Research Hybrid Electric Flying in the Dutch Caribbean

Studytour Case

by

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Research for Dutch Ministry of Infrastructure and Watermanagement

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Abstract

This report is written by two master students of Aerospace Engineering at Delft University of Technology. The assignment comes from the Innovation team at the Dutch Ministry of Infrastructure and Watermanagement, as a case for partial funding of the Studytour of the study society of Aerospace Engineering, the VSV 'Leonardo da Vinci'. In this abstract, we would like to thank all people who helped us; Michiel Selier from Ampaire, who gave us a great insight in the electric flying industry and helped us along the way by providing some technical insight. Jos Hillen from Bonaire Airport, who helped us understand the options in the current infrastructure. Martin Nagelsmit from NLR, who helped us along the way with his expertise and experience in researching electric aircraft and their feasibility. And lastly, Arjan van Vliet from the Ministry itself, who motivated us and helped us along the way.

Executive Summary

In part of the sustainable movement through the world, the Dutch ministry would like to combine two problems in the current state of the Dutch Caribbean. These two problems are the limited connection between the islands, and the fact that flights between them are not environmentally friendly. This is tackled by the idea of hybrid electric flying between the islands. This report is looking into the options which are available for this sustainable transportation. The airline Divi Divi Air is taken as the ground point, as this airline is already flying between these islands in the Britten-Norman BN-2 Islander (9 passsengers) and the De Havilland Canada DHC-6 Twin Otter (19 passengers). An alternative for one of these airplanes is investigated. The pool in which is looked, as well as the main information is seen in Table 1.

	Zunum Aero [28][17][27]	**Faradair** [13]	**Eviation** [12][5][15]	**Ampaire**	**Scylax** [26][16][11]	**ZeroAvia** [31]
Powertrain	Hybrid	Hybrid	Electric	Hybrid	Electric	H2-electric
Passengers	12	18	9	4	9	Unknown
Range [km]	1300	>1852	1000	300	300	550
Cruise speed [km/h]	547	370	440	225	300	Unknown
Procurement cost	>$4.5M	$4M	$4M	Unknown*	$2M	Unknown
Operating cost	$250/hr	Unknown	$200/hr	Unknown**	$170/hr	Unknown
MTOW [kg]	5216	Unknown	5900	2100	3500	2700
Req. field length [m]	762	300	Unknown	500	300	Unknown
Payload [kg]	1164	5000	1250	Unknown***	800	Unknown
Battery weight [kg]	1043	Unknown	3600	Unknown	1000	N.A.
Available	2022	2025	2022	2022	2027	Unknown
Status	On hold	In dev	Testing	Prototype	In dev	Prototype

Table 1: Overview of selected planes' characteristics

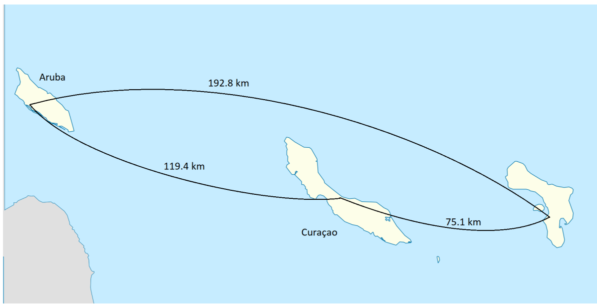
In addition to that, the airports on the islands are investigated. This includes the distance between them in Figure **??**, the availability of green energy, and the airports on the islands. It is concluded that green energy is available, but additional infrastructure for this energy will still be needed.

A short analysis on the need for ground personnel training, and the current situation of flights in Divi Divi Air are investigated. It is noted that additional training for the ground crew is not needed. The new optimal schedule for maximum charging times is presented in **??**.

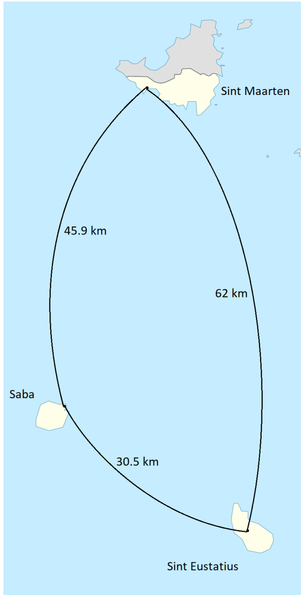
Charging every roundtrip		Charging after 3 roundtrips	
To Aruba	Back in Curaçao	To Aruba	Back in Curaçao
6:40	7:40	6:40	7:40
8:47	9:47	7:40	8:40
10:54	11:54	8:40	9:40
13:01	14:01	15:15	16:15
15:08	16:08	16:15	17:15
17:15	18:15	17:15	18:15

Table 2: New flight schedule if start and end times are kept intact.

Finally, an analysis on the battery weight and maximum take off weight relative to the range is performed in order to see how realistic the aircraft designs are. The benchmark for this is the Pipistrel aircraft which is the first certified electric aircraft. The result is shown in Figure 2.



(a) Distances between the ABC islands visualized



(b) Distances between the Leeward islands visualized

Figure 1: Distance between the islands

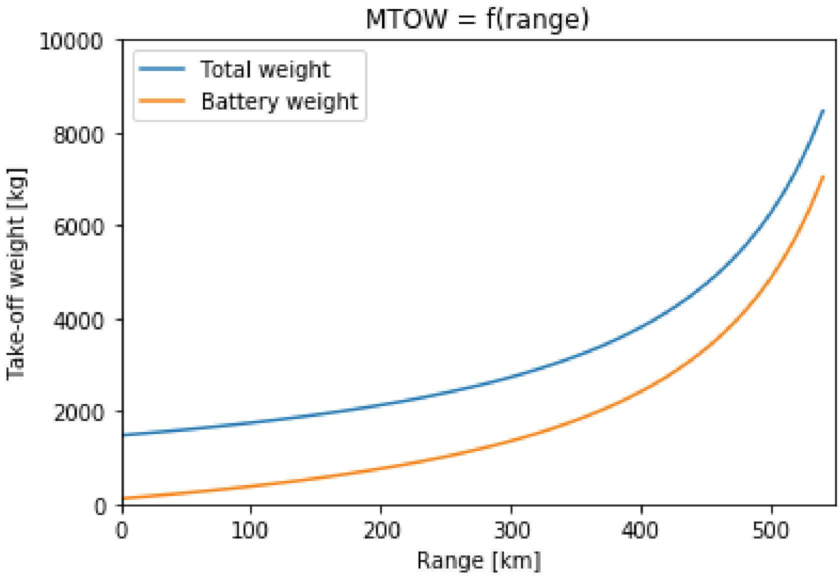


Figure 2: Total and battery mass as function of range

Lastly, a short overview on the costs is made. This overview assumes the replacement of one 9 seat aircraft with an electric variant. The costs of purchasing the aircraft, installing solar panels which will generate the same amount of electricity as the aircraft will use, training four pilots on said aircraft, cost of the electricity used, and the operating cost. The same analysis is done for the Islander which would be replaced. The result is that it is cheaper to use the electric aircraft with an investment period of ten years.

1 Introduction

Just as recent years has proven the technical and economical viability of electric cars, so too many people dream about the electrification of aircraft to curb the enormous environmental and financial cost of burning kerosene for power and propulsion in aviation. Given the implications of weight addition in aircraft and the energy density of battery storage versus kerosene, electrification in aviation is a much more complicated task. A small group of people have set out to make this change happen, though, and as of 2020, we are seeing more and more initiatives for experimentation and operation of (hybrid-)electric aircraft.

The market for electric aircraft given current technological feasibility is only limited to small aircraft, but a number of start-ups have presented designs for commercial electrical aircraft, mainly for short regional routes in remote areas or archipelagos. At this moment, these routes are dominated by aircraft in the 5-19 passenger segment, such as the Britten-Norman BN-2 Islander (9 passsengers) and the De Havilland Canada DHC-6 Twin Otter (19 passengers). In this report, the feasibility of replacing these aircraft for routes between Aruba, Bonaire and Curacao (the ABC islands) is assessed.

The main airfields on the ABC islands and the Leeward Islands are assessed in Chapter 2, to get an idea of the requirements and possibilities imposed by the airfields. In the context of circular economy, it is also assessed whether the airplanes can be flown on sustainable energy. Chapter 3 elaborates on the selection of aircraft provided to us by Nanette Lim from LVNL, and introduces a number of aircraft also deemed feasible for this application. Chapter 4 covers the implications of (hybrid-)electric flight for the personnel involved. How the selected aircraft can be implemented operationally on current routes is assessed in Chapter 5.
Given the experimental state of all (hybrid-)electric flight projects, we have conducted a very brief feasibility study in order to obtain an indication of whether the current designs are attainable or too optimistic. This study is presented in Chapter 6. A final cost overview of substituting the chosen aircraft in service is given in Chapter 7

2

Suitable Locations

In this chapter, the suitable locations for hybrid electric flights will be discussed. This will start with a short analysis of the airports on the islands, and the infrastructure the airports have. The distance between the islands will also be taken into account. The chapter will close with a short look into the availability of green electricity on these islands.

2.1. Airports

This section will shortly look into the airports on the six islands in the Dutch Caribbean. This is some info on the landing strip, and terminals. In addition to that, the movements per year are looked up to get a reference of how busy the airport is.

2.1.1. Aruba - Aeropuero Internacional Reine Beatrix (AUA)

This is an international airport with main flights to and from the United Stated and the Netherlands. The runway is 2743 meters long, and there are two terminals; one main terminal for the jets, and a smaller terminal for privately owned aircraft. In 2019, the airport had around 32,500 movements [10].

2.1.2. Bonaire - Bonaire International Airport (BON)

Bonaire International Airport also has its main flights to the United States, and to the Netherlands. It has a runway of 2880 meters. This airport also has two ramps. One for the large jets, and one for smaller aircraft, and privately owned planes. In 2018, BON had around 16,000 movements [7].

2.1.3. Curaçao - Curaçao International Airport (CUR)

This is the biggest airport of the ABC islands. This airport has the most flights to the US and the Netherlands. It has a runway which is 3410 meters long. The airport houses one terminal. It does however host spots for general aviation aircraft, and smaller passenger aircraft. In 2015, the airport hosted around 40,500 movements.

2.1.4. Sint Maarten - Princess Juliana International Airport (SXM)

Sint Maarten is the largest of the Dutch Leeward Islands, and has the largest airport. This airport receives flights mostly from the US and the Netherlands. It has a runway which is 2300 meters long. The airport has a one terminal with 13 gates, and facilities for smaller and privately owned aircraft. In 2015 the airport had around 60,000 movements.

2.1.5. Saba - Juancho E. Yrausquin Airport (SAB)

Saba only has one small airport with the shortest runway of any of the islands, and only hosts scheduled flights to Sint Maarten. This runway is 400 meters long. This runway is inaccessible to jet aircraft, but propeller aircraft can still land here. It should be noted that aviation fuel is not available on Saba. This airport has around 3,000 movements per year (2016).

2.1.6. Sint Eustatius - F. D. Roosevelt Airport (EUX)

This island also has a small airport, although the runway is larger than the one on Saba. This runway is 1300 meters long and can accommodate turboprop aircraft and some small jets. The airport only hosts scheduled flights to some other islands nearby (Sint Maarten as one of these). This airport has around 5,500 yearly movements (2016).

	Jet Accessible	Runway length [meters	yearly movements
Aruba	Yes	2743 m	32,584 (2019)
Bonaire	Yes	2880 m	16,033 (2018)
Curaçao	Yes	3410 m	40,483 (2015)
Sint Maarten	Yes	2300 m	60,000 (2015)
Saba	No	400 m	3,070 (2016)
Sint Eustatius	Only small jets	1300 m	5,760 (2016)

2.2. Distance Between Islands

This section will investigate the distances between the islands, and estimate the flight times. This will help determine the minimum range chosen Hybrid Electric Aircraft needs to have. The most important part of this is the distances between the islands in each others proximity. This means the distance between the ABC islands will be investigated and the distance between the Leeward islands. This will start with the ABC islands.

2.2.1. Aruba Bonaire Curaçao

The distances between the ABC islands are as follows:

- Aruba to Bonaire is 192.8 km
- Aruba to Curaçao is 119.4 km
- Bonaire to Curaçao is 75.1 km

This is also summarized in the map in Figure 2.1a.

2.2.2. Sint Maarten Saba Sint Eustatius

The distances between the Leeward islands are as follows:

- Sint Maarten to Sint Eustatius is 62 km
- Sint Maarten to Saba is 45.9 km
- Sint Eustatius to Saba is 30.5 km

This is also summarized in the map in Figure 2.1b.

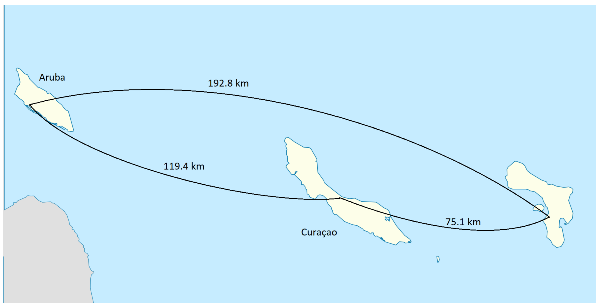
2.3. Availability of Green Energy

The availability of green energy at the airports is important to decide where the main hub for the hybrid electric planes will be. In order to make the hybrid electric aircraft a sustainable option for flying, the electricity used to charge the planes should be generated in a sustainable way. Because of this, the availability of green energy on each island is investigated. This will weigh in for the location of the main hub for the aircraft. This main hub will be where the aircraft are charged. Especially in the beginning of the project, it is much cheaper if only one base location is made per island group.

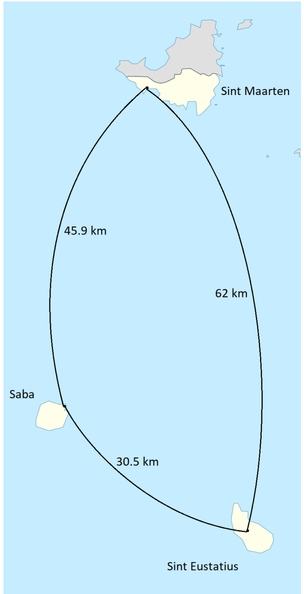
2.3.1. ABC Islands

First a look at the ABC islands.

Aruba



(a) Distances between the ABC islands visualized



(b) Distances between the Leeward islands visualized

Aruba has a plan to cover 100% of its electricity demand by 2020 [1]. This plan was made in 2012. If this turns out to succeed, the island of Aruba is a great location for electric flying.

Bonaire
Bonaire also has a plan to cover 100% of its energy generation by green electricity. This was started after a fire in the old diesel generator in 2004. The current status is about 33%, and work is being done on a bio gas generator [2].

Curaçao
Curaçao now generates 34% of its energy in a renewable way. This is a great start, but there are no plans as of yet to go to 100% like the other two islands. This means if charging stations are installed on Curaçao, plans for more sustainable energy generation should also be considered (either by the governing body or the airport) [29] [20].

Since most of the island's visitors are tourists, it is useful to place the hub on the island with the most inbound flights. In this case, that would be Curaçao. In addition to that, Curaçao is the middle island. This is a very important factor in the location of the hub since the longest flight does not have to be part of the envelope.

2.3.2. Leeward Islands
The leeward islands are much smaller than the ABC islands.

Sint Maarten
Sint Maarten has a renewable energy goal to have 80% of its energy be sustainably generated by 2020. In 2025, this is supposed to be 100% [21].

Saba
Now, Saba generates 40% of its energy supply in a sustainable way. There are plans to increase this [18].

Sint Eustatius
Now, Sint Eustatius generates 46% of its energy in a renewable way. There are plans to increase this [18].

For the Leeward islands, the placement of the main hub is a much easier decision. Sint Maarten is the only island with an international airport. Because of this, Sint Maarten has a lot more incoming flights. Therefore, the hub should be placed on Sint Maarten. The aircraft might still be able to fly between Saba and Sint Eustatius because the distances between these islands is much smaller compared to the ABC islands. In addition to this, Sint Maarten is the furthest along in their sustainability goals.

3
Airplane candidates

In this chapter the identification and selection of appropriate planes for this mission profile is documented. An overview of the shortlist including both available plane models and in-development plane models is given and additional plane models that are deemed viable for this mission are presented. All parameters of the planes are given in the conclusion for the sake of conciseness, they are presented in Table 3.2

3.1. Shortlist

In this section the planes from the shortlist[19], delivered by the Ministry, are elaborated upon.

Name	**Hybrid/electric**	**PAX**	**Range [km]**	**Status**
Zunum Aero ZA10	Hybrid	12	1500	Available (?)
Faradair BEHA M1H	Hybrid	18	1850	To be certified in 2025
E-fan X	Hybrid	100	xx	Prototype
Eviation Alice	Electric	11	1000	Test phase, certified 2022
Wright 1	Electric	186	539	Start testing in 2030
Boeing Sugar Volt	Hybrid	135	6482	Prototype

Table 3.1: Most important data from the shortlist sheet.

Based on this dataset, it is evident that for the flights between Aruba, Bonaire and Curacao only the Zunum Aero, Faradair BEHA and Eviation Alice are suitable. For that reason, these airplanes are elaborated upon in the subsections below to assess their viability in a more detailed manner.

3.1.1. Zunum Aero ZA10

Zunum Aero is developing an hybrid-electric airplane with a range of over 700 nautical miles with a 12-passenger payload. Unfortunately however, many news reports indicate that JetBlue and Boeing have withdrawn as investors to the project, and since a round of layoffs has followed indicating that the company is not reliably developing their hybrid-electric aircraft anymore. For this reason the status of the Zunum Aero ZA10 is given as ’on hold’in Table 3.2[17]
Figure 3.1 is a rendered impression of the Zunum Aero ZA10’s design.

Figure 3.1: Impression of the Zunum Aero ZA10[3]

3.1.2. Faradair BEHA M1H

Faradair is a company developing hybrid-electric aircraft with Very Short Take-Off and Landing (VSTOL) capability, only needing a 300 meter field for take-off and landing due to their triple box wing. The total cost for this plane is listed as $4 million at this moment. Faradair aims to get the plane certified for passenger transport in 2025.
It should be noted that this is a rather ambitious timeline given the company's accomplishments so far, but it may just as well be that they are focusing on the plane itself rather than generating publicity for it. For now, given the information available, it is assumed that the information is up to date. This means that the Faradair BEHA M1H is a good candidate, looking primarily at the passenger number, runway length and cargo/passenger convertibility. For the required mission, this plane will operationally be very similar the the currently used Twin Otter or Islander.
At this moment, however, the only progression in testing seems to be the 2017 scale model featured on their website. A rendered impression of the final product can be seen in Figure 3.2

Figure 3.2: Impression of the Faradair BEHA M1H[14]

3.1.3. Eviation Alice

Eviation is a Israeli company aiming to build a $4 million 9-seater fully electric aircraft with a range of 540 NM (excl. reserve) at speeds of up to 280 kts. The electric power for this aircraft comes from 3.6 metric tonnes (60% of the plane's MTOW) of Li-Ion batteries. They are able to dedicate such a large portion of the MTOW to the batteries because the company is betting on a 95% composite structure, reducing structural weight significantly.[12]
This aircraft has a significantly smaller payload than the currently used planes, but given the progression Eviation has made in this project it may be a viable candidate for HEF on the Islands. A possible solution would be to leverage the lower operating costs of the aircraft to allow more flights to take place, so as to not compromise on passenger seat supply on the routes.From the mentioned aircraft until now, this seems to be the only one progressing in their testing phase (despite a setback following a fire during a ground test[5]). A prototype of the plane presented on the Paris airshow in 2019 can be seen in Figure 3.3.

Figure 3.3: Eviation Alice prototype at the Paris airshow in 2019

3.2. Additionally proposed aircraft

In this section, three other promising projects are introduced and discussed .

3.2.1. Ampaire Cessna 337 EEL

Ampaire is a company that aims to change the aviation industry to electric on a step-by-step basis. At the moment, they have flown one of the only hybrid-electric planes in existence, the Ampaire Cessna 337 EEL. This airplane is built from a converted Cessna Skymaster 337. The fact that this plane is built from an existing airframe makes certification easier, which is significant since multiple sources have confirmed that this is an underestimated part of the product-to-market process.

The aircraft is currently testing with an Hawaiian airline. Given the progression of this project, it looks promising. The passenger number, however is much lower than this mission profile requires. This is not necessarily a dealbreaker, but requires mentioning.

After speaking to Michiel Selier, representative for Ampaire in Europe, the company seems to have a very clear but more importantly attainable strategy for gaining market share for hybrid-electric flight. Mr. Selier confirmed that the Ampaire team has also started top level development of a retrofitted Twin Otter, which would fit this mission profile perfectly. It’s projected to be available by 2024. It would be a possibility to lease the Ampaire Cessna 337 EEL to bridge the time gap between now and the commercial release of the hybrid-electric Twin Otter. This strategy may also provide some valuable knowledge on the commercial operation of hybrid-electric aircraft.

Figure 3.4: Ampaire Electric EEL modified Cessna 337 in flight

3.2.2. Scylax E10

Scylax is a company based in Germany that aims to build a lightweight, 10-seater (incl. pilot) fully electric aircraft with a range of 300 km, to be extended to 600 km as battery technology improves. It

seems that they have a strong business case for their E10 aircraft, and they seem a little more realistic in their promises than Eviation Alice (which is the closest competitor at this point).
They are aiming at a hub-and-spokes model where the spokes will be the first part of the chain to be electrified. The idea behind the Scylax E10 is that every international Central European airport can be reached fully electrically from any other (smaller) airport.
Another important market of the E10 is that of small island hoppers such as in this mission. They have substantiated this goal by teaming up with East Frisian FLN (a small German airline) to replace their old Islanders with new E10s when they reach production.

Figure 3.5: Scylax E10 rendering

3.2.3. ZeroAvia

ZeroAvia is the only company in our selection that chose hydrogen as their main energy carrier. They have succesfully completed a test flight using a Piper Matrix (6 seats) using a hydrogen fuel cell.
Where ZeroAvia differs from the others, is that they do not have a set product lineup that they're aspiring towards. At this moment, they are using existing airframes (much like Ampaire), outfitting them with fuel cell propulsion systems to demonstrate and test hydrogen fuel cell powertrain capabilities.
Their most recent project is the conversion of a 19-seater aircraft to use a 600 kW fuelcell powertrain. It is not known what airframe they will use for this, but it seems that this is promising for the mission described in this report. It should be noted that this optimism may be premature, as there are currently no concrete plans that point to a commercial product becoming available soon.

Figure 3.6: ZeroAvia's Piper Matrix with replaced powertrain shown (nose is closed during flight)

3.3. Summary

In this section, the final candidates for this application will be discussed and summarised. First, the plane parameters are given as described in the beginning of this chapter. The data can be found in Table 3.2.

	Zunum Aero [28][17][27]	**Faradair** [13]	**Eviation** [12][5][15]	**Ampaire**	**Scylax** [26][16][11]	**ZeroAvia** [31]
Powertrain	Hybrid	Hybrid	Electric	Hybrid	Electric	H2-electric
Passengers	12	18	9	4	9	Unknown
Range [km]	1300	>1852	1000	300	300	550
Cruise speed [km/h]	547	370	440	225	300	Unknown
Procurement cost	>$4.5M	$4M	$4M	Unknown*	$2M	Unknown
Operating cost	$250/hr	Unknown	$200/hr	Unknown**	$170/hr	Unknown
MTOW [kg]	5216	Unknown	5900	2100	3500	2700
Req. field length [m]	762	300	Unknown	500	300	Unknown
Payload [kg]	1164	5000	1250	Unknown***	800	Unknown
Battery weight [kg]	1043	Unknown	3600	Unknown	1000	N.A.
Available	2022	2025	2022	2022	2027	Unknown
Status	On hold	In dev	Testing	Prototype	In dev	Prototype

Table 3.2: Overview of selected planes' characteristics

* ”Procurement cost comparable to a similar size new twin-piston aircraft, but lower cost of ownership. Also depends on customer wishes for cabin etc.” Ampaire
** ”Energy (fuel + electricity) costs reduction target is 50-75%. Fuel costs depends highly on route length (shorter routes is more electric = cheaper). Maintenance cost reduction.” Ampaire
*** ”Reduced w.r.t. original aircraft but depends highly on flight distance (payload range diagram).” Ampaire

From the data presented in this chapter, we can draw a few conclusions regarding the feasibility of the aircraft for the specific mission described in this report. The Zunum Aero will not be considered because of it's present status.
Ampaire and ZeroAvia's prototypes seem to be quite fitting for this mission, however we can't be certain if their models can be leased for prolonged times to set up commercial routes. For now, it seems that they use them for testing and demo flights only, however this may change in the future.
Regarding Faradair, there is a lot of uncertainty around their progression but overall their design seems to be perfectly fitted for the mission at hand. Availability in 5 years may present a problem if the intention is to make hybrid electric flying available within a short timeframe. Additionally, given their progression it's doubtful whether they will be able to deliver in 2025.
Roughly the same as for the Faradair BEHA M1H can be said for the Scylax E10, but it's development time is still 7 years at the moment of writing and their capacity is much lower. The upside to this is that their projection is much more likely to meet expectations in the end.

3.4. Conclusion

To start operation in late 2020 or early 2021, it is recommended to contact either Ampaire or ZeroAvia to see if it would be possible to obtain a tender for their aircraft. Both companies are currently in possession of a flight-capable, 4-6 passenger, hybrid-electric aircraft. Although the currently-used planes usually have a higher payload capacity, these planes are currently the only available (along with the Pipistrel Alpha Electro, which is not suitable for commercial transportation). Ampaire may have a slight preference over ZeroAvia given their development of a hybrid-electric Twin Otter, much better suited for the mission at hand. This aircraft could replace the current aircraft upon release to better fit the mission.

In case operation will not start until 2022 or later, the recommendation would be to enter into a partnership with Eviation or Scylax, as their aircraft are fully electric (no emissions) and have higher payload capacity than what is now available. It should be noted, however, that at this should be re-evaluated at that point to take into account the developments in the field at that time.

4

Training

In order to fly electric aircraft, some adaptations have to be made. This is in equipment like charging stations, and the aircraft themselves. However, electric aircraft might also require additional training before commercial flights can be performed. This training can be for the flight crew, but the ground personnel might also need training.

4.1. Ground Personnel

After speaking with a developer of electric aircraft (Ampaire), the ground equipment barely has to be supplemented. In addition to that, no training for the ground personnel is needed in order to host the aircraft. Since these are still small aircraft, it is normal that the ground crew does not need special training to handle the aircraft. The only training which is needed is for the maintenance of the aircraft. However, this is not specific to electric aircraft. In addition to that, electric aircraft will need less maintenance time since the engine has much less moving parts. This will decrease the downtime of the aircraft.

4.2. Flying Personnel

In order to fly the electric aircraft, a Commercial Pilot License (CPL) is needed. For the United States, this commercial pilot license is enough for aircraft without a turbofan engine and under 5700 kg (12,500 pounds) MTOW. Since the electric aircraft will not include a turbofan engine, the MTOW is the only requirement. Of the aircraft which were researched only one has a MTOW above 5700 kg. In addition to that, the type rating only needs to be possessed by the pilot in command. The second pilot does not need to have it. Another positive point to this, is that these rules already apply to the DHC-6 Twin Otter. This means that no obvious change needs to be made to current airlines, whom mostly use the Twin Otter. [8]

4.3. Cost

This cost of training will only apply to the pilots. As stated above, for most aircraft a CPL is sufficient. This will bring no training cost into the equation whatsoever. If the type rating does have to be acquired because the aircraft is too heavy, this will work the same as other type ratings. The type rating of a Twin Otter would be comparable in cost, if that would be needed. This cost is about 10,000 euros. This is a typical cost for this size aircraft. Note that only the pilot in command needs the type rating, not both flying pilots.

5
Current Situation

For the current situation, the flight schedule of Divi Divi Air is taken. Divi Divi flies between the ABC Islands from its hub in Curaçao. Their fleet consists of three De Havilland Canada DHC-6 Twin Otters, and three Britten-Norman BN-2P Islanders. The Twin Otter has a capacity of 19 passengers, and the Islander can take a maximum of 9 passengers.

The regular schedule for Divi Divi Air only consists of flights between the ABC Islands. However, from this an analysis can still be done on the turn around time. Divi Divi Air only uses the Twin Otter to fly to and from Bonaire, while it uses both Twin Otter and Britten-Normans to fly to and from Aruba. Aruba also has a lot more flights. Divi Divi Air also does charter flights. Looking at the schedule, it can be concluded that one Twin Otter and one Britten-Norman is being used for Aruba, and one Twin Otter is being used for Bonaire. I can be seen in Table 5.1 that the turn around time on the islands is very short, while the aircraft are stationary on Curaçao for quite long. These flights can be rearranged in order to have a larger turn around time if the aircraft cannot go back and forth without charging. The total distance to and from Aruba, which is the longest distance, is about 240 km. This falls within even the shortest range of the aircraft researched in chapter 3.

To	Daily flights	Travel time	Minimum turnaround time	Average turnaround time
Aruba	15 (8 TO, 7 BN)	30 min	5 min	14 min
Bonaire	6 (6 TO)	30 min	25 min	25 min

Table 5.1: Divi Divi Air flights from Curaçao to Bonaire and Aruba [6]

The second part is to look at the stationary time on Curaçao. This needs to be checked to make sure the aircraft have enough time to charge again, or an alternative has to be found. The times of the Britten-Norman is depicted in Table 5.2.

Departure time Curaçao	Departure time Aruba	Time Stationary on Aruba	Time stationary on Curaçao
06:40	07:15	00:05	00:15
08:00	08:45	00:15	00:15
09:30	11:45	01:45	00:15
12:30	13:15	00:15	01:45
15:30	16:15	00:15	00:15
17:00	17:45	00:15	overnight

Table 5.2: Flight times of the Britten-Norman Islander

This table includes the times the aircraft is stationary on either island assuming that the flight takes 30 minutes (the time the airline states in flights scheduling). When looking at the Pipistrel, it can charge at 20 kW. However, if the other electric aircraft charge at this power, it will take about 36 hours for the Eviation Alice to full charge assuming 200 W/kg battery. For this reason, the assumption is made that the aircraft can charge much quicker.

The schedule can be optimized to keep the aircraft on Curaçao as long as possible after each flight to make sure it can charge as much as possible. This will be necessary if the Scylax is chosen. If the Eviation is chosen, the aircraft can make 3-4 roundtrips before it has to be charged. In that case, only one long stop on Curaçao needs to be planned. As seen in Table 5.3, the time the aircraft has to charge for the first option -charging after each roundtrip- is 1 hour and 7 minutes. For the second option where the aircraft only has to charge every 3 roundtrips, the charging time is 5 hours and 35 minutes.

Charging every roundtrip		Charging after 3 roundtrips	
To Aruba	Back in Curaçao	To Aruba	Back in Curaçao
6:40	7:40	6:40	7:40
8:47	9:47	7:40	8:40
10:54	11:54	8:40	9:40
13:01	14:01	15:15	16:15
15:08	16:08	16:15	17:15
17:15	18:15	17:15	18:15

Table 5.3: New flight schedule if start and end times are kept intact.

6
Feasibility check

In order to validate the feasibility of the aircraft mentioned in Chapter 3, a top-level calculation was made. The method for these calculations is briefly explained and the results are presented and compared to the planes proposed earlier.

6.1. Methodology

In this section, the methodology for obtaining the numbers presented below is documented for verification purposes. The code for the script can be found in Appendix **??**. The methodology of this estimation is loosely based on the method described in Riboldi et al(2018). It takes the total weight as the sum of the separate parts, as shown in Equation 6.1[24].

$$W_{TO} = W_e + W_{pl} + W_{bat} + W_m \tag{6.1}$$

With W_{TO} denoting the total weight (take-off weight), W_e the empty weight, W_{pl} the payload weight, W_{bat} the (required) battery weight and W_m the motor weight.

6.1.1. Payload weight

The payload weight is determined by multiplying the number of passengers by 90 (kg per passenger, as per the Pipistrel Alpha Electro). It has to be noted that this is quite a conservative estimate, as this allows no luggage allowance for heavier passengers. For true commercial applications, usually 10-15 kg per passenger is added for luggage.

6.1.2. Battery weight

The battery weight is determined from the required energy divided by the energy density. The value for energy density is taken as 198 wH/kg or 712800 J/kg as per the Pipistrel Alpha Electro. It's battery contains 21 kWh in 106 kg (2 packs of 53 kg[22]).

6.1.3. Motor weight

Motor weight is determined by Equation 6.2.

$$W_m = P_{req,climb} / \left(\frac{P}{W}\right)_{average} / \eta_{motor} \tag{6.2}$$

$P_{req,climb}$ denotes the maximum power requirement from the motor, which occurs during climb. This is calculated using standard aircraft mechanics relations. $\left(\frac{P}{W}\right)_{average}$ denotes the average power to weight ratio of electric motors (taken as 10 kW/kg, which is about average for the Emrax motors on which the Pipistrel motor is based). η_{motor} is the motor efficiency, taken as 98%.

6.1.4. Empty weight

As per Riboldi et al., this means that the take-off weight can be reduced to a function of the empty weight. This provides one equation with two unknowns. The second relation between the take-off weight and the empty weight is taken from historical data in the paper, but given the limited availability of such data, the airframe weight (empty weight) was approximated as a linear function of the number of passengers, as can be seen in Equation 6.3

$$W_e = 132 * PAX \tag{6.3}$$

The 132 in this equation comes from the Pipistrel Alpha Electro, which has 132 kg of empty weight per seat. This is a rather imprecise estimation, but a more detailed weight estimation for electric planes would be out of the scope (time-wise) of this investigation.

Because battery and motor weight are dependent on the weight of the plane, these weight estimations have to be iterated to find the final value. This is simply done by error minimization.

6.2. Results

In this section, the results from the weight estimation described above are presented. As noted in the section above, this is a very rudimentary weight estimation, and there is no such thing as a 'conventional' weight estimation for electric planes given the absence of historical data.

The results are calculated for 9 passengers, to give them relevance against the most suitable electric planes, the Eviation Alice and Scylax's E10.

6.2.1. Take-off and battery mass

The weight estimation described above was used to get an idea of how the aircraft total mass and battery mass develop as a function of range. The results are plotted in Figure 6.1.

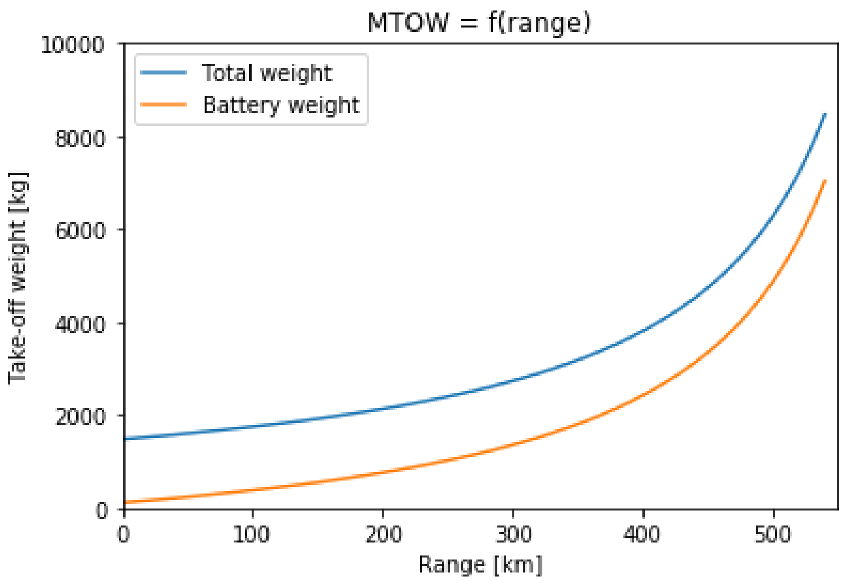


Figure 6.1: Total and battery mass as function of range

It can be seen that as range increases, total weight seems to be ascend increasingly. It can also be noted that the battery fraction of the plane's mass increases with respect to range, as would be expected due to the snowball effect. The battery mass fraction as function of range can be found in Figure 6.2.

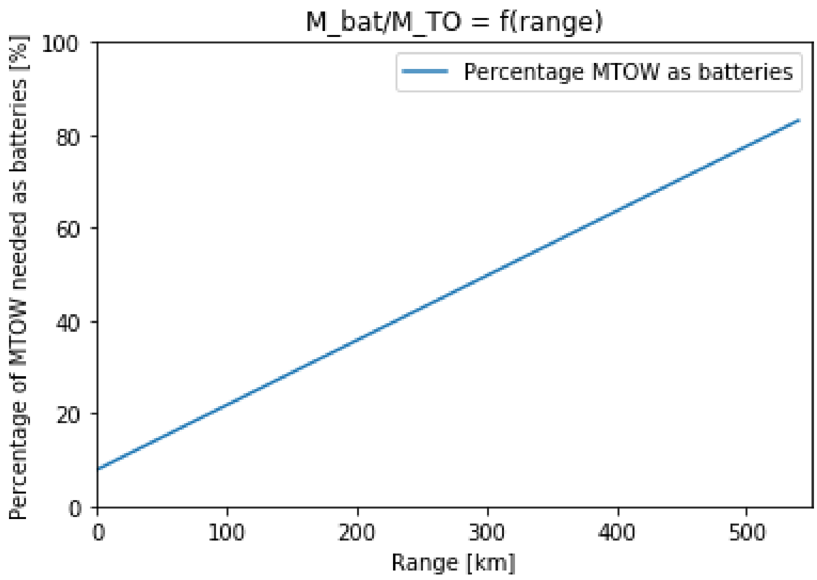


Figure 6.2: Fraction of MTOW as battery weight as function of range

The most obvious and curious thing about this graph is that the battery mass fraction seems to linearly increase with range. It is suspected that this specific behaviour is attributed to the weight estimation model rather than the actual physics. It can be safely said, however, that the battery mass fraction would increase with range, and as such there is a maximum feasible range at which the required battery mass exceed the plane's total mass.

6.3. Conclusion

Many assumptions (all based on the Pipistrel Alpha Electro) have been made to conduct this weight estimation. Given recent advancements in material science and structural design and manufacturing, it may be possible to reduce airframe weight such that ranges improve vastly.
There is, however, a problem in achieving long range which simply has to do with energy density of the batteries, as pointed out by countless others. It seems that battery-powered flight is possible (as proven by Pipistrel), but improvements are necessary for it to match the range performance of conventionally powered aircraft.

To assess feasibility of the selected electric aircraft: Scylax's E10 seems to both have the most realistic estimation of capability and timeframe, while this data suggests Eviation is overestimating their capacity.

7

Cost Overview

In this chapter, an estimation of the overview of the cost will be made. This will consist of one time expenses like; the aircraft itself, the charging infrastructure, possible improvements to the generation of green energy at the airport. It will also have recurring expenses like; the electricity cost, training of pilots, maintenance.

Note that this overview is for the replacement of one Britten-Normander with either the Scylax or the Eviation. This means that some costs will not change, and therefore are not posted. These are costs like; personnel, standplaces for the aircraft, revenue for the flights.

The budget is shown in Table 7.1, Table 7.2, and Table 7.3. As already stated, the budget consists of two parts; recurring costs and nonrecurring costs. The nonrecurring costs are only applicable for the electric aircraft. This is the purchase of the aircraft, corresponding to the price stated in Table 3.2. It is an estimated cost to install solar panels which will generate as much green energy as the aircraft will use [23] [30] [4]. And lastly, it is an estimated value to educate four pilots in order to get a type rating. This last part might not even be necessary.

The recurring costs are costs that correspond to using the aircraft itself. This is the cost for electricity [20], which is included because of current regulations regarding the use of solar panels. This is relatively expensive on Curaçao by governing rules. In addition to that, the operating cost stated in Table 3.2 is used. The aircraft will fly six hours each day; six times back and forth to Aruba, which is 240 km per roundtrip.

Now the next step is comparing the results of this budget with flying the Britten-Norman Islander instead. This will have no nonrecurring costs, as the aircraft is already purchased and pilots are already flying it. In addition to that, no solar field has to be constructed. This means that the only costs are the fuel cost and the maintenance. For maintenance, the figure for the Scylax is taken [25] [9]. In order to properly compare the expenses of the electric aircraft with the Islander, the nonrecurring costs are spread out over 10 years.
From this, the conclusion can be made that electric flying will be beneficial, even in the short term. This stems mostly from the high price of avgas (aviation gas) compared to the electricity. The conclusion after this cost overview is that electric flying is economically feasible. In addition to that, the Scylax seems the best option.

What	Cost	Amount	Cost
Islander aircraft	€ 3,000,000.00	0	€ -
Solar panels	€ 82,296.80	0	€ -
Pilot trainings	€ 10,000.00	0	€ -
			Yearly cost
Set cost	€ -	0.1	€ -
Fuel	€ 2,333.82	365	€ 851,844.30
maintenance	€ 944.76	365	€ 344,837.40
Total yearly			€ 1,196,681.70

Table 7.1: Cost breakdown of flying the Britten-Normander Islander

What	Cost	Amount	Cost
Eviation aircraft	€ 4,000,000.00	1	€ 4,000,000.00
Solar panels	€ 366,808.59	1	€ 366,808.59
Pilot trainings	€ 10,000.00	4	€ 40,000.00
			Yearly cost
Set cost	€ 4,406,808.59	0.1	€ 440,680.86
Electricity	€ 248.83	365	€ 90,823.68
maintenance	€ 1,108.92	365	€ 404,755.80
Total yearly			€ 936,260.34

Table 7.2: Cost breakdown of flying the Evaition Alice

What	Cost	Amount	Cost
Scylax aircraft	€ 2,000,000.00	1	€ 2,000,000.00
Solar panels	€ 339,637.58	1	€ 339,637.58
Pilot trainings	€ 10,000.00	4	€ 40,000.00
			Yearly cost
Set cost	€ 2,379,637.58	0.1	€ 237,963.76
Electricity	€ 230.40	365	€ 84,096.00
maintenance	€ 944.76	365	€ 344,837.40
Total yearly			€ 666,897.16

Table 7.3: Cost breakdown of flying the Scylax E10

8 Conclusion

In this report, it has been shown that (hybrid-)electric flight for island hopping is a possibility in the near future. Some challenges do present themselves, but these can be overcome with conventional contemporary technology and knowledge.

From the analysis in this report, it shows that the ABC Islands are perfectly suited to implement and experiment with (hybrid-)electric flight. With current technology, as shown by the projects at Ampaire and ZeroAvia, hybrid-electric flight is already possible. Although the aircraft from these companies are not commercially available yet, they do demonstrate the possibility of flight aided by electric power.

Other projects are progressing quickly, and promise to deliver a commercially available, fully electric flight before 2030. The most promising projects, Eviation Alice and Scylax E10, plan to get commercial planes out by 2022 and 2027, respectively. Both of these planes could, according to their specifications, perform a round-trip to both Bonaire and Aruba from Curacao. A short plausibility check has been done on these planes and it was determined that Scylax has a relatively realistic aircraft design and timeline, whereas Eviation overestimates their specifications and most likely underestimate their time to market.

To handle the longer charging times of the aircraft, flight schedules must be altered slightly to accommodate for this. Notably, the turnaround times for the airplanes in current Divi Divi schedules on Aruba and Bonaire are very short, indicating there is no time to charge on these islands. It would be possible to select a plane with sufficient range to make the round trip and save on the turnaround time on Aruba and Bonaire. This would be consistent with the current schedule that also has the planes stationary overnight.

Additionally, it has been estimated that the impact (both cost and experience-wise) on the ground and flight crews for changing to electric flying is rather small. Pilots can be type certified to fly the electric planes, but this is in many cases not even a necessity. The total cost estimation is that flying electrically on a yearly basis is quite a lot cheaper than using conventional planes. This discrepancy is mostly caused by the lower price per unit of energy when using electricity.

In the end, the switch from conventional aircraft to (hybrid-)electric aircraft is a more sustainable and also cheaper option. Therefore, it is recommended that it is investigated which exact aircraft should be procured and how operations with this aircraft should be planned. Starting with one aircraft should allow for some experience in operating electric aircraft, which would also be a valuable asset given the experimental nature of this technology.

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