1). The underlying assumption is that the Stratobus-30 can perform (roughly) the same mission as each of the identified aircraft.

Three other aircraft types have been identified as having performance that overlaps with the performance of the Stratobus-30:

- De Havilland Canada DHC-7
- Short 360
- Short 330

However, due to relatively old age of these aircraft, they have not been included in the study. Some characteristics of each of the three aircraft are included in Annex 1 (section 1.2).

All the selected aircraft are powered by turboprop engines. This ensures a sufficient available power to reach cruise velocities of the order of 500 km/h. Also, all the hydro and amphibious aircraft have been deliberately excluded from the analysis.

The air carriers that currently operate these aircraft have been identified from [3.1] and [3.2]. It is estimated that about 80% of the aircraft of interest in operation today have been identified through these two sources. The list of air carriers, together with the number of aircraft in operation, the type of aircraft and the average age of the fleet is included in Annex 2.

The processing of the collected air carrier data resulted in a total number of aircraft of 720 units. These aircraft are in operation today with air carriers all around the world.

The data were arranged to highlight some key aspects. In Figure 2, one shows the repartition of the total number of aircraft (in absolute number of units and percentage of total) per different regions of the world. In this representation:

- North America comprises the US, Canada, Mexico and all the countries in Central America
- Europe comprises all the countries on the European continent + the Russian federation
- Australia comprises Australia, New Zealand and all neighboring countries
- Africa comprises all the countries on the African continent
- Asia comprises all the countries on the Asian continent (excluding the Russian federation)
- South America comprises all the countries on the South American continent
- Finally, the region “Islands” comprises all the archipelagos or island-countries situated far from any continent

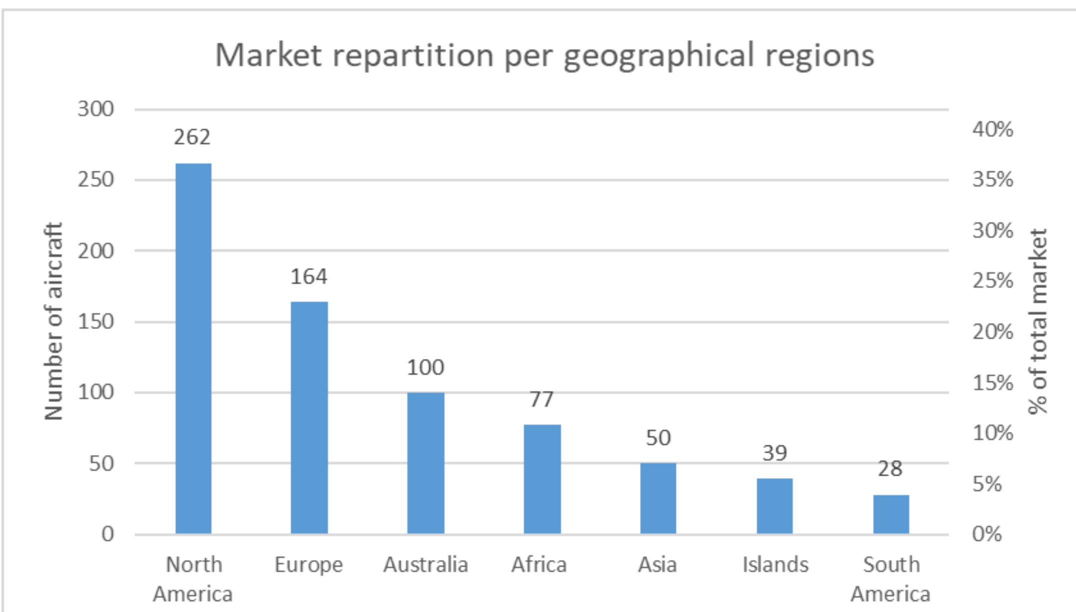

Figure 2 - Repartition of aircraft per regions of the world

As expected, 262 aircraft (~36% of total market) can be identified in North America. This is followed by Europe, Australia and Africa. Surprisingly, South America hosts the least number of such aircraft, about 4% of the total market.

The conclusion to be drawn from Figure 2 is that North America, Europe and Australia are the largest markets for the aircraft types of interest. Incidentally, these are the world regions in which active steps are being made for the development of hydrogen infrastructures for transport applications. In the world of aviation, emphasis is placed on large airliners, requiring significant amounts of liquid hydrogen per mission.

It follows that a hydrogen-powered Stratobus-30 could capture a significant share of the market in the three regions, should this aircraft become available in the near future.

Figure 3 shows the repartition of the worldwide fleet of aircraft of interest per aircraft type. It can be noticed that ~63% of the entire market is composed of just three aircraft: Saab 340 (25%), DHC-8-100 (20%) and ATR-42 (18%). As shown in Annex 1, the Saab-340 capacity is 34 seats, the DHC-8-100 can seat between 37 and 39 passengers and the ATR-42, the larger of the three, has a total capacity of 48 passengers.

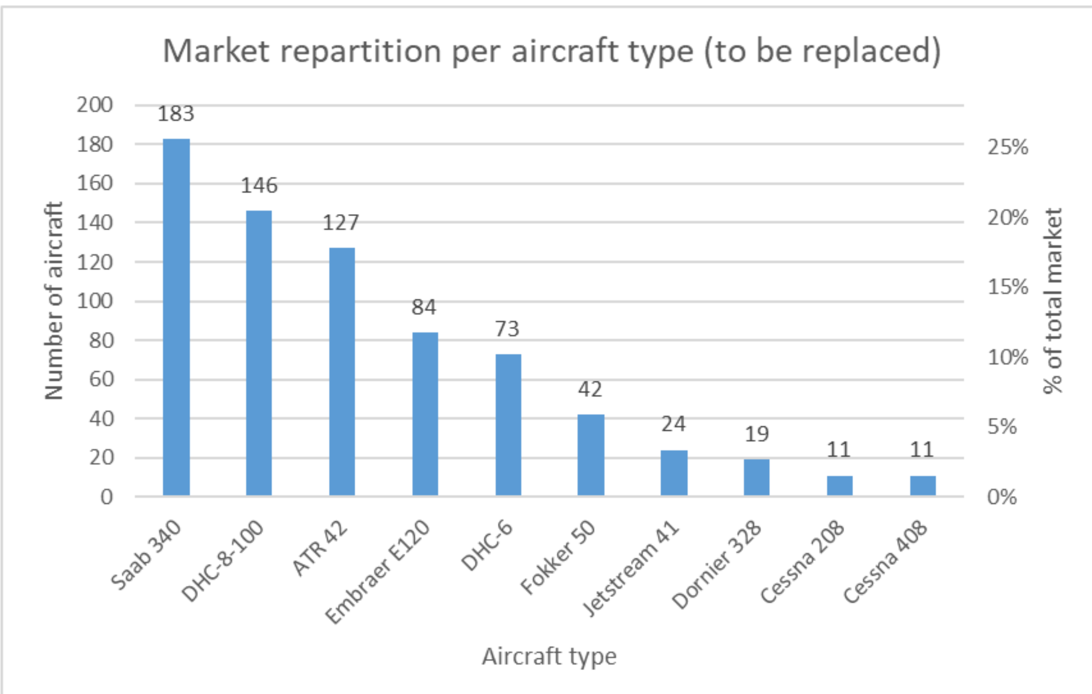

Figure 3 - Repartition of aircraft per aircraft type

Figure 4 shows the market repartition per aircraft capacity – the number of seats per aircraft is indicated in square brackets on the x-axis. It can be seen that 456 aircraft units (63% of the total market) have a capacity between 29 and 39 seats. The conclusion out of this representation is that a new 40-seater aircraft with performance at least similar to existing aircraft and lower cost would capture at least 63% of the existing market.

Figure 5 shows the market repartition per average aircraft age. 494 aircraft (68% of the total market) have an average age between 25 and 35 years. It is expected than in the next ten years all these aircraft will be out of service. A replacement is needed.

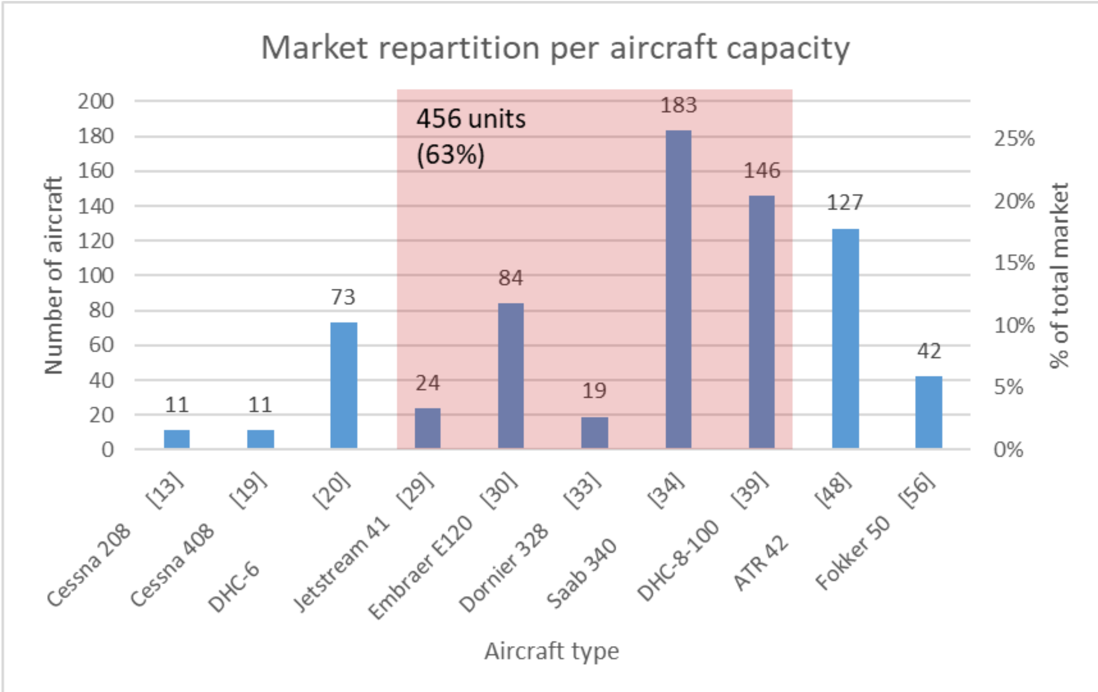

Figure 4 - Repartition of aircraft per aircraft capacity

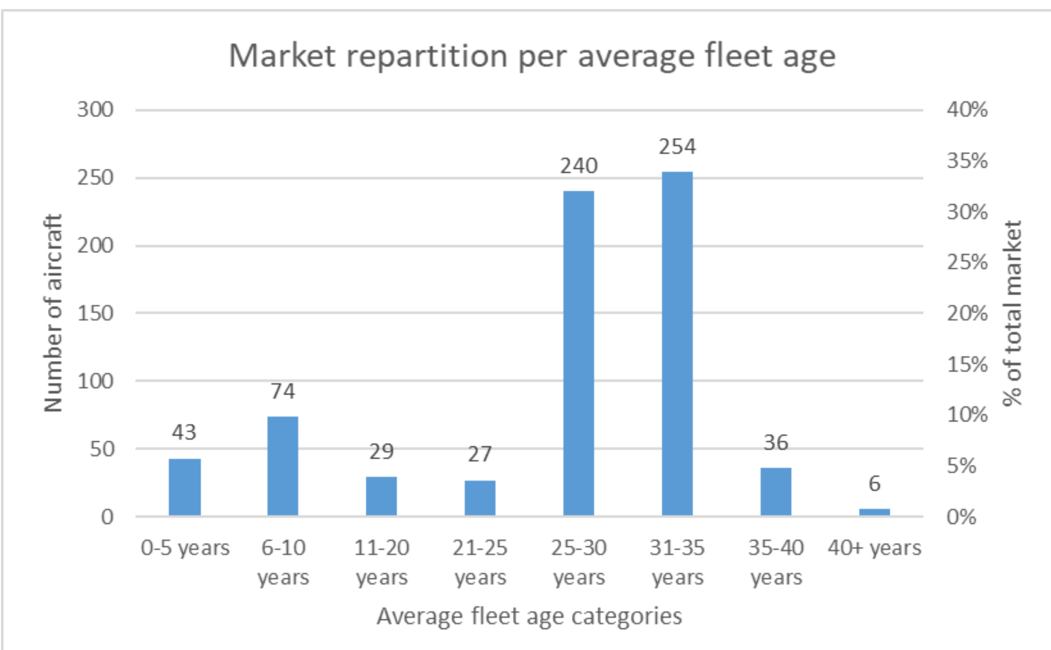

Figure 5 - Repartition of aircraft per fleet average age

The conclusions that can be drawn out of this analysis:

- A new 40 seat aircraft with performance similar to the performance of existing aircraft (speed ~500 km/h, range >1000km) would be able to capture about 68% of the existing market, roughly 500 aircraft.
- This aircraft should be commercially available within the next 10 years to replace the ageing fleets. Given that air transport companies need to plan their fleet replacement in advance, the development of this aircraft should be announced in the next 5 years.
- The most widely used aircraft today is the Saab-340, with a capacity of 34 seats and range of 870km. A one-to-one replacement of this aircraft alone would ensure a market of 183 units (~25% of the existing market)
- The largest part of the market – 526 units (~73% of total) is situated in North America, Europe and Australia. These regions are leading the way in the implementation of refueling infrastructures for zero-emission aircraft, including hydrogen-powered aircraft. Therefore, 5 to 10 years from now, the hydrogen refueling infrastructure will be developed to a great extent in these regions to ensure an easy operation of the Stratobus-30.

Please note that the analysis shown in this paragraph is focused purely on the existing market. The underlying assumption is that the air transport companies that are operating such aircraft today are interested in replacing their fleet with similar capacity aircraft, but 100% green. One of these companies – Wideroe (from Norway) – operates 23 DHC-8-100 aircraft on the nordic routes. The author of this report has reliable information according to which the company is now actively searching for sustainable alternatives for its fleet. In the absence of other options, the company is looking at hybrid electric and full electric aircraft with similar (or lower) passenger capacity.

As discussed in Paragraph 4 of this report, other airlines, not traditionally operating 30-40 pax aircraft, are actively exploring the possibility of extending their fleet with this type of aircraft. An example of such an airline is United Airlines (USA).

Another example is HOP!, the regional transport arm of Air France-KLM. Recently, as shown in [3.3], France introduced a ban on internal flights for which a voyage by train is shorter than 2.5 hours. This is a perfectly justified measure today, given the level of pollution aircraft produce. This measure reduces the revenues of HOP!, that was previously operating regular flights on the banned routes. The question now arises: would HOP! be interested in purchasing a given number of Stratobus-30 for restarting operations on the banned routes? The most likely answer is yes, provided the operational cost of this aircraft is comparable with the cost of the train.

What needs to be retained from this analysis is that the potential market today for small and medium capacity aircraft is ~720 units. This value may be slightly higher (~800 units) given the non-exhaustive character of the analysis. In addition to these aircraft (that need replacement in the next 10 years) one can identify an additional market need on the side of regular airlines. These airlines, today operating flights with higher capacity aircraft (A320-like), are willing to expand their fleet with smaller capacity aircraft. Although not quantified, this market can be equal or even larger than the market analyzed in this paragraph.

3.2 Air cargo and special missions

Air cargo market

The air cargo field is an industry in its own, very different from passenger transportation. A brief overview of the decomposition of this industry, its status in 2022 and a forecast for 2027 are given in ref. [3.6]. According to this source, the "*global air freight market was valued at $270 billion in 2019, and is projected to reach $376.8 billion by 2027, registering a CAGR of 5.6%".*

The market can be segmented according to a variety of criteria:

- The type of service: freight, express, mail, other services
- The destination: domestic and international
- The end use: private and commercial
- The region: North America, Europe, Asia-Pacific and LAMEA (Latin America, Middle East and Africa)

The freight transported via air cargo is usually high value (electronics, jewelry, pharmaceuticals) or perishable products (fruit, flowers, vegetables, frozen and chilled items, etc). During the COVID-19 pandemic, air cargo was extensively used for transporting large batches of vaccine around the world.

Reference [3.7] provides useful insight into how companies active in the commercial exploitation of aircraft adopt air cargo as part of their business model. It turns out that there are four categories of business models associated to this industry:

- Category A: Passenger airlines that increase their revenues by selling space in the storage compartment of their aircraft. This is common practice and it is estimated that this type of business represents about 5-10% of the revenue of commercial airlines. This percent is extremely variable depending on the region of the world, the type of airline and the type of fleet.
- Category B: Companies that offer exclusively air cargo services. Their fleets are composed 100% of cargo aircraft and normally offer airport to airport transport services. The aircraft used in this business model are large, transcontinental or transoceanic, offering significant payload capacity over long distances.
- Category C: Companies offering integrated services. An integrated service is one in which the good is transported by a single company from door to door. Companies are equipped with road, rail, naval and air vehicles offering a variety of transport options. Examples of companies using this business model: FedEx, UPS, DHL, etc.
- Category D: Companies with mixed aircraft fleet, both for passenger and for cargo. In some cases, depending on the commercial potential, a passenger aircraft can be transformed for cargo, operated as cargo airliner for a given period of time and then transformed back for passenger transport.

Air cargo businesses falling in category A do not require the development of special aircraft features, other than ensuring the cargo bay of the aircraft is suited for receiving payload, in addition to passengers' baggage. This drives requirements as accessibility (dedicated access to cargo compartment allowing fast loading/unloading), storage volume (ideally, for standardized containers) and dedicated attachment points. An airline operational model in which it connects multiple cities in a single mission (see Paragraph 3.5 for extra details) enhances the business potential for this mode of cargo transportation.

Out of the four categories of business, category B is least appropriate for the envisaged Stratobus-30 aircraft. The relatively low speed of the aircraft (compared to turbofan-powered aircraft) and the low cargo capacity make it unattractive for air-cargo focused companies. The fuel saving potential of the Stratobus-30 is not a real advantage, as the cost per tonne-kilometer is not the main driver for the market (as opposed to time of delivery).

Category C is a little more accessible than category B. The main advantage of category C business is that the logistics company has an interest to load the cargo into the aircraft as close as possible to the collection point and to unload it from the aircraft as close as possible to the destination point. This minimizes the delivery time and also the cost. An operational model in which the Stratobus-30 (cargo version) is operated from small and very small airports, much closer to the city centers offers a number of advantages:

- The logistics company can reduce the time between item collection and loading into the aircraft
- It is easier for a logistic company to open a base in or next to a small or very small airport as the density of housing and commercial activities is usually lower around these facilities
- The cost of opening and maintaining a logistics base in or next to a small or very small airport is lower than the cost of a similar base in a bigger airport
- The logistics company can reduce the time between item unloading from aircraft and item delivery to the destination point, as the destination small or very small airport is, most of the times, closer to the city center than a regular airport

It turns out that FedEx, one of the three world giants in logistics, is putting together a fleet of small cargo aircraft. According to ref [3.8], FedEx is already operating a fleet of 6 Cessna 408 SkyCourier aircraft. Also, according to [3.9], FedEx plans an expansion of its fleet up to at least 50 Cessna 408 units. It is worth noting that the cargo capacity of the Cessna 408 is 6000 lbs (2700 kg).

Air companies operating within a category D model are the most obvious target for a Stratobus-30 cargo version. The most common operational model is air transport services that connect remote areas. These areas can be:

- isolated regions due to weather conditions (small settlements surrounded by ice and rough terrain – for example in Greenland or large parts of Canada)
- islands close to the mainland (for example in the UK and Ireland)
- islands in archipelagos (for example in Central America)
- regions in the mainland with difficult direct accessibility due to water and mountains (for example, in the European Nordic states – Finland, Sweden, Norway).

Reference [3.10] provides an overview of the air cargo potential of these regions. Airlines normally operate mixed fleets, both for passengers and cargo. The air transport services for these regions are not a premium service, but a must have. The direct consequence is that the cost per tonne-kilometer of cargo is a defining factor in the profitability of the company providing the service. As shown in Paragraph 5 of this report, the operational cost of the Stratobus-30 (irrespective of its payload) is prone to be much lower than the operational cost of an equivalent aircraft.

The conclusion of this analysis is that a Stratobus-30 for passenger transportation should also take into account the possibility of using extra bay space for cargo applications. Regular airlines could enhance their profits using this extra source of revenue. Also, a dedicated cargo version of the aircraft can serve a market large enough for complementing the sales of the passenger aircraft. This market is represented by airlines serving areas with difficult accessibility.

Market for special missions

A national or regional government has, in many cases, a unit responsible for emergency situations. This unit is equipped with a range of vehicles allowing fast intervention. In some cases, these units also have an aviation department. For the particular case of the Romanian Government, the Ministry of Internal Affairs has a unit named General Inspectorate for Aviation (GIA). The main roles of this unit are:

- to perform aerial monitoring of social events (manifestations, protests, gatherings, etc.)
- aerial monitoring of road traffic
- fast dispatch of intervention forces in case of disasters
- surveillance and monitor of border regions
- medical units dispatch in regions affected by disasters
- air ambulance services, etc.

In 2023, the fleet of Romanian GIA comprises 4 helicopters and 2 aircraft, each aircraft with a seven-seat capacity [3.11]. The aircraft are modified and equipped for medical interventions. Discussions with GIA revealed the fact that there is a great interest in acquiring a Stratobus-30 type aircraft. The most important characteristics of the desired aircraft are the low operating costs, flexibility of operations, and zero-emissions features.

Most developed or in-development countries have similar structures, either civil or with a military character. These structures might be interested in the capabilities offered by a Stratobus-30 type of aircraft. The potential market is relatively small and the aircraft would need to be adapted and customized for the needs of each structure. Nevertheless, the customization is mostly related to the systems installed on the aircraft, and not with the aircraft itself.

3.3 Island-hopping

Another substantial market that can be addressed by the Stratobus-30 aircraft is the inter-island air transport. There are many regions around the world in which this type of transport is seen as a form of public transport. The only alternative is sea transport which, although cheaper, is slower than air travel. As public transport is a service that needs to be provided by the local, regional or state authorities, the inter-island "hops" are often subsidized. A reduction in the cost of transportation would be of interest not for the airlines themselves, but for the public authorities. A more economical fleet of aircraft resulting in lower operational cost is translated in a reduction of the subsidy, at equal price for the customer. Therefore, the envisaged aircraft needs to be advertised not necessarily to the airlines, but to the governments of the concerned islands.

Ref [3.12] provides a list of the island-states members of the *Small Island Developing States* union. There are 52 members in the union. The common interest of this union of countries, under the UN patronage, is to identify possibilities of implementing cheap and sustainable means of transportation, that fully serve the public interest.

Apart from the SIDS states, there are other countries that have a mixed continental / islands geography, for example Greece. With distances between islands ranging 100-200km, the region is suited for mission profiles that include more than 2 hops without refueling time. A hydrogen-powered aircraft like the Stratobus-30 allows for enhanced operational performance when compared with battery-electric aircraft. This operational performance is characterized by higher transport capacity per unit of time, as the range of the aircraft allows multiple take-offs and landings without refueling. The aircraft thus becomes more competitive than its battery-electric counterparts.

Another example of air transport model optimization is the case of Binter air carrier, operating in the Canary Islands (Spain). The company operates a fleet of 23 ATR-72, connecting all the islands of the archipelago. Looking at the connections between the two main islands of the archipelago, Gran Canaria and Tenerife, one can see that on a weekday, the company operates four direct flights: at 8:15, 14:00, 17:35 and 22:20. While the flights at 8:15 and 17:35 are (almost always) fully booked, the flights at 14:00 and 22:20 have a low loading factor, due to lack of demand. A possible way of addressing this issue is by replacing one ATR-72 (72 seats) with three smaller aircraft, 30-seaters, like the Stratobus-30. This allows operating three simultaneous flights (or very closely spaced in time) at rush hours and also using only one aircraft for the slots in which the demand is low. In all cases, all the aircraft would operate at 100% load factor.

The last consideration is related to the sustainability aspect of air travel in between islands. As mentioned before, one perfect example in this respect is Wideroe – a Norwegian air operator. The company currently operates a fleet of DHC-8 and is considering the replacement of these aircraft with zero-emission aircraft. Unlike other airlines, Wideroe is actively pursuing this goal. As mentioned in [3.13], the company has initiated a partnership with Rolls-Royce (UK) and Tecnam (Italy) for the development of a commuter-sized (11 seats) battery electric aircraft, based on the Tecnam P2012 platform. This illustrates that airlines don't always wait for OEMs to develop a product that satisfies their need, but are taking the development initiative themselves, when the OEMs don't have the vision to do so.

The conclusion of this analysis is that the inter-islands air travel is a potential market for the Stratobus-30. There are different methods of approaching this market: replacement of existing aircraft, optimization of existing operating modes, providing a zero-emission alternative to other means of transportation, like ferries. In most cases, the main beneficiary of a more performant aircraft is not the airline, but the government that subsidizes this type of transportation.

3.4 New operational model – the airborne "train"

Let us assume we look at the transport options for connecting two cities, A and B, situated at a distance of, say 700km. Given the relatively large distance between these cities, using personal car is not always a good option, in particular if sustainability is important (EVs rarely have a range that is greater than 300km). The only options are:

- Public road transport (coach, bus) - if this option is available
- Train

- Air travel

One might ask, at this point, what is the main difference between air travel and road/train travel, leaving aside the cost and time of the trip? The answer is simple and obvious: while both the train and the bus connect cities A and B plus many intermediate cities in between the two, air travel only connects A and B, without serving any intermediate city. This has a major implication on the profitability of air transportation, compared to the other two options. While ground-based transport systems ensure a loading factor in excess of 100% (we define here the loading factor as the number of travelers with respect to the number of seats available in the vehicle), aircraft are limited to a maximum of 100%. Moreover, if the loading factor for the aircraft is, as it usually happens, lower than 100%, the flight quickly becomes not profitable. Therefore, air transportation between cities A and B is only profitable if the demand is high enough to be able to completely fill the aircraft. This might be the case if A and B are big cities, with a historical or strong economic connection. However, looking at the total number of cities in a given country, one can see there are only a handful of cities that have such a connection. The rest do not offer a market big enough for justifying a direct air connection. At this point, a natural question arises: why isn't air transportation operated the same way as ground transportation, with intermediate stops? It is the author's opinion that aside from small time and fuel penalties, there are two main obstacles to this mode of operation: regulation and lack of airport infrastructures.

Discussion about regulation

Anyone who used air transportation before is familiarized with the "pain" of getting onboard the aircraft. One needs to be at the airport at least 2 hours before the departure. Given that the airport is usually far from the city, a minimum one hour commute from home/work to the airport is expected. Therefore, at least 3 hours are lost between the moment one leaves the house to the moment the aircraft starts to taxi.

In the airport, the safety-driven procedures are complex and time consuming: boarding and baggage check-in, identity verification, security check, waiting at the boarding gate for the aircraft to arrive, waiting for the incoming travelers to get off the aircraft before boarding, in most cases – waiting for the crew to be replaced with a different one, waiting for the aircraft to be serviced: refueling, waste removal, resupply with various products, etc. Although for long commutes (international, over large distances, or trans-oceanic flights) all these procedures are fully justified, why one needs to obey the exact same rules for short, internal flights? If persons 1 and 2 leave from city A at the same time, willing to travel to city B, person 1 by plane and person 2 by train, by the time person 1 becomes airborne, it is very likely that person 2 has already reached the destination, assuming performant train services. The train and road public transport do not have the same safety constraints as air transport. For the specific case of the train, you just arrive at the train station, buy the ticket 5 minutes before boarding and just… jump in. For the bus, the situation is largely similar.

What can be done, in this case, for drastically reducing the time required for boarding an internal air flight, without compromising safety?

It is the author's belief that, in order for such an operational model to become viable, the passenger should arrive at the airport 15 minutes before aircraft take-off. For this to be possible:

- No check-in procedure should be performed. The ticket, bought online or at the place of boarding (in this latter case with at least 15min before aircraft touch-down) should be enough for getting in the aircraft.
- The collection of the baggage should be done in a simplified manner – just deposit your luggage in the container with your destination marked on it (several containers should be available close to the boarding gate, each dedicated to an intermediate or final destination).
- For internal flights, and for trips with low capacity aircraft (30+ seats), security checks should be much more rapid than for international trips.
- Once the aircraft lands, the passengers who need to descent do so, while the rest wait patiently in the cabin.
- Baggage processing: while people get off from and board the aircraft, the containers for the current destination are unloaded, and the containers for next destinations are loaded into the aircraft. The unloaded containers are just opened and people retrieve their own baggage.

Such a boarding / deboarding process can only be put in place if a dedicated area in the airport is reserved for this type of flights. Alternatively, small and very small airports can be used for this type of operations, as discussed next.

Efficient passenger and baggage processing allows having no more than 15 minutes elapsed between the moment the aircraft touches down and the moment it takes-off for the next intermediate (or final) destination. Longer waiting times are negatively affecting the total length of the trip. While on the ground, the aircraft does not need to refuel, nor discharge of wastes or resupplies are required. Only passengers and baggages are quickly processed. The powertrain of the aircraft will not be turned off. Although the propellers are not powered, for avoiding injuries on the passenger's side, the fuel cells will continue to produce energy that is being used for recharging the on-board batteries.

Is this mode of operation allowed by the regulations in place today? If yes, implementing it is just a matter of willingness. If not, the blocking points should be identified and a discussion should be launched with the concerned authorities. The author's knowledge on this subject is not extensive enough to be able to provide a correct answer here. Further investigation is required.

<u>Discussion about airport infrastructure</u>

It has already been stated that operations from a big airport are not convenient for passengers, as the commute time to the airport is, usually, significant. This observation is also valid, to some extent, on the aircraft side. Operations on a big, crowded airport introduce delays due to the need for long taxis (after landing and before take-off), waiting for a take-off slot to become available, etc. It follows that the optimal airports for this type of operations are small and very small airports.

These airports (and aerodromes) are normally much closer to the city, facilitating faster passenger access. This are spaces not usually destined to commercial exploitation. They serve for the operation of General Aviation aircraft. There is no dedicated passenger-processing area and, in some cases, there is no control tower. Given the need for a minimal passenger processing infrastructure, providing these very small airports with the required equipment is more a logistic problem rather than a technical one. However, the lack of classical airport infrastructure (for ATM purposes) poses a challenge to aircraft operations, in particular in the following conditions:

- Night operations (as the very small airports are normally only used during the day)
- Low visibility operations in VFR airports (as almost all very small airports are only equipped for visual flight)

It follows that during nighttime or in poor weather conditions, the aircraft would be unable to serve that particular very small airport. Luckily, recent progress has been made towards solving both these problems: usage of GPS-based approaches as precision approaches (SBAS-based) to allow low visibility operations in VFR airports that are not equipped for RNAV precision approaches. This system uses an array of antennas on the ground which increases the GPS precision enough to perform low visibility procedures with reduced horizontal and vertical visibility (similar to a CAT I ILS approach). As seen in [3.4], this GPS-based approach methodology is in the process of being certified in the UK. Therefore, no need for expensive ILS infrastructure, when the GPS-based system can successfully be implemented. Moreover, the GPS-reliant system can be further improved by extension of the GNSS network. As seen in [3.5], the European navigation system, Galileo, can now reach commercial horizontal accuracy of 20cm and vertical accuracy of 40cm, much better than what the GPS provides commercially (the GPS can also offer better accuracy, but this is only reserved for military applications).

Potential market

Given the adoption of the newly-proposed, train-like operation, one would be interested to know, at this point, what is the potential market this mode of operation opens up. Unfortunately, such an analysis cannot be performed in a general manner. The potential market is highly dependent on a series of factors, among which:

- The total surface of the country under consideration
- The state of development of the rail and road networks
- The density of airports and very small airports
- The need for population mobility between different regions of the country

For exemplifying the concept, one will select an implementation case focused on Romania.

In Figure 6 one can see a representation of the regular airports and very small airports in Romania. The airports are depicted in brown, the name of the city being served is specified on top of the symbol and the distance from the airport to the city center is marked next to the symbol. The very small airports are marked with blue symbols. The symbols represent a fueling station, as implementation of a hydrogen fueling station is intended for each of these entities. As of today (January 2023), only three internal routes are served regularly: Bucharest – Timisoara, Bucharest – Cluj-Napoca and Bucharest-Iasi (other routes are served with low frequency – i.e. once a week). These routes are indicated with purple lines. These are connecting the biggest four cities of the country and the flights are operated by TAROM, the national air carrier, using ATR-72 aircraft. More internal routes had been operated by TAROM in the past, but these were gradually reduced due to low loading factors, making them unprofitable.

The routes marked in yellow are examples of routes that can be implemented in a train-like operational model, with a frequency of up to 6 flights per day. If we take as example the central route (Bucharest – Baia-Mare) the distance between the cities, in straight line, is 408km. The only travel possibilities today are by road and by train.

By road, it takes 8h 10min to travel from Bucharest to Baia-Mare, assuming continuous drive and using the shortest route. It is worth mentioning that the drive is extremely dangerous as there is no motorway connecting the two cities and the route crosses the Carpathian Mountains. During the winter time, most of the roads in the mountains are closed and connecting the two cities becomes a real challenge.

By train, the distance between these two cities takes 12h 20min. The train also crosses the mountains and the average speed is extremely low.

Given these poor connectivity options between the two cities, the demand for traveling is almost non-existent. People from Baia-Mare have become used to living without visiting Bucharest, the capital, unless really pressing matters determines them to undertake the trip, usually planned in advanced and seen as a real challenge.

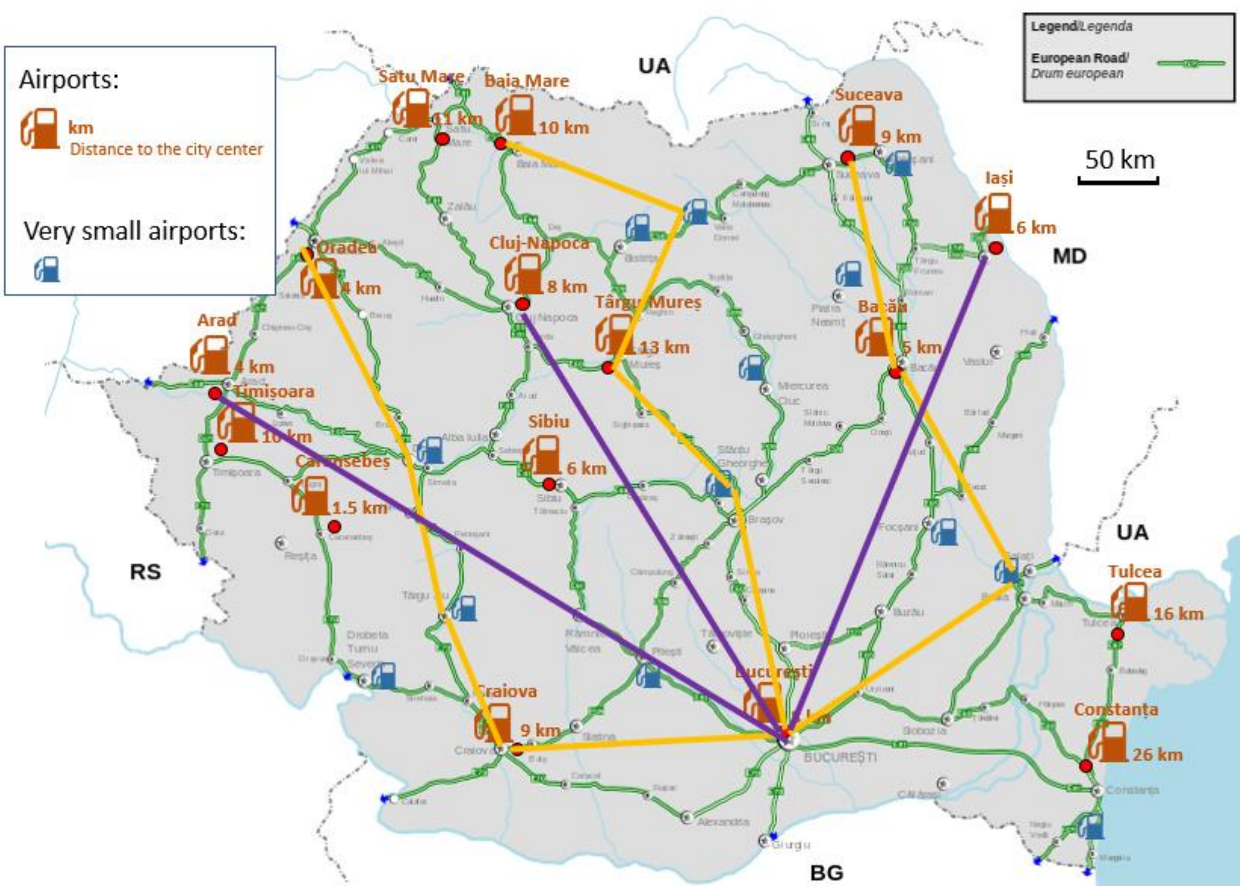

Figure 6 - Airports and very small airports network in Romania – proposed routes

The proposed flight would have four legs, connecting four cities: Bucharest – Brasov – Targu Mures – Vatra Dornei – Baia Mare. Even if the demand for an air connection between each of these cities and Bucharest is low, when served in series, the demand ads-up and the aircraft loading factor per mission increases to more than 100%.

A direct flight from Bucharest to Baia-Mare would take 50min, considering an average aircraft speed of 500km/h. Assuming 15min stationing in each of the three intermediate cities, the trip time would increase by 45min compared to the direct flight. An additional 10min per segment can be assumed due to increase in the length of the trip and slower speed on the descent and climb phases. This amounts to an extra 40min. Therefore, the total increase in trip time is 1h 25min. Also adding the initial duration of 50min, the total trip time now amounts to 2h 15min. This is still much better when compared with 8h 10min by car and 12h 20min by train.

At least 5 such routes can be identified for Romania. Connecting almost all the cities served by an airport or very small airport. A minimum of 2 aircraft per route would be required for creating a flight frequency of 4-6 flights per day. Therefore, **the novel air transport network in Romania would require 10 Stratobus-30 aircraft for connecting all the cities of the country with the capital and among themselves**. The Romanian Government is considering the development of such an air transport network in the future, relying on zero-emission aircraft. As a consequence, the development of the Stratobus-30 is of interest for the Romanian Ministry of Transportation. A letter expressing the interest of the Romanian Ministry of Transportation for this aircraft is available.

Romania is not a singular case among the European countries. Other countries, with bigger surface and bigger need for connectivity would surely be interested in this type of air operations. This is not something in existence today. The potential market can only be deduced indirectly, as no direct evidence can be put forward for supporting this.

3.5 Point-to-point between secondary airports

The analysis in this paragraph relies on the information available in ref [3.14] – *Current challenges and future prospects for EU secondary airports*. This is a report produced by the European Parliament – Directorate-General for Internal Policies, in 2015, and meant to provide suggestions for improving the legislation associated to secondary airports.

In this document, a secondary airport is defined as an airport with a traffic lower than 5 million passengers per year.

A general conclusion of the report is that in the EU, secondary airports are severely affected by the development of large airports, named hubs. In fact, these large airports compete with the small ones for the most profitable source of income – low cost carriers (LCC).

Several types of activities have been identified for the secondary airports:

- Public Service Offerings (PSO). This is the type of public transport-like operation identified also in Paragraph 3.3. The airlines are required to operate a minimum number of flights, with a maximum limit on the price of the ticket. These companies are heavily subsidized by the governments. The

EU countries in which this type of operation is most common: France, Scandinavia, Greece, Islands of Scotland.

- Provide access to a hub airport. This is a type of activity every secondary airport wishes to develop. The main problem with this is the lack of slots on the main, hub airports. As a consequence, airlines have low interest in connecting the secondary and the main airports, as the main airport would become too crowded.
- Support business travel. This is one of the main sources of income for the secondary airports all around Europe. Traditionally, the business aviation industry was not sensitive to the price value of the airport taxes, but recently this has started to become an issue. As such, secondary airports have been forced to reduce taxes to continue to conduct business with private jets operators.
- Leisure travel and tourism. This is an activity highly reliant on the LCC operations on such airports. As major airports are making efforts to relocate LCCs on their premises, secondary airports see a continuous decrease in this type of traffic. Moreover, the flux of passengers associated to this type of travel is highly seasonal, with peaks during the summertime and lows during the wintertime.
- Migrant and worker traffic. This type of activity is intense in the regions in which significant ethnic or cultural minorities are localized – e.g. southern part of France has a high density of workers from Northern Africa (Tunisia, Maroc, Algeria). These workers are regularly travelling to and from their home regions.

Out of these five types of operations conducted by secondary airports, two have the potential to constitute a market for the Stratobus-30 aircraft: leisure travel and migrant/worker migration.

While the airline operating mode described in Paragraph 3.4 relies mostly on domestic flights (internal to any given country), the operation involving connection of secondary airports is also open to international travel. Connecting secondary airports located in two different countries (for example, Romania and Italy – a distance of maximum 1500km) would capture a part of the market that is now served by the LCC (WizzAir and Ryanair). As explained above, these carriers are now migrating from secondary to bigger airports. For equal price of the ticket, or even slightly higher compared to LCC's offer, people would rather take a trip from the airport that is closer to their point of departure.

Another point of interest for this type of operation (connection between secondary airports) is the competition with the rail. While some countries have an extended rail network (e.g. Germany), other do not have this "luxury" (e.g. in Eastern Europe). In addition to the rail network not being developed enough, the average speed of the train is very low. As mentioned in Paragraph 3.4, a direct connection between different secondary airports of the country could address the needs of a significant number of travelers.

Even in developed countries, the rail network does not fully cover the mobility need. For example, in France, although on the North-South direction the rail infrastructure allows rapid transit, on the East-West direction, almost all rail routes go through Paris. This is inconvenient both in terms of price and time. A direct air connection between eastern and western airports in France would attract many travelers that now have no other alternative than the train.

When it comes to the Stratobus-30 – train competition, it is shown that the cost of exploitation of the Stratobus-30 can be very low (see Paragraph 5), making it competitive with both rail and road transport.

The final consideration in this analysis is related to the type of aircraft used for connecting secondary airports today. The excerpt from ref [3.14], page 31 is self-explanatory: "*Currently these* [routes] *are flown by turboprop aircraft such as Beech 19's, Saab 340's and Jetstream 31 and 41 aircraft with seat capacities of between 19 and 40 seats. There are no new model aircraft planned or in production to replace aircraft in these categories. Manufacturers of jets with 50 or less seats are now replacing these with larger models precisely because the cost economics of these smaller models are increasingly unsustainable.*

These aircraft are ageing and the nature of their flying is "high cycle" meaning frequent but short flights which puts the greatest strain on the airframe and requires heavier maintenance and design life limitations."

This gives a clear indication of:

- The need of using small aircraft (19-40 seats) on these secondary routes
- The fact that the small aircraft in exploitation today seem to incur cost/seat higher than the cost/seat of bigger aircraft
- The fact that there is no new aircraft model in development that can replace the existing models
- The fact that the aircraft operating on these routes are subjected to "high cycle" exploitation

It can be inferred that a new 30-seater aircraft with low operating cost per seat, with zero-emissions, capable of covering both short and medium distances and requiring little maintenance would be a highly desirable product for maintaining in operations the secondary routes active today and for opening new such routes. It is the author's opinion that, although difficult to quantify, the availability of such an aircraft (the Stratobus-30) would open new business perspectives for airlines across Europe, mostly for the domestic and regional airlines. The market is there, waiting for a product to capture it.

4 Study of the competition

For the purpose of this analysis, one will consider competition a company that offers an aircraft with the following characteristics:

- Capacity around 30 passengers (+/- 10 passengers)
- Zero-emissions: powered by batteries, or hydrogen or a combination of the two
- Estimated EIS before or shortly after 2030

There are not many companies developing such aircraft today. A non-exhausting list of companies actively involved in the development of technologies for zero-emission aviation is indicated next.

Companies developing hydrogen powertrains:

- **Universal Hydrogen** [4.1] – US based. The company is developing hydrogen-based powertrains and hydrogen storage systems and is also developing hydrogen supply solutions. The goal of the company is to offer a high-power powertrain that can be integrated on existing turboprop airliners (e.g. DHC-8, ATR-42/72).
- **ZeroAvia** [4.2] – US/UK based. The company is actively developing hydrogen-based propulsion systems. The company did not announce any intention of developing an aircraft. As Universal Hydrogen, they position themselves as powertrain suppliers (for the moment).

- **GKN Aerospace** [4.3] – UK based. The company goes one step further than the previous two companies and develops the entire propulsion system: hydrogen storage –> energy chemical to electrical conversion → high power electric systems → thrust effectors (ducted fans). The company wants to position itself as full propulsion systems provider for the next generation of zero-emission aircraft.
- **H2Fly** [4.4] – Germany based. The company is a spin-off of DLR. As for the other companies, H2Fly seems to focus on the development of hydrogen-powered powertrains. It is not entirely clear whether the company is targeting the development of a commercial aircraft in the long run.
- **MTU** [4.5] – Germany based. The company is focused on the development of a hydrogen powertrain for aviation.

Companies developing hydrogen-powered aircraft:

- **Deutsche Aircraft** [4.6] – Germany based. The company is focused on developing the next generation of Dornier 328, labeled "eco". This aircraft is equipped with latest generation turboprops, most likely using SAFs. In addition, the company is working (together with DLR and other German partners) on the development of the Dornier 328H2-FC demonstrator, powered by Fuel Cells and hydrogen. However, the development is now at the stage of R&D. No clear intention has been publicly announced for the development of a commercial zero-emissions aircraft.

- **Cranfield Aerospace** [4.7] – UK based. The company is developing a hydrogen fuel cell powered aircraft on the basis of the BN-2 Islander. This aircraft is a 1960s design, 9 seater, retrofitted with hydrogen powertrain. The aircraft is being developed in the context of R&D project Fresson, funded by the UK government.

- **Embraer** [4.8] – Brazil based. The company recently made public a strategy for the development of a new line of aircraft: SAF-powered, hybrid-electric, hydrogen-electric. Of interest for this analysis is the company's objective to develop two aircraft under the Energia project: a 19-pax and a 30-pax, both propeller-driven. By 2030 they plan to develop the SAF-powered version and by 2035 they plan to adapt the designs for hydrogen fuel cells. The estimated range with hydrogen is 200 NM (370 km).

- **Pipistrel** [4.9] – Slovenia based. The company launched in 2021 a development project for a 19-seater hydrogen powered aircraft, named Miniliner. The projected EIS is 2030/2031. The aircraft will be powered by a combination of fuel cells and batteries for allowing a max take-off distance of 800km. According to Pipistrel, this ensures access to 80% of

European airports. The target range for this aircraft is between 300km-400km, but the maximum range, with liquid hydrogen, will be around 1850km. The installed power is about 2 MW. According to a market analysis performed by the company, there is a market for around **1500** such aircraft, worldwide.

- **Avions Mauboussin** [4.10] – France based. The company has launched the development of two small aircraft: a 2-seater (Alerion M1h) and a 6-seater (Alcyon M3c). For both aircraft, an initial thermal-electric hybrid version will be developed. The design will be next adapted for hydrogen fuel cells. The company plans to have the 2-seater available for commercialization by 2024. No EIS is specified for the 6-seater.

- **Electric Aviation Group** [4.11] – UK based. The company is developing a 100-seater aircraft, that can use both SAFs and hydrogen fuel cells. The range of the aircraft is 1200 NM (2200 km). The operational model relies on refueling the aircraft only at its operational base, in the assumptions that other airports will not have a H2 infrastructure readily developed. The EIS is planned for 2030.

- **Aviation H2** [4.12] – Australia based. Following a feasibility study, the Australian company decided to launch a project for fueling a Falcon-50 aircraft with ammonia sourced from green hydrogen. The main challenge for the company is onboard storage of ammonia and the modification of the turbofan engine to run on ammonia instead of Jet-A. It is not clear what are the future development prospects for the company.

- **Airbus** [4.13] – France/Germany based. The company's strategy is already widely known in the world of aviation. The company is planning the development of three aircraft types, all using hydrogen as an energy carrier, with a projected EIS in 2035. The lowest capacity of the three designs is a turboprop-like aircraft converting liquid hydrogen into electricity by means of fuel cells. The capacity is expected to be lower than 100 seats and the projected range is ~1000 NM (1850 km).

Out of all the companies/projects listed above, the real competition for the Stratobus-30 is represented by:

- Deutsche Aircraft (if it decides to launch the Dornier 328H2-FC program in commercial development)
- Embraer "Energia" – with its H2 powered 30-seater with EIS in 2030
- Pipistrel – with its Miniliner design, 19-seater, EIS in 2030/2031
- To a lesser extent, Cranfield Aerospace, with its H2-powered, 9 seats, BN-2 Islander (EIS much before 2030)

This analysis first proves that there are many companies developing H2 powered aircraft with capacities under 100 seats. By extension, this proves there is a substantial market for this type of aircraft (one must assume that the development of a new aircraft type is relying on a detailed market analysis). In this respect, Pipistrel's estimate of the market for 1500 units is encouraging.

Second, this analysis puts into evidence the required characteristics of the new aircraft, depending on the type of market to be approached. For example, Deutsche Aircraft and Cranfield Aerospace are focusing on retrofitting existing aircraft with H2 powertrains. This ensures a relatively fast time to market, reduced design time and cost, but has a major disadvantage: the resulting product is not at all optimized for running on hydrogen. The initial platform was designed for a different type of fuel and, no matter how much adjustment is performed, it won't be optimal for hydrogen.

One can see Embraer's range target: 370km. This might be originating in an extensive market analysis or, more likely, in the need to reduce the storage volume of hydrogen. Embraer's aircraft are betting on good aerodynamic performance and high loading factor. It seems the space available for on-board hydrogen storage is greatly reduced. The implication is that the resulting aircraft can only be used for short routes and all the airports on which it operates must be equipped with hydrogen refueling infrastructure.

Finally, Pipistrel's design seems to be the most promising and, in fact, the only real competitor for the Stratobus-30. The only disadvantages of this aircraft are the low capacity (19 seats), the usage of liquid hydrogen (which poses significant technological and operational challenges) and the high power/MTOW ratio (leading to high fuel consumption and, in turn, leading to high operational costs). The Stratobus-30 has the capacity to overcome all these shortcomings, with a higher capacity (30+ seats), the usage of gaseous hydrogen and low power/MTOW ratio.

Up to this point of the analysis, one was able to point out the existence of a market for H2-powered aircraft by looking at the OEMs that have already launched aircraft development projects. Therefore, the market existence is determined indirectly. Next, one will try to quantify, in a direct manner, the existence of a market for 30-pax zero-emissions aircraft. The aircraft on which this analysis is based is a battery-electric aircraft, the ES-30, developed by the Swedish company Heart Aerospace [4.14]. The company started the development of a full electric 19-seater but, mid-course, changed the development strategy and reoriented it towards the development of a bigger aircraft, a 30-seater. This suggests that the market for a 30-seater is bigger than the market for a 19-seater (looking at this information in the context of Pipistrel's analysis, which identified a market of 1500 19-seater H2 powered aircraft, one can infer that the market for the 30-seater is superior to 1500 units).

Due to shortcomings in the battery technology, the ES-30 will only have a range of 200km in full electric mode. This range will be extended to 400km with a thermal range extender using SAFs. If, additionally, the capacity is reduced from 30 pax to 25 pax, the range with the thermal range extender is increased up to 800km. This suggests that a range of 200km (and even 400km) is not enough for such an aircraft. 800km starts to become acceptable but, if a further range increase is required, the reduction in capacity is severely diminishing the commercial potential. It can be deduced that a range of 800km+ with 30 pax would be highly desirable.

The information available in [4.15] offers important clues related to the development of a zero-emissions, 30 pax aircraft. These clues are summarized next.

- *"[the launch of the ES-30] coincides with a soaring and competing trend to retrofit older commuter planes with new electric or hydrogen propulsion systems, for which significant orders have been secured by start-ups including ZeroAvia and Universal Hydrogen, both well-backed by major industry players and venture capital investors*". This statement indicates the fact the airlines are today willing to adopt one-to-one replacement of their fleet with aircraft that are retrofitted for H2 operation. As stated before, these aircraft are not optimized for hydrogen operations, meaning the fuel consumption will be high. If an equivalent aircraft is being offered, that can fulfill the same mission but with lower hydrogen consumption, it is anticipated that the demand would be much higher.
- A study performed by Distrelec and available in [4.16] reveals that the European nordic routes have the greatest potential for the adoption of a 30-pax aircraft. The total CO2 emissions eliminated by the adoption of a "clean" aircraft are staggering. The countries most suited for such an aircraft are: "*Norway with a potential to reduce flight carbon emissions, of up to 29,038 tonnes[…], followed by Sweden with 17,260 tonnes, Finland with 6,264, Denmark with 4,177, Greenland with 2,390, and Iceland with 1,994."*
- Heart Aerospace seems to be backed by important names in the aviation industry, in the form of direct investments and grants: United Airlines, Air Canada, Saab, Breakthrough Energy Ventures, EQT Ventures, European Innovation Council, Lower Carbon Capital, Mesa Air Group, etc. This suggests that there is a sufficient amount of private capital on the market that can be used for the development of a competitive zero emission aircraft, provided this aircraft has technical and operational characteristics superior to what is already on the market or in development today.
- So far, Heart Aerospace has secured, for their ES-30 aircraft, 230 firm orders and LOIs for the purchase of extra 236 units as follows:
  - 200 orders and 100 options from United Airlines and Mesa Air Group
  - 30 orders from Air Canada
  - LOIs for 40 units from Rockoton
  - LOIs for 96 units from Braathens Regional Airlines, Icelandair, SAS and New Zealand's Sounds Air.

The conclusion of this analysis is that today, there is a market for at least 466 aircraft with a sitting capacity of 30 passengers and with very low range – 200km in clean electric. For increased range, the aircraft cannot be considered zero-emissions as it uses SAFs for the range extension. Once again, it can be concluded that a Stratobus-30 aircraft with a capacity of 30+ seats and ranges in excess of 1000km in zero-emission mode would be in much higher demand, provided the cost of operation is comparable to the cost predicted by Heart Aerospace for their ES-30. The lack of H2 infrastructure can be overcome by designing the Stratobus-30 for a long enough range, sufficient to perform a mission (return trip) without the need to refuel at the destination airport. Hydrogen energy combined with superior aerodynamic performance allow for this type of range in the case of Stratobus-30.

5 Analysis of cost of operation

This paragraph is dedicated to identifying the cost structure of an airline operating the Stratobus-30 and quantifying, where possible, the financial advantages the Stratobus-30 can introduce, compared to other, similar aircraft.

Reference [5.1] provides a good overview of the total cost of an airline and how this cost is reflected in the ticket. Hereafter, one illustrates the cost structure as provided in this referenced material.

A. Airline fixed costs
   - A.1 Aircraft depreciation (or rental costs)
     The most common practice in the industry is to consider 4% depreciation per year. This translates into a total exploitation life of 25 years for the depreciation of the entire cost. However, as seen in Figure 5, the exploitation time for the types of aircraft of interest for this analysis is in excess of 30 years.
   - A.2 Maintenance costs
     This cost component can be considered either as a fixed component, or as a function of flight hours per aircraft.
   - A.3 Aircraft insurance costs
     The insurance cost is a function of the type of aircraft and type of exploitation.
   - A.4 Reservation and booking costs
     If the airline collaborates with third parties for commercializing the tickets, there is an extra cost associated to this service, compared to the case in which the tickets are only available on the airline's websites.
   - A.5 Staff and management costs
     The staff is all the non-flying personnel employed by the airline.

B. Flight operating costs
   - B.1 Staff costs (cabin crew, including pilots)
     This is related to the cost of the flying personnel – pilots and flight attendants. While the number of pilots – two – is fixed for any type of passenger-carrying aircraft, the number of flight attendants is variable. An ICAO recommendation results in one flight attendant for the Stratobus-30. This number is, however, dependent on national regulations.
   - B.2 Cost of fuel
     Together with the cost of staff (flying and non-flying) the cost of fuel is one of the most significant cost components. For A320/B737 like aircraft, the cost of fuel (Jet-A) amounts to around 17% of the total cost per flight, according to an estimation provided by the FAA.
   - B.3 Landing fees
     This is a tax perceived by the airport for each aircraft that uses the runway. The tax is highly dependent on country, size of airport, size and type of aircraft, the moment of the day in which the runway is used.
   - B.4 Airport and government taxes
     This is a type of tax implemented by some countries in the form of a "hidden" taxation of the fuel used in aviation (as directly taxing it is forbidden in the EU countries). An example of such tax is the UK's Air Passenger Duty tax, applicable only for flights that take-off from UK soil.

B.5 Overflight fees en route

This applies to international flights. It is a tax perceived by each country over which the aircraft flies. It incorporates the air traffic management and navigation services provided to the aircraft. The tax is variable depending on the country and whether the flight is over land or over water.

B.6 Ground handling fees

This is a fee that covers the airport services outsourced by the airline: refueling, baggage handling, etc.

Trying to quantify the cost of exploitation of the Stratobus-30 would require making a large number of hypotheses, estimating values that are not known and imagining a specific operating scenario for the aircraft. All these would introduce a high degree of uncertainty in the analysis. Luckily, for the purpose of the analysis reported in this document, there is no need for an accurate evaluation of the *total* cost. Most cost components are country and airline dependent and won't change much depending on the type of operated aircraft. On the contrary, there are some cost components in direct relation with the considered aircraft. For example:

- A.1 Aircraft depreciation. This cost is a direct function of the total cost of the aircraft.
- A.2 Maintenance cost. Once again, this cost is a strong function of the aircraft. It is an aircraft characteristic defined by design.
- B.2 Cost of fuel. One has the interest of operating an aircraft that consumes as little fuel as possible. Also, not only the cost of the fuel is important, but also its availability.
- B.3 Landing fees. To a much lesser extent, this cost can be influenced by the aircraft's characteristics like: level of perceived noise, take-off and landing distances that could make some small and very small airports (that inherently have very low fees) inaccessible.

The cost component A.1 can be evaluated by looking at the cost of the similar aircraft in existence today (aircraft included in Annex 1). It was made the point that a possible market for the Stratobus-30 is the direct replacement of a number of aircraft being operated today by airlines worldwide. An estimation of the cost (as new) for these aircraft is included in Table 1, and is sourced from [5.2]. The cost per seat is then calculated for having a common reference, as each aircraft has a different number of seats.

It can be seen that the cost per seat varies between $125 000 and $406 000. For a 30-seater, which is the envisaged capacity of the Stratobus-30, this would translate into a cost range between $3.75 mil and $12.2 mil. The range is wide, but it gives a rough idea of the cost to be considered for this aircraft. One can argue that, given the zero-emissions characteristics of the Stratobus-30, an airline would be willing to pay slightly more for the aircraft, as the initial expense will be compensated overtime by eliminating carbon taxes.

Assuming $12.5 mil the initial cost of the aircraft, the annual depreciation (equal to 4%) is equivalent to $500 000. Further assuming four missions per day, 260 days a year (weekends not included), the depreciation per mission amounts to $481, equivalent to $16 per passenger per mission, with a loading factor of 100%. If the average mission length is 800km, this cost component comes down to 2 cents per passenger per km (1.84 eurocents per passenger per km).

Aircraft type	Cost (new) when launched [mil$]	Equivalent cost today [mil$]	Cost/seat [$]
ATR-42-600	$19.5	$19.5	$406 000
BA Jetstream 41	$1.6	$7	$241 400
DHC-6 [ref 5.3]	-	$5.9	$295 000
DHC-8-100	-	$12	$307 700
Dornier 328	-	$8	$266 700
Embraer 120	-	$11	$366 700
Fokker 50	-	$7	$125 000
Saab 340	-	$10	$295 000
Cessna 208	-	$2.32	$178 500
Cessna 408	-	$5.5	$290 000

Table 1 - Cost per aircraft (as new) for existing aircraft - see Annex 1. Source: [5.2]

Cost component A.2 is extremely difficult to assess for a to-be-developed aircraft. A reduction of this component can be ensured by having a system with a low number of moving parts, having robust and reliable sub-systems and ensuring that some components can be reused following overhaul, rather than replaced. Also, the maintenance cost can be minimized by implementing a continuous health monitoring system (HMS), rather than imposing maintenance activities at fixed intervals (operating hours). The HMS continuously compares the state of the aircraft subsystems with the state of the equivalent subsystems on a digital twin. When a subsystem is found to be in a non-satisfactory state (indicating a high probability of failure) the operator is notified that a maintenance action is required. It has been proven, over time, that this maintenance technique is much more cost-effective than the classical approach.

Cost component B.2 – Cost of fuel – can be estimated directly for the Stratobus-30, by calculation. The calculation is performed on a predefined mission with a length of 1400km. A hybrid powertrain architecture is selected, composed of hydrogen fuel cells using gaseous hydrogen and electric batteries. The analysis makes a comparison between the cost of development of the powertrain for the Stratobus-30 and the Dornier 328, hydrogen powered version. It turns out that while the development of the powertrain for the Stratobus-30 amounts to 1.18 mil €, the equivalent cost for the powertrain of the Dornier 328 is 6.37 mil €. For the considered mission, the cost of energy (hydrogen + electricity) is 551.5 € for the Stratobus-30 and 2409.2 € for the Dornier 328. For the Stratobus-30, this comes down to 1.31 eurocents per passenger per km.

The currently flying Dornier 328 aircraft has a fuel consumption of ~1.22 kg Jet-A per km, according to [5.4]. As given in [5.5], the price of Jet-A fuel in Europe in ~1063.65 $/mt, meaning 1.063 $/kg. This implies that the cost of fuel per km for the Dornier 328 is ~1.3 $/km, i.e. ~1.19 euro/km. This translates into 3.97 eurocents per passenger per km.

It follows that the cost of fuel per seat per km for the Stratobus-30 is roughly 3 times lower than the equivalent cost of nowadays Dornier 328. An average price of 10 €/kg of H2 has been considered in this analysis. By the time the Stratobus-30 enters commercial operation, the price of “green” hydrogen is expected to have a significant drop, thus making the cost of fuel/mission even lower than the current estimation.

One critical aspect in the fuel availability analysis is that for the 1400 km mission, the estimated hydrogen requirement for the Stratobus-30 is 53.2 kg (compared to 232.4 kg H2 for the Dornier 328). This implies that, given the small mass, hydrogen can be stored in gaseous form onboard the Stratobus-30 (this is not possible for the Dornier 328). Gaseous, pressurized storage is much more convenient than liquid, cryogenic storage, from multiple points of view:

- The storage technology is readily available
- The storage technology is mature enough and proven safe in real exploitation conditions, in the automotive industry
- The refueling is more accessible and easier than for cryogenic hydrogen. The energetic input required for cooling the hydrogen is higher than the energy input required for pressurizing it → lower cost per kg of pressurized H2 (when compared to liquefied H2).

There are four main outcomes of this financial analysis of the Stratobus-30:

1. The overall cost of the commercial aircraft should be around $12.5 mil (or lower) to be competitive with existing, operating aircraft of similar capacity.
2. Out of this total cost, about $1.28 mil (1.18 mil euro), roughly 10%, is the cost of the electric powertrain (hydrogen fuel cells + batteries + hydrogen storage system)
3. The depreciation cost of the aircraft can be as low as 1.84 eurocents per passenger per km
4. The cost of energy per mission (hydrogen + electricity) is low: 1.31 eurocents per passenger per km. By comparison, the cost of fuel for the existing Dornier 328 is 3.97 eurocents per passenger per km

The four conclusions of this analysis indicate that an airline operating a classical Dornier 328 and a Stratobus-30 on the same mission (same airports, same mission length, same number of staff, etc.) would be more satisfied by the financial performance of the Stratobus-30 compared to the one of the Dornier 328. On top of that, the Stratobus-30 is a zero-emission aircraft.

6 Market-driven requirements

This paragraph contains a list of requirements the Stratobus-30 needs to meet, requirements that stem from the market analysis performed in previous chapters. The aircraft's access to various markets is dependent on the designer's ability to incorporate a large number of these requirements (maybe all) in the final design.

Each requirement is accompanied by the context which triggered it and a justification.

A. <u>Design-related requirements</u>

Requirement DES-1: *The Stratobus-30 shall be a zero-emission aircraft.*
Context: Irrespective of the targeted market, sustainability is a must. All new aircraft need to ensure the maximum level of sustainability allowed today for its characteristics (size, capacity, range, speed, etc.).
Justification: As of today, the hydrogen-electric and battery-electric powertrain technologies allow the development of a true zero-emission aircraft. Net-zero, although more accessible from a technical point of view, represents just a transition technology towards zero-emission. Net zero shall not be considered as an option.

Requirement DES-2: *The Stratobus-30 shall have a capacity between 30 and 40 seats.*
Context: Compatibility with existing operational fleet today, as shown in Paragraph 3.1 – Figure 4
Justification: It can be seen that the existing market today favors aircraft with a capacity between 34-39 seats (329 aircraft). The market for 29-33 seaters, although existent, is much smaller (127 aircraft).

Requirement DES-3: *The Stratobus-30 shall have folding wings.*
Context: Compatibility with existing operational fleet today.
Justification: Although a wingspan of 56m (the current wingspan of the Strato-2C) increases the aerodynamic performance and leads to a significant decrease in fuel consumption, operation on most medium, small and very small airports will be impeded. Immediately after landing, in the taxi phase, the Stratobus-30 shall be able to fold its wings and decrease the apparent wingspan to no more than 30m. Shortly before take-off, in the taxi phase, the wings shall be deployed to the original configuration.

Requirement DES-4: *The Stratobus-30's cargo bay shall be easily accessible, allowing fast removal and insertion of small air containers, along with passenger's baggage.*
Context: Suitability for cargo operations.
Justification: As shown in Paragraph 3.2, the Stratobus-30 could also be used for air cargo operations, in addition to passenger transport (the same aircraft, on the same flight, passengers + cargo).

Requirement DES-5: *The Stratobus-30 shall have avionics allowing night and low visibility operations in airports that do not have ILS capacities.*
Context: Suitability for the train-like operation, using small and very small airports.
Justification: This capability opens up a large market for the aircraft, if operation on small and very small airports is allowed in such conditions.

Requirement DES-6: *The Stratobus-30 shall be equipped with a powertrain using a combination of gaseous hydrogen (+ fuel cells) and electric batteries.*
Context: Simplification of hydrogen infrastructure on airports.
Justification: Providing compressed gaseous hydrogen and operating with it is much simpler than operations with liquid hydrogen. The refueling infrastructure can be developed faster and with much lower costs. Also, the same infrastructure can be used for other consumers (public transport, personal vehicles, trucks, trains, etc.) facilitating investment from local authorities.

Requirement DES-7: *The Stratobus-30's structure shall allow high-cycle operation for a period of at least 25 years, with minimum maintenance.*
Context: (1) Suitability for current operations from secondary airports. (2) Suitability for the train-like operation, using small and very small airports.
Justification: A train-like operation introduces a differentiation between mission and cycle. Mission = take-off from base and land at the destination airport. Cycle = take-off from one airport and land on another airport. One mission can involve 1, 2, 3, 4 or more cycles, depending on the envisaged intermediate stops. It follows that the degradation of a "classical" structure is faster in this mode of operation, leading to a shorter life of the aircraft. If a "classical" aircraft can be operated for 40+ years, at

least 25 years of life will be targeted for the Stratobus-30, for ensuring complete depreciation, with a rate of 4% per year.

Requirement DES-8: *The Stratobus-30 shall incorporate a predictive maintenance system, in which the state of each subsystem is evaluated in real time and a maintenance intervention is planned only when needed.*
Context: Competitivity with similar capacity aircraft in existence today.
Justification: The cost analysis reveals that the cost of maintenance is a significant component of the total cost. A minimization of this component is imperative.

Requirement DES-9: *The Stratobus-30 shall produce a maximum level of noise in take-off and landing, with an intensity at least 10% lower than observed in modern, same capacity, propeller-driven aircraft.*
Context: Suitability of operation on small and very small airports.
Justification: The small and very small airports are usually close to inhabited areas. Also, the traffic on these airports is usually low. A significant increase in traffic – driven by the operation of the Stratobus-30 – would cause negative reactions from the community living nearby the airport, unless the noise produced by the aircraft is low. Also, the landing fees on certain airports might be correlated with the noise intensity.

B. Performance-related requirements

Requirement PERF-1: *The Stratobus-30 shall have a cruise speed of 500 km/h.*
Context: Compatibility with existing operational fleet today.
Justification: For capturing a big part of the existing market, the performance of the new aircraft should be as close as possible to the performance of existing aircraft.

Requirement PERF-2: *The aircraft's commercial range (excluding reserve fuel) shall be minimum 1600km.*
Context: (1) Compatibility with existing, similar aircraft. (2) Performance similar to the one targeted by the competition.
Justification: The maximum range of current aircraft is ~1800-1850km. The maximum range of the battery-electric ES-30 aircraft is 800km. The Stratobus-30 needs to have two times ES-30's range, to be able to fulfil the same missions as the ES-30, without needing to refuel at the destination airport.

Requirement PERF-3: *The Stratobus-30 (or a version of the aircraft) shall have STOL capabilities. A take-off and landing distance of no more that 800m shall be targeted.*
Context: (1) Suitability for island-hopping operation. (2) Suitability for the train-like operation, using small and very small airports.
Justification: Operation from small and very small airports opens completely new markets for the aircraft. A dedicated version of this aircraft can be developed for this type of operations. A potential solution: implementation of electric motors in the landing wheel that supply extra power for take-off and provide braking during landing.

Requirement PERF-4: *The Stratobus-30 shall have weather-related operating characteristics that are not worse than the characteristics of existing, similar aircraft (e.g. Dornier 328, DHC-8, Saab-340, etc.)*
Context: Compatibility with existing, similar aircraft.
Justification: The structural design and flight and maneuverability characteristics shall allow the Stratobus-30 to perform equally well in adverse weather conditions as an existing aircraft of similar capacity.

C. Business-related requirements

Requirement BUS-1: *The Stratobus-30 shall become commercially available within the next 5 to 7 years (2028 to 2030 horizon)*
Context: Compatibility with existing operational fleet today.
Justification: An EIS later than 2028/2030 makes the existing fleet of commuter/regional aircraft obsolete. As new, similar aircraft are not available, airlines will reorient themselves to alternative markets and operational modes.

Requirement BUS-2: *A cargo version of the Stratobus-30 shall be developed.*
Context: Suitability for cargo operations.
Justification: As shown in Paragraph 3.2, a dedicated cargo version of the aircraft could capture a part of the market that today is served by smaller aircraft (e.g. Cessna 408).

Requirement BUS-3: *The entity developing the Stratobus-30 shall offer the possibility of developing customized aircraft, suited for a variety of purposes: aerial monitoring, medical missions, charter transport of dignitaries, transport of law enforcement troops, etc.*
Context: Suitability for special missions – see Paragraph 3.2
Justification: Although the market for this type of application is not as big as for commercial passenger or cargo transportation, it should not be ignored.

Requirement BUS-4: *The total price of the Stratobus-30 (list price) shall be lower than $12.5 mil.*
Context: Competitivity with similar capacity aircraft in existence today.
Justification: The cost analysis reveals that this is the maximum value a “classical” 30-seater would cost today. A higher cost needs to be accompanied by significant performance benefits, resulting in potential for increased profit for airlines.

7 Concluding remarks

This investigation reported in this document reveals the commercialization potential for the Stratobus-30, a zero-emission, hydrogen powered aircraft developed from the Strato-2C experimental platform. Depending on the design characteristics, performance and business goals of the new aircraft type, the potential market can be quantified as follows:

a. Replacing the current global fleet of commuter/regional aircraft (10 to 50 seats) represents a total market of ~720 units. The new aircraft should be available within the next 5 to 7 years for capturing this market.
b. The air cargo market is relatively small. Legacy logistics companies could potentially be interested in such a cargo aircraft. As an example, one identified a potential order for ~50 Cessna 408 SkyCourier placed by FedEx.
c. The island-hopping market is significant. This is difficult to quantify. At least 52 island-states (members of the SIDS union) could potentially be interested in implementing an air transport system relying on this aircraft. Additionally, in countries like Greece, UK (Scottish islands), Scandinavian countries (Denmark, Norway, Sweden, Finland), due to the nature of their landscape, a Stratobus-30 could capture a significant market.
d. The connection of secondary airports is a market that still exists today, but is slowly fading away. The availability of an aircraft like the Stratobus-30 could revive this mode of operation.
e. A new mode of operation, train-like, could create a completely new market, at least equal in size to what's already available. For the case of Romania alone, at least 10 aircraft would be required for this newly proposed market.
f. Finally, another potential market is represented by special operations. As an example, the Romanian Ministry of Internal Affairs is interested in purchasing at least one Stratobus-30 for internal needs.

The potential market can also be inferred by the data released by competitors:

- Pipistrel estimates a global market of ~1500 units for hydrogen-powered, 19-seater aircraft
- The Norwegian company Heart Aerospace has already secured firm orders and LOIs for 466 units of ES-30, a battery-electric + SAF-based range extender, 30-seater aircraft.

The competition on the 30-40 seater aircraft seems to be represented by only two companies – Deutsche Aircraft and Embraer. The competition for smaller aircraft (2-19 seats) seems to be more diverse. For 100+ seats aircraft, again two competitors can be identified. Additionally, there is quite a large number of companies now developing hydrogen powertrains that could potentially be retrofitted to existing aircraft.

One thing that needs to be explicitly mentioned is that the proposed Stratobus-30 **IS NOT** equivalent to the re-engined Strato-2C platform. This is a completely new aircraft, whose design is based on the Strato-2C. The Stratobus-30 would have totally different design requirements compared to the Strato-2C. Nevertheless, a big part of the technology developed for the Strato-2C can be reused. This has a significant positive impact on the economics of the Stratobus-30 development programme.

The market analysis reported in this document has revealed a set of requirements the Stratobus-30 should incorporate, for maximizing the captured market. Some of these requirements are challenging from a technical perspective – e.g. folding wings. This justifies the proposal of developing the Stratobus-30 in two steps:

- **Step 1** - an R&D project in which:
    - The technical challenges associated with such a development are identified and addressed. There are many EU-funded projects developing technologies that could potentially be incorporated into the Stratobus-30 concept
    - Technical solutions are developed and matured that can contribute to the diversification of the modes of operation the aircraft is capable of (e.g. GPS-based landing in VFR airports, in low visibility conditions)
    - An extensive and in-depth market research is performed for identifying with a high degree of accuracy the available market for each mode of operation the aircraft is capable of
    - The ecosystem required for the development and operation of the aircraft is identified and engaged with: technology integrators, suppliers of technology, airlines, airports, local and central authorities (for the refueling infrastructure), certification authorities, etc.
    - A Stratobus-30 demonstrator is produced and flight-tested, proving without any doubt that the technology is viable and accurately determining the performance of the aircraft
- **Step 2** – a commercial development project in which:
    - Private investment is identified for the development
    - A production line is developed for in-series manufacturing of the aircraft
    - The commercial aircraft is developed and certified

It goes without saying that once Step 1 is completed, Step 2 becomes completely risk-free, thus facilitating the investment.

If multiple entities support the initiative and contribute to the justification of the endeavor, Step 1 can be implemented with a mix of funding (grants, non-reimbursable) from the Romanian government, German government and the European Commission. Other entities/countries would be welcome to join the project.

It can be seen that across the Atlantic, NASA is heavily supporting the development of the successor of the Boeing 737 in the form of a very high aspect ratio wing aircraft for transonic operation – ref [7.1]. It is obvious that high AR is the key to extremely low fuel consumption, irrespective of the type of fuel (kerosene, SAF, hydrogen or even electricity from batteries). Given the work that has already been done for the development of the Strato-2C, it would be regrettable not to take advantage and convert this work into a product that can change the future of global regional aviation.

And that product is nothing else but… the Stratobus-30.

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9 Annexes

9.1 Annex 1 – current aircraft the Stratobus-30 can replace

9.1.1 Aircraft considered in this analysis

Fokker 50

Entry Into Service: 1987
Capacity (passengers): 46 - 56
Speed (cruise): 500 km/h
Range: ~1700 km
Take-off distance: 1350 m
Landing distance: 1130 m
Wingspan: 29 m
Units produced: 213
Country of origin: Netherlands

Avions de Transport Regional ATR42 (AT42)

Entry Into Service: 1985
Capacity (passengers): 48
Speed (cruise): 535 km/h
Range: ~1300 km
Take-off distance: 1107 m
Landing distance: 966 m
Wingspan: 24.57 m
Units produced: 484
Country of origin: France / Italy

De Havilland Canada DHC-8-100 (DH8A)

Entry Into Service: 1984
Capacity (passengers): 37-39
Speed (cruise): 500 km/h
Range: ~1889 km
Take-off distance: 1000 m
Landing distance: 780 m
Wingspan: 25.89 m
Units produced: 1258
Country of origin: Canada

Saab 340

Entry Into Service: 1984
Capacity (passengers): 34
Speed (cruise): 524 km/h
Range: ~870 km
Take-off distance: 1285 m
Landing distance: -
Units produced: 459
Country of origin: Sweden

Dornier 328

Entry Into Service: 1993
Capacity (passengers): 30-33
Speed (cruise): 620 km/h
Range: ~1852 km
Take-off distance: 1000 m
Landing distance: 1200 m
Wingspan: 20.98 m
Units produced: 217
Country of origin: Germany

Embraer EMB120 (E120)

Entry Into Service: 1985
Capacity (passengers): 30
Speed (cruise): 552 km/h
Range: ~1750 km
Take-off distance: 1420 m
Landing distance: 1380 m
Wingspan: 19.78 m
Units produced: 357
Country of origin: Brazil

British Aerospace Jetstream 41

Entry Into Service: 1992
Capacity (passengers): 29
Speed (cruise): 546 km/h

Range:	~1433 km
Take-off distance:	1524 m
Landing distance:	1280 m
Wingspan:	18.29 m
Units produced:	100
Country of origin:	United Kingdom

De Havilland Canada DHC-6 (DHC6)

Entry Into Service:	1966
Capacity (passengers):	19-20
Speed (cruise):	297 km/h
Range:	~741 km
Take-off distance:	366 m
Landing distance:	320 m
Wingspan:	19.81
Units produced:	844
Country of origin:	Canada

Cessna 408 SkyCourier

Entry Into Service:	2022
Capacity (passengers):	19
Speed (cruise):	390 km/h
Range:	~715 km
Take-off distance:	1116 m
Landing distance:	-
Wingspan:	22.02 m
Units produced:	14
Country of origin:	United States

Cessna 208 (C208)

Entry Into Service:	1984
Capacity (passengers):	9-13
Speed (cruise):	344 km/h
Range:	~1982 km
Take-off distance:	626 m
Landing distance:	495 m
Wingspan:	15.87 m
Units produced:	>3000
Country of origin:	United States

9.1.2 Aircraft not considered in this analysis

De Havilland Canada DHC-7

Capacity (passengers): 50
In commercial service: < 17
Produced: 1975-1988

Short-360

Capacity (passengers): 36
In commercial service: < 40
Produced: 1981-1991

Short-330

Capacity (passengers): 30
In commercial service: limited
Produced: 1974-1992

9.2 Annex 2 – Airlines fleet data

Airline (Name - country)	Continent	No of aircraft	Aircraft type	Average age (years)
748 Air Services (Kenya)	Africa	6	DH8A	33
ACE Air Charter Express (US)	North America	5	E120	29
Aerogaviota (Cuba)	North America	4	ATR42	21
AeroGeo (Russia)	Europe	5	DHC6	7
Aerojet (Angola)	Africa	2	E120	36
Aeromar (Mexico)	North America	4	ATR42	17
Air Antilles (Guadeoupe)	North America	5	ATR42	15
Air Antilles (Guadeoupe)	North America	2	DHC6	5
Air Chathams (New Zealand)	Australia	3	Saab340	33
Air CM Global (UK)	Europe	3	DH8A	30
Air Creebec (Canada)	North America	15	DH8A	33
Air Inuit (Canada)	North America	3	DH8A	34
Air Panama (Panama)	North America	4	F50	32
Air Rarotonga (Cook Islands)	Islands	2	Saab340	28
Air Seychelles (Seychelles)	Islands	5	DHC6	8
Air Tahiti (French Polynesia)	Islands	2	AT42	9
Aircraft Leasing Services (ALS) (Kenya)	Africa	8	DH8A	34
Airest (Estonia)	Europe	7	Saab340	37
Airfast Indonesia (Indonesia)	Asia	5	DHC6	16
AirJet Angola (Angola)	Africa	1	E120	30
AirJet Angola (Angola)	Africa	2	Jetstream 41	28
Airlink (South Africa)	Africa	6	Jetstream 41	28
Airnorth Regional (Australia)	Australia	4	E120	34
Albatros Airlines (Venezuela)	South America	3	E120	34
Amapola Flyg (Sweden)	Europe	11	F50	33
Ameriflight (US)	North America	16	E120	26
Ameriflight (US)	North America	3	Saab340	33
As Salaam Air (Tanzania)	Africa	2	DH8A	25
Asia Pacific Airlines (Papua New Guinea)	Australia	3	DH8A	32
Aurora (Russia)	Europe	3	DHC6	9
Avmax Chad (Chad)	Africa	2	DHC6	4
Bahamas Air (Bahamas)	Islands	3	ATR42	7
Berry Aviation (US)	North America	9	E120	28
Bighorn Airways (US)	North America	3	DH8A	32
Blue Bird Aviation Yemen (Yemen)	Asia	3	DH8A	31
Bluebird Aviation (Kenya)	Africa	3	DH8A	31
Bluebird Aviation (Kenya)	Africa	1	F50	32

Budapest Air Service (Hungary)	Europe	3	E120	34
Canadian North (Canada)	North America	13	ATR42	29
Castle Aviation (US)	North America	7	Saab340	31
Cayman Airways Express (Cayman Islands)	Islands	2	Saab340	25
Central Mountain Air (Canada)	North America	5	DH8A	32
Central Mountain Air (Canada)	North America	3	Dornier 328	26
ChukotAVIA (Russia)	Europe	4	DHC6	10
Daily Air (Taiwan)	Asia	4	DHC6	8
DANA (Nigeria)	Africa	4	Dornier 328	4
Dannish Air Transport (Denmark)	Europe	6	ATR42	32
Diexim Expresso (Angola)	Africa	2	E120	32
Dynamic Aviation (US)	North America	4	DH8A	32
Eastern Airways (UK)	Europe	9	Jetstream 41	28
Easy Fly (Colombia)	South America	14	ATR42	6
EZ Air (Netherlands Antilles)	Islands	3	Saab340	31
FedEx Feeder (US)	North America	17	ATR42	32
FedEx Feeder (US)	North America	11	Cessna 408	1
Fiji Link (Fiji)	Islands	1	ATR42	8
Fiji Link (Fiji)	Islands	4	DHC6	6
First Flying (Japan)	Asia	2	DHC6	8
Fleet Air International (Hungary)	Europe	2	ATR42	35
Fleet Air International (Hungary)	Europe	4	Saab340	36
Flightlink (Tanzania)	Africa	2	E120	30
Freedom Airline Express (Kenya)	Africa	2	E120	30
Freight Runners Express (US)	North America	3	E120	28
Gomair (DRC)	Africa	2	F50	33
Guna Airlines (Nepal)	Asia	4	Jetstream 41	27
IBC Airways (US)	North America	10	Saab340	35
InterCaribbean (Turks and Caicos)	Islands	8	E120	29
Isles of Scilly Skybus (UK)	Europe	4	DHC6	43
Japan Air Commuter (Japan)	Asia	9	ATR42	4
Jetways Airlines (Kenya)	Africa	4	F50	34
Karun Airlines (Iran)	Asia	5	F50	31
Kokomo Private Island Resort (Fiji)	Islands	2	DHC6	9
Legends Airways (US)	North America	7	Saab340	26
LIAT (Antigua and Barbuda)	Islands	3	ATR42	9
Link Airways (Australia)	Australia	11	Saab340	26
Loganair (UK)	Europe	6	ATR42	21
Loganair (UK)	Europe	5	Saab340	32
Loganair (UK)	Europe	3	DHC6	20
Maandeeq Air (Somalia)	Africa	2	F50	34

Maroomba Airlines (Australia)	Australia	3	DH8A	32
MASwings (Malaysia)	Asia	6	DHC6	9
Mayair (Mexico)	North America	3	F50	33
MHS Aviation (Germany)	Europe	3	Dornier 328	27
Mocambique Expresso (Mozambique)	Africa	2	E120	32
Mokulele Airways (US)	North America	11	C208	
Nyxair (Estonia)	Europe	2	ATR42	16
Nyxair (Estonia)	Europe	6	Saab340	33
Olympic Air (Greece)	Europe	3	ATR42	9
Olympic Air (Greece)	Europe	2	DH8A	30
Pacific Coastal Airlines (Canada)	North America	9	Saab340	29
Pakistan International Airlines (Pakistan)	Asia	3	ATR42	16
PAL Airlines (Canada)	North America	2	DH8A	33
Pascan Aviation (Canada)	North America	5	Saab340	29
Pegasus Air Services (Indonesia)	Asia	3	DHC6	5
Pel-Air (Australia)	Australia	3	Saab340	38
Perimeter Aviation (Canada)	North America	6	DH8A	33
PNG Air (Papua New Guinea)	Australia	8	DH8A	36
Private Wings (Germany)	Europe	9	Dornier 328	25
Proflight Zambia (Zambia)	Africa	3	Jetstream 41	29
Purolator (Canada)	North America	2	DH8A	34
Purolator (Canada)	North America	1	Saab340	30
RAF-Avia (Latvia)	Europe	3	Saab340	35
Ravn Alaska (US)	North America	10	DH8A	30
Reignwood Aviation (China)	Asia	4	DHC6	6
Renegade Air (Kenya)	Africa	2	F50	32
REX Airlines (Australia)	Australia	58	Saab340	29
Rimbun Air (Indonesia)	Asia	2	DHC6	9
Rise Air (Canada)	North America	5	ATR42	30
Rise Air (Canada)	North America	5	Saab340	33
Rosneft (Russia)	Europe	7	DHC6	7
Ryan Air Service (US)	North America	2	Saab340	35
Safarilink Aviation (Kenya)	Africa	2	DH8A	31
Sahara African Aviation (South Africa)	Africa	7	E120	29
Sarpa (Colombia)	South America	2	E120	33
Satena (Colombia)	South America	7	ATR42	16
SETE Linhas Aereas (Brazil)	South America	2	E120	30
Silver Airways (US)	North America	8	ATR42	4
Silverstone Air (Kenya)	Africa	8	F50	33
Skippers Aviation (Australia)	Australia	4	DH8A	33
Skippers Aviation (Australia)	Australia	3	E120	34

Sky Express (Greece)	Europe	4	ATR42	26
Skystream Airlines (Estonia)	Europe	2	Saab340	36
Southern Airways Express (US)	North America	2	Saab340	30
SprintAir (Poland)	Europe	10	Saab340	36
Star Aviation (Algeria)	Africa	2	DHC6	5
Summit Air (Canada)	North America	2	DH8A	35
Swiftair (Spain)	Europe	5	ATR42	32
Swiftair (Spain)	Europe	6	E120	35
Swiftair Hellas (Greece)	Europe	2	E120	35
TAG Airlines (Guatemala)	North America	7	Saab340	32
Taiga Air (Russia)	Europe	2	DHC6	4
Voyageur Airways (Canada)	North America	20	DH8A	34
Wasaya Airways (Canada)	North America	1	ATR42	34
Wasaya Airways (Canada)	North America	4	DH8A	35
Western Air (Bahamas)	Islands	2	Saab340	35
WestJet Link (Canada)	North America	4	Saab340	25
Wideroe (Norway)	Europe	23	DH8A	28
Winair (Netherlands Antilles)	Islands	2	DHC6	41