BEE-PLANE PROJECT REPORT 2016-2017
ESTACA Final-year project

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Summary

Table summary

Acknowledgment

We are highly indebted to M. Xavier Dutertre for his guidance and constant supervision as well as for providing necessary information regarding the project but also for his support in completing the project.

We are very grateful because we managed to complete our project assignment within the time given by our professor Nassim Rizoug who we also sincerely would like to thank for the guidance and encouragement in finishing this assignment and for teaching us in this course.
We would like to express our special thanks of gratitude to the school, which gave us the opportunity to do this wonderful project on the topic of the Bee-Plane, which also helped us in doing considerable research, and we came to know about so many new things thanks to ESTACA.

This assignment couldn't be completed without the effort and co-operation from our group members, Constance Chirol (team leader), Sophie Olias-Zeitschel, Romain Neuville, Benjamin Olier and Stéphane Faure.

Finally yet importantly, we would like to express our gratitude to the students from Centrale Paris for the support and willingness to spend some time with us answer our many questions.

Abstract

As part of our final year as aerospace engineering students, we have chosen to work on one of the proposed topics about a plane which could revolutionize the world of aerial transport: the Bee-Plane.

The Bee-Plane project is a Research & Development collaborative project for short-haul and medium-haul flights with a detachable fuselage. This program, which implicates several high engineering schools in France, was created and launched by Mr. Dutertre. A web site has been created to follow the progress of this project: http://www.bee-plane.fr/.

The aeronautic field, which is always looking for new challenges, has found another point of interest today with Xavier Dutertre's Bee-Plane project. The idea of a detachable plane concept dates from 1950. With the help of new technologies, the Bee-Plane concept has been studied since October 2011.

The fuselage enables to receive the passengers (basket), and can be detached from the technical part (bee) including the avionics, engines and landing gears.
The business idea of this concept is to make an analogy with bee carrying pollen. Its goal is to save time on ground compared to the A321 (same type of aircraft category) with a capacity of 200 to 220 passengers, while leading to a reduction of operating costs.

Résumé

Dans le cadre de notre projet de dernière année de cycle ingénieur, nous avons choisi de travailler sur l'un des sujets proposés concernant un avion qui pourrait révolutionner le monde du transport aérien : le Bee-Plane.

Le projet Bee-Plane est un projet collaboratif de Recherche & Développement pour des vols court-courrier et moyen-courrier avec un fuselage détachable. Ce projet, dans lequel sont impliqués plusieurs écoles d'ingénieur en France, a été créé par Monsieur Dutertre. Un site internet a été conçu pour visualiser la progression de ce projet : http://www.bee-plane.fr/.

Le secteur de l'aéronautique est toujours en quête de défis, c'est pour cela que Monsieur Xavier Dutertre relance un concept datant de 1950. Avec l'aide des nouvelles technologies, le concept du Bee-Plane a été étudié depuis Octobre 2011.

Le fuselage central peut ainsi accueillir des passagers (dans le basket) et peut se détacher de la structure technique (le bee) dans laquelle on retrouve les équipements de vols, l'avionique, les moteurs et les trains d'atterrissages.

L'idée commerciale de ce concept de faire référence à une abeille transportant du pollen. Le but est de gagner du temps au sol comparé à un avion commercial classique du type A321 dont la capacité d'embarquement est de 200 à 220 passagers.

Introduction

Airports and airline companies are constantly trying to improve their performance. Reducing fuel consumption, relieving the plane traffic jams and decreasing operating costs are big issues for aeronautic industry.

The Bee-Plane project could be a solution. With its structure, several new applications can be imagined: a transportable hospital, a water bomber, …

The purpose of this future aircraft is to decrease the operating costs and airlines purchasing by 30%. Moreover, the bee can fly without the basket and the plane could be a drone-operated plane. As a result, it can change baskets quickly and will substantially reduce the time between two flights.

Figure 1: Flying Bee-Plane, credit Supméca, 2014

The concept is inspired by the military airplane *Fairchild XC-120 Packplane* (**figure X**) under which its removable fuselage is attached. Nevertheless, the project was abandoned and only a prototype was made because of economic issues. Nowadays, the economic issues are more relevant: the objective is to reduce the waiting time between two flights**.**

Figure 2: Fairchild XC-120 Packplane

Context

The Bee-Plane is based on Technology Readiness Level (TRL) commonly used within aeronautical industry. TRL are a type of measurement system used to assess the maturity level of a particular technology. Each technology project are evaluated against the parameters for each technology level and it is assigned a TRL rating based on the projects progress.
Currently, the project entered in TLR2 (Technology Readiness Level 2), phase between the basic technology research and the feasibility study. Several engineering schools participate and work to make this project real.

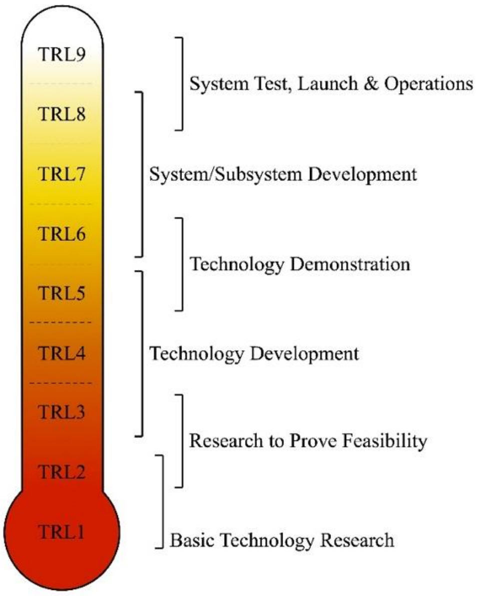

Figure 3: Technical Readiness Level

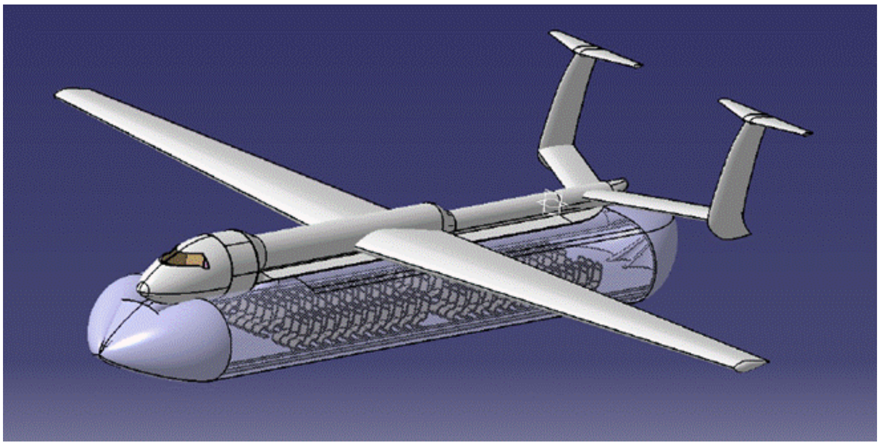

Figure 4: Bee-plane TRL2

Approach

Our team is specialized in “Integration of Propulsive Systems and on-board Power”, so our study focuses on the following points:

- Confirm the advantages for a mixed propulsion configuration (two TP400-D6 engines and a central turbofan CFM56-3C1)

- Study about a possible hybridization of the CFM56-3C1

- Creation of an interface for a flight plan (Paris-Nice)

The requested workload was significant: it then seemed unlikely to manage all of these deliverables on time maintaining a certain level of quality. So, after our first call meeting with our tutor, we realized that the importance was not to provide a detailed report with exact results, but rather to improve the studies that had already been done and therefore improve the maturity of the Bee-Plane project.
Having learned about the subject and being aware of the disposable tools, such as the Technoplane server, we split the tasks and have kept this distribution for the entire project.

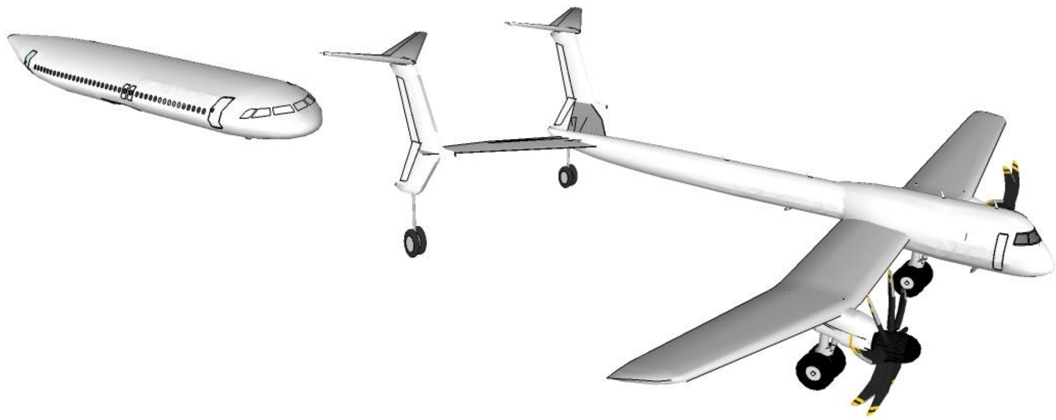

Figure 5: Connect-Plane v12-3 twin-engine - separated basket

Initial situation

- *Engine Integration on a detachable fuselage plane (ESTACA 2015)*

This study allows us to know why is the configuration with three engines (2 TP400 + 1 CFM56-3C1) for Bee-Plane.

This configuration is the best choice to lower fuel consumption. But, it should be noted that maintenance of military engines is more expensive than civil engines, and we have one more engine with this configuration. At last, although TP-400 is certified for civil flight, it has never been used in this configuration.

The thrust delivered by the three engines is more important than the necessary power on each segment. According to this study, we agree on the results found for the choice of engines. Then, with the use of different calculation methods, we obtained similar results comparing with old projects. We have also noticed that the CFM56-3C1 engine is an over-sized turbofan regarding the necessary thrusts respecting the take-off slopes.

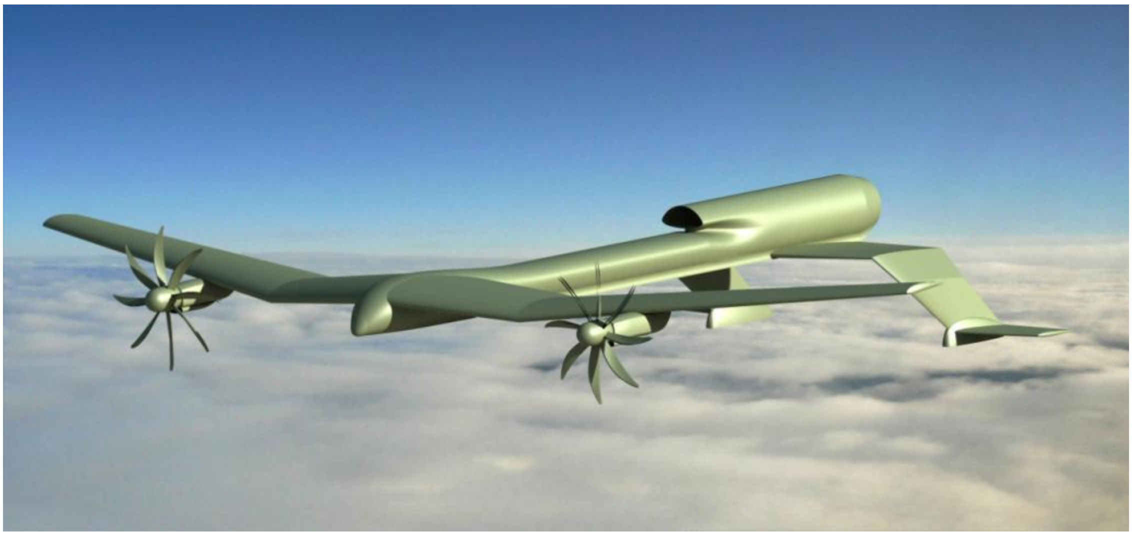

Figure 6: X Bee-Plane, credit ESTACA, 2015

C_x	0,40494926
C_z	2,66168592
Finesse	6,2598928
Finesse Max.	14
Trust per engine	153 850 N
Minimal need Trust	326930 N
TP400-D6 conso SFC_cruise	0.3852 (Kg/(daN.h))

Table 1 : Bee-plane characteristics

- *XML Description – Engine description to enhance the Bee-Plane motorization (ESTACA 2016)*

This is a modelling project involving the creation of a XML engine database and the creation of a numerical optimization algorithm.

An XML document gathering the data about any kind of aircraft has been written. This file is not yet completed and some information are missing. However, the file format is fixed and describes logically the working of an engine. The DTD file describes the XML file. This XML language will be used in the future projects as a reference.

This interface allows the user to calculate the Specific Fuel Consumption of an existing engine. This code can still be improved by modifying the assumptions considered in this project. However, the present code gives an idea of the consumptions and can be used in a pre-study.

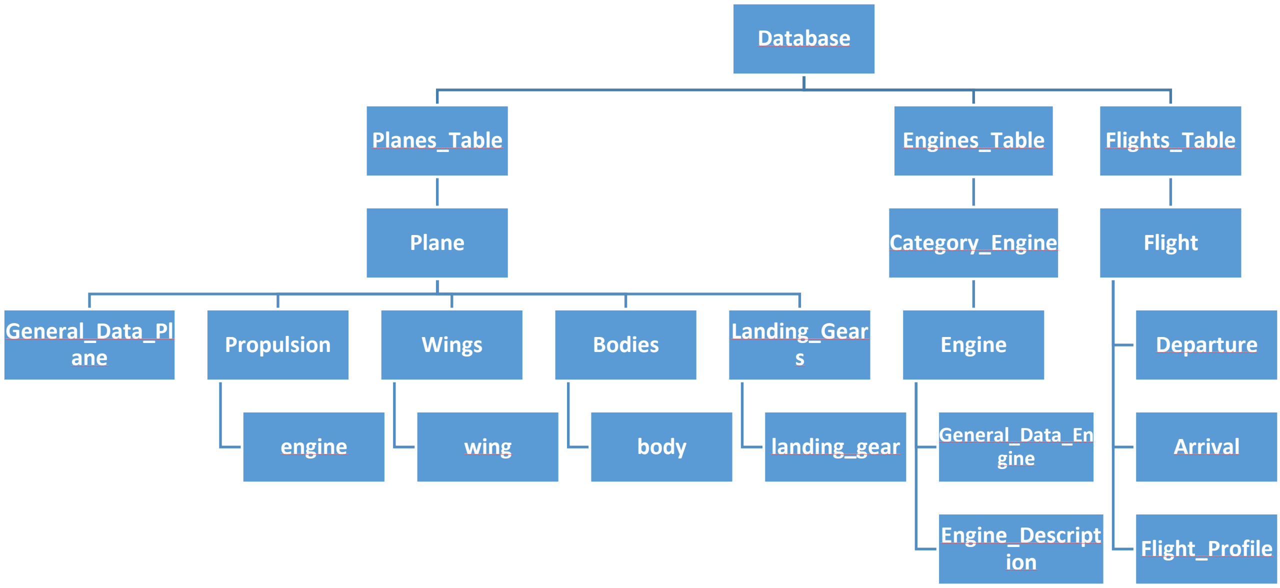

Figure 7: Database Architecture

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Development of the PW150A version

I. Bee-plane's state of progress

The Bee-plane's parameters are listed below. They are as they were when we took charge of the project.

PARAMETERS	VALUES	COMMENTARIES
MTOW (KG)	100 000	Maximum take-off weight
MEW (KG)	68 600	Manufacturer Empty Weight
MEW_BEE (KG)	46 103	Bee only
MEW_BASKET (KG)	22 497	Basket only
S (M²)	150	Wings area
Z (M)	7620	Service ceiling (25 000 ft)
V (M/S)	155	Cruise speed
MACH	0.5	V / sound velocity
JET-A1 (KG)	30600	Total fuel weight
JET-A1 BEE (KG)	11000	Fuel weight (bee)
JET-A1 BASKET (KG)	19600	Fuel weight (basket)
CL/CD	14	Cz/Cx (finesse)

Table 1: Initial Bee plane parameters

II. Performance calculation, cruise case.

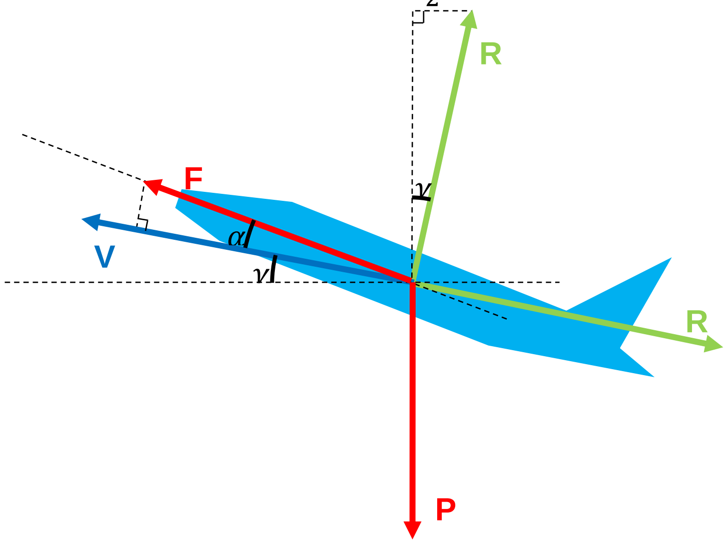
The main aim of this part is to calculate all the flight performances of the plane based on the work of the previous student teams. We will do this study with four different engines: The PW150A manufactured by Pratt & Whitney installed on the Bombardier Dash-8 Q400, the TP400 used on the military cargo plane A400M and the AE 2100 A and AE 2100 D3 manufactured by Rolls-Royce for the Saab 2000 and the C-130.

Turbopropulseurs						
	P (kW)	Thrust (N)	Fuel (kg/h)	Avion	Speed (m/s)	Mach
PW150A	3781	32546	934	Q400	147,8	0,477
TP400	8200	70583	1967	A400M	216,9	0,718
AE2100A	3095	26641	792	Saab 2000	184,7	0,612
AE2100D3	3424	29473	871	C-130	178,6	0,586

We will test a four-engine version of the bee-plane using the Pratt & Whitney and Rolls-Royce turboprops, the TP400 will be used for a twin-engine version.

We can notice that the cruise speed is really different from one engine to the other, it varies between Mach 0,47 and Mach 0,72 whereas the Bee-plane has a cruise speed of Mach 0,5. The main goal of the Bee-plane is to save fuel, we don't need high speed so Mach 0,5 seems a good compromise between efficiency and speed.

We start our calculations with the lift equation: $R_Z = \frac{1}{2}\rho.S.C_Z.V^2$



The lift is supposed to compensate the weight of the plane so we have: $P = R_Z.\cos(\gamma)$

In the case of the cruise flight $\cos(\gamma) = 1$ because during level flight the climb rate is 0.

The air density is determined by the International Standard Atmosphere table with a cruise altitude of 25 000 ft. (7 620 m).

We chose the following NACA aerofoil for the wings of the Bee: NACA 4412 and NACA 4415. They are identical except for the relative thickness of respectively 12 and 15 % (corresponding to the last two digits). The NACA 4412 is used on the ATR72 that is why we thought it would be a good choice for the Bee-plane. The NACA 4415 has been used by previous Bee-plane teams, its greater thickness allows the wings to have a greater space capacity for the landing gears and will be beneficial for resisting the bending moment generated by the lift.

Here is an overview of what those aerofoils look like:

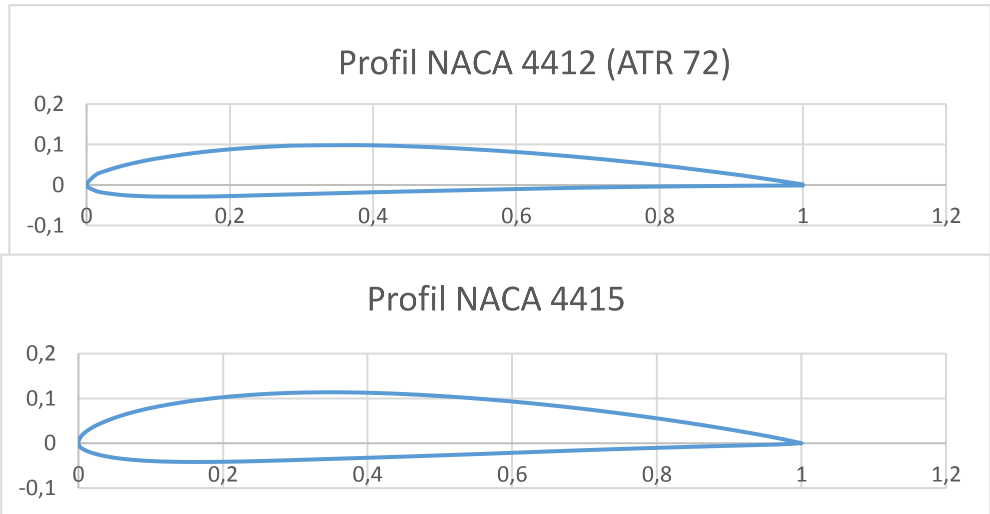


Figure 8 : profils 4412 and 4415

The maximum CL/CD ratios (lift and drag coefficients Cz & Cx) of those aeroils are obtained for an algle of attack of 4° (4412) and 4,75° (4415).

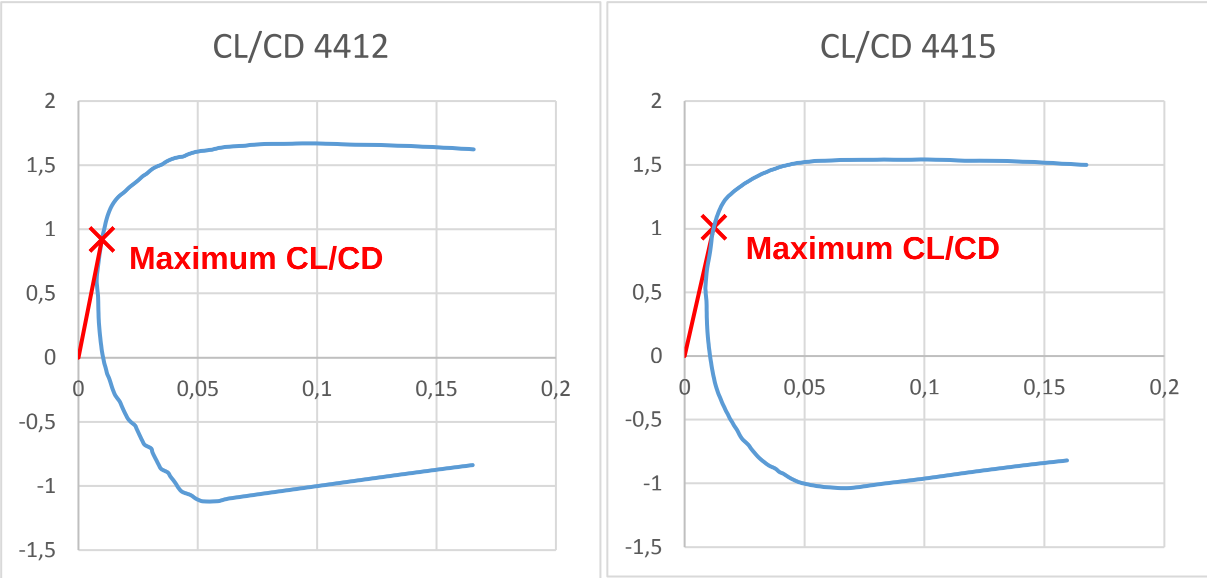
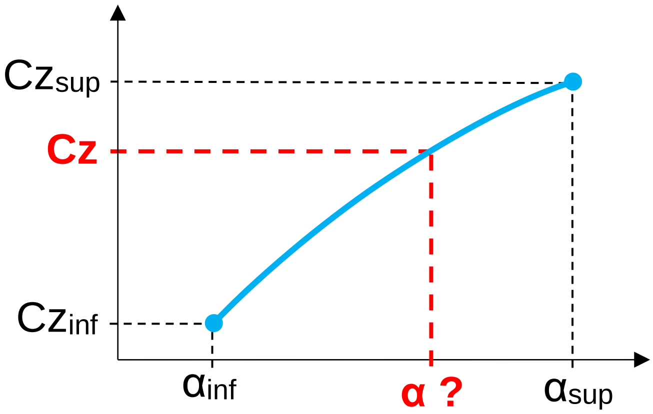


Figure 9: CL/CD of our NACA profils

It is time consuming to determine which value of angle of attack will provide the lift needed for a certain flight point for each aerofoil because we have to calculate the lift coefficient with this formula: $C_Z = \frac{2.m.g}{\rho.S.V^2}$, find the two values that bracket the one we need in the NACA table, find the corresponding values of angle of attack and do a linear interpolation to find the exact angle needed. It takes a lot of time to do all this so we wrote a script to do it automatically, it was really interesting to do and even if it took us some time it was really worth it.

Here is how it works:



$$\alpha = \frac{(Cz - Cz_{inf}).(\alpha_{sup} - \alpha_{inf})}{Cz_{sup} - Cz_{inf}} + \alpha_{inf}$$

The inferiors and superiors values are find thanks to a VLOOKUP function in EXCEL.

It can also be used to know all the NACA coefficients based on the angle of attack, for example, for the CL/CD ratio f the formula becomes:

$$f = \frac{(\alpha - \alpha_{inf}).(f_{sup} - f_{inf})}{\alpha_{sup} - \alpha_{inf}} + f_{inf}$$

III. Wings area calculations

To maximise the range, we need to make sure the cruise flight happen at the best CL/CD ratio. With the lifts coefficients for which the CL/CD ratio are best we calculate the wings areas needed for the level flight for the MTOW and MNFW (Maximum No fuel Weight).

Calculation of the wings areas needed to fly at best CL/CD in cruise flight.

weight / NACA	Wings area (m²)	
	100000	**68600**
4412	161	111
4415	147	101

Table 2:Wings area of each NACA profil

$$S = \frac{2.R_Z}{\rho.C_Z.V^2}$$

Datas	
R_Z	68,6 ; 100 t (x9.81)
ρ	0,5508 kg/m^3
C_Z	0,921 ; 1,0113
V	155 m/s

The choice of a 150 m² wings area seams a bit high since with the NACA 4415 the plane is never heavy enough to fly at best CL/CD ratio, even at MTOW.

The thing to keep in mind is that we don't fly at the best CL/CD ratio all the time. Indeed, the fuel is consumed throughout the flight which means the weight is always different and the lift coefficient needed to compensate it is never the same. The important value is the average CL/CD ratio during the entire cruise, not just the maximum.

We also have to be sure that the wings area is sufficient for take-off. But as we have a turbofan used only for take-off we should not have any problem regarding take-off, we will have to make sure of that in the subsequent stage of the study.

IV. Wings area optimisation

We will now calculate the perfect wings area allowing us to fly at the best CL/CD ratio. It is not a value that can be obtained with a single calculation since the average CL/CD ratio depend on the wing area, we have to try a lot of values until we converge to the final result.

Each wing area in each cell of the table is calculated as follows:

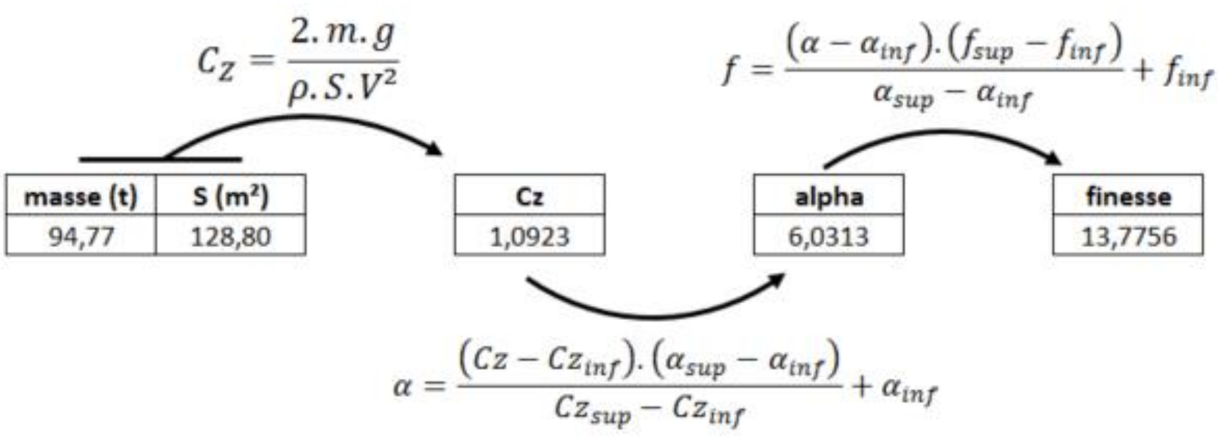


Figure 10 : Method of calculation of wing area

weight / S (m²)	68,60	73,83	79,07	84,30	89,53	94,77	100,00	Mean CL/CD
128,6868	13,0859	13,3848	13,7561	14,0006	13,9491	13,7687	13,3612	13,6152
128,7158	13,0851	13,3837	13,7546	13,9997	13,9496	13,7704	13,3634	13,6152
128,7447	13,0844	13,3827	13,7532	13,9988	13,9501	13,7721	13,3657	13,6153
128,7737	13,0836	13,3816	13,7517	13,9979	13,9507	13,7739	13,3679	13,6153
128,8026	13,0828	13,3805	13,7503	13,9971	13,9512	13,7756	13,3701	13,6154
128,8316	13,0821	13,3795	13,7488	13,9962	13,9517	13,7773	13,3723	13,6154
128,8605	13,0813	13,3784	13,7474	13,9953	13,9523	13,7790	13,3745	13,6154
128,8895	13,0805	13,3773	13,7459	13,9944	13,9528	13,7807	13,3767	13,6155
128,9184	13,0798	13,3763	13,7445	13,9935	13,9533	13,7824	13,3789	13,6155
128,9474	13,0790	13,3752	13,7430	13,9926	13,9539	13,7842	13,3811	13,6156
128,9763	13,0782	13,3742	13,7416	13,9917	13,9544	13,7859	13,3833	13,6156
129,0053	**13,0775**	**13,3731**	**13,7402**	**13,9908**	**13,9549**	**13,7876**	**13,3855**	**13,6157**
129,0342	13,0767	13,3720	13,7387	13,9900	13,9555	13,7893	13,3877	13,6157
129,0632	13,0759	13,3710	13,7373	13,9891	13,9560	13,7900	13,3899	13,6156
129,0921	13,0752	13,3699	13,7358	13,9882	13,9565	13,7905	13,3921	13,6155
129,1211	13,0744	13,3689	13,7344	13,9873	13,9571	13,7911	13,3943	13,6153
129,1500	13,0737	13,3678	13,7329	13,9864	13,9576	13,7917	13,3965	13,6152

Table 3: Wing area calculation

We calculate the mean CL/CD ratio during the cruise for each value of wings area. The different weights are used to represent the different cruise steps and calculate the average value during the entire cruise time.

We start by calculating the lift coefficient needed to compensate the weight, then we find in the NACA tables the angle of attack allowing this lift coefficient. We use our linear interpolation script in order to calculate the right value even though it doesn't appear in the table. From the angle of attack we are able to find the CL/CD again with the use of the linear interpolation script. All that remains is to calculate the average CL/CD coefficient to find the greater one.
We have converged on the ideal value for the wings area : 129 m².

It is possible to determine the perfect wing area for any mission, we just have to replace the weight at the beginning and end of the cruise flight (100 and 68.6 tons here). We did the calculation for the most dimensionning case: flight at max range with the max fuel capacity.

V. .Engine power calculations

We will now determine which engine configuration best respond to our needs. For that we calculate the engines powers needed to compensate the drag of the plane:

	masse (t)	68,60	73,83	79,07	84,30	89,53	94,77	100,00
	Cz	0,79	0,85	0,91	0,97	1,03	1,09	1,15
	NACA 4412							
	α (°)	2,78	3,34	3,90	4,47	5,05	5,63	6,23
	finesse	12,19	12,77	13,12	13,39	13,59	13,66	13,54
Engine power (%)	PW150A	0,55	0,56	0,59	0,61	0,64	0,67	0,72
	TP400	0,50	0,52	0,54	0,56	0,59	0,62	0,66
	AE2100A	0,67	0,69	0,72	0,75	0,78	0,82	0,88
	AE2100D3	0,60	0,62	0,65	0,68	0,71	0,74	0,79
	NACA 4415							
	α (°)	2,80	3,18	3,54	4,17	5,06	6,00	6,91
	finesse	13,08	13,37	13,74	13,99	13,95	13,79	13,39
Engine power (%)	PW150A	0,51	0,54	0,56	0,59	0,62	0,67	0,73
	TP400	0,47	0,49	0,52	0,54	0,58	0,62	0,67
	AE2100A	0,62	0,66	0,68	0,72	0,76	0,82	0,89
	AE2100D3	0,56	0,59	0,62	0,65	0,69	0,74	0,80

Table 4: Engine power according to NACA profiles

$$Engine\ power = \frac{9{,}81.\,weight}{Thrust.\,number\ of\ engines.\,CL/CD}$$

$$Thrust = \frac{Power}{aircraft\ velocity}.\,\eta$$

a. Aerofoil choice: NACA 4412 or 4415?

After calculating the average engine power we find that the NACA 4415 aerofoil requires less engine power. Although the 4412 aerofoil has a better CL/CD ratio the 4415 gives the plane a better CL/CD ratio by having a greater lift coefficient thanks to the biggest thickness. The thickness also has the advantages of offering more space for the landing gears and is beneficial for the wings structure: the lever arm will counteract the bending torque generated by the lift more effictively, therefore saving weight.

➔We finally choose the **NACA 4415** which only offer advantages.

b. Range calculation:

NACA 4412		
Range (km)	PW150A	7365
	TP400	7585
	AE2100A	7111
	AE2100D3	7157

NACA 4415		
Range (km)	PW150A	7593
	TP400	7819
	AE2100A	7331
	AE2100D3	7379

NACA 4412		
Range (km)	PW150A	7365
	TP400	7585
	AE2100A	7111
	AE2100D3	7157

NACA 4415		
Range (km)	PW150A	7593
	TP400	7819
	AE2100A	7331
	AE2100D3	7379

Tableau 5: Range depending on NACA profiles

$$Range\ (km) = \frac{3600.fuel\ quantity\ (kg).V(m/s)}{consumption\ (kg/h).mean\ engine\ power\ (\%)}$$

c. Critical evaluation of those ranges compared to the A321:

We have a better range than the A321 because we have 50% more fuel capacity, we fly at a lower velocity and altitude and we use more efficient engines (turboprops against turbofans). We have also to take into account that our aerodynamic is inferior (maximum CL/CD of 14 against 17), and we are heavier. The choice of the NACA 4415 is once again confirmed by the range.

VI. Take-off performances

In order to attach and detach the Basket from the Bee, the plane landing gears are capable of extending and retracting in order to lower the plane at the right height to be able to raise the Basket off the ground. This fonctionnality is also used to increase the angle of attack during take-off. IMFA (Institut Français de Mécanique Avancé) students have developed landing gears that can extend up to 1.5 meters, Mr. Dutertre thinks it is far too much and asks us to do our calculations with an elongation of 1 meter maximum.

The distance between the main landing gears and the tail landing gear is 15 meters.
Calculation of the angle of attack gained with the elongation of the landing gears:

$$\alpha = \tan^{-1}\left(\frac{1}{15}\right) = 7{,}6°$$

Added to the pitch angle of the wings (4,75°) we obtain an take-off angle of attack of **12,35°**.
The Bee-plane is equipped with double slotted fowlers flaps that increase the wings area by 30% and the lift coefficient by 85%.

$$R_Z = \frac{1}{2}\rho.1{,}3.S.1{,}85.C_Z.V^2$$

With $C_Z = 1{,}461$ at $\alpha = 12{,}35$ $\rho = 1{,}225\ kg.m^{-3}$

Velocity needed for take-off: $V = \sqrt{\frac{2.R_Z}{\rho.1{,}3.S.1{,}85.C_Z}} = 60{,}38\ m.s^{-2}$

Drag produced: $R_X = \frac{1}{2}\rho.1{,}3.S.1{,}85.C_X.V^2 = 109454\ N$

Thrust margin (%) $= 100.\left(\frac{nb_{engines}.Prop_{thrust}+Fan_{thrust}}{R_Z} - 1\right)$

Slope (°) : $\gamma = \sin^{-1}\left(\frac{nb_{engines}.Prop_{thrust}+Fan_{thrust}-\frac{1}{2}.\rho.1{,}3.S.1{,}85.C_X.V^2}{9{,}81.MTOW}\right)$

Take-off Thrust Margins & Slopes						
	Nominal Case		Turbofan failure		Turboprop failure	
Engine	Margin (%)	Slope (°)	Margin (%)	Slope (°)	Margin (%)	Slope (°)
PW150A	**89,14**	**5,71**	**18,94**	**1,21**	**59,41**	**3,80**
TP400	**99,18**	**6,35**	**28,97**	**1,85**	**34,69**	**2,22**
AE2100A	**67,56**	**4,32**	**-2,64**	**-0,17**	**43,22**	**2,76**
AE2100D3	**77,91**	**4,99**	**7,71**	**0,49**	**50,98**	**3,26**

Table 6: Take-off margins and slopes

We used the least powerful turbofan used by the hybridization part, its thrust is 76 840 N. The most hazardous case is the turbofan failure because it is the engine that produces the most thrust. We note that the Rolls-Royce engines are not powerful enough. It is a surprise because the C130 has a MTOW of 74 tons and is capable of taking-off with only 3 turboprops, at first glance we thought that 4 of those engines should be sufficients for a MTOW of 100 tons but the slope in the case of the turbofan failure is clearly not enough for certification. We finally chose the PW150A which seems the best engine on the market for the Bee-plane.

VII. Twin-engine and four-engine planes pros and cons

To help us decide between a twin-engine and four-engine configuration we have compared the profits of each solution. Presented below are the advantages and disadvantages of twin-engine planes. The advantages of the four-engine are disadvantages of the twin-engine and vice versa.

Twin-engine planes	
Advantages	**Disadvantages**
① Maintenance costs ③ Installed power ④ Best bypass ratio ⑤ Lower weight ⑥ ETOPS Certifications	② Engine failure consequences ③ Oversized engines

Table 7: Advantages and disadvantages of a twin engine plane

Commentaries:

① Maintenance costs are greatly reduced since there is only two turbofans to be maintained against four. Maintenance times are also reduced and that allows us to save a lot of money because a plane on maintenance doesn't generate any returns. The maintenance on a twin-engine turbofan takes more time and workforce as a result of their great size but the difference is still favorable compared to the maintenance of four engines.

② Having an engine failure on a four-engine plane doesn't cause as many problem as in the case of a twin-engine.

③ To be certified a plane must be capable of taking-off with an engine failure. A twin-engine plane should be able to take-off with only one engine and a four-engine with three. In the twin-engine case we have a turbofan generating no thrust but a lot of drag while the other generate thrust on a single side of the plane. These two phenomena combined create a huge torque which would have to be compensated by the rudder, creating even more drag. As a consequence a twin-engine have more than twice the power needed for take-off installed whereas a four-engine has only 33% more power than needed. We may note that what is a disadvantage for the engineers may be an advantage for an airline company. Indeed, we have far too much power installed than needed but an airline company could be happy to have a better climb rate, a smaller take-off distance and so on.

④ We have only two engines which must provide as much thrust (if not more so, cf. point 3) as the four turbofans of the four-engine plane, those turbofans are therefore more powerful and large. The bypass ratio (BPR) allows a better efficiency. The BPR is limited by the turbofans' diameter that is why the twin-engine have a better bypass ratio than the four-engine, allowing us a better efficiency. We will not benefit from this advantage since we are using turboprops.

⑤ The weight of two engines is obviously lower than four engines even though those are smaller and lighter. A lower weight will use less fuel and increase the efficiency and range.

⑥ Before the ETOPS certifications became effective the A340 was the only plane authorized to operate certain routes. ETOPS certification removed the advantage of the four-engines by allowing some twin-engine to take the same routes as the A340. Since then the four-engine airplanes have fallen into disuse because of the less expensive and more efficient twin-engines being capable to fulfill the same missions.

From those aspects alone it is clear that the twin-engine planes present far more benefits. Yet there is no turboprop with the right power for our need, the TP400 is far too powerful and there is no smaller engine powerful enough. The TP400 also present the disadvantage of being a military product: it will be really expensive to purchase and maintain.

We therefore choose the four-engine configuration.

Hybridization

In this part, we will develop a new thing for the Bee-plane: the hybridization of the turbofan already used in the mini-Bee. This idea is to use Auxiliary Power Unit electrical power to boost take-off performances of the turbofan and then minimize the fuel consumption during it, which is maximum into this period of the flight.

I. But how to realize this?

First, we must be aware that the original turbofan is a CFM56-3C1. Our goal is to change this CFM by another turbofan which will be hybridized by APU and an electrical engine and batteries. We have chosen an engine developed by Safran Aircraft Engines, the SaM146, intended for 100 PAX planes, which have performances close to the latter but with lower mass and consumption and most of all lower costs.

You can find below a comparison between the CFM56-C1 and the SaM146:

Turbofan	CFM56-3C1	SaM146
Thrust (lb)	20000	17800
Thrust (kN)	105	77
Length (m)	2,36	2,07
Fan diameter (m)	1,52	1,224
Weight (kg)	1939	1519
Specific Consumption	0,59	0,629

Table 8: CFM56-3C1 and Sam146 comparison

We have three aims concerning the electrical engine:

1) A small engine because it has to be close to the turbofan
2) Not too heavy
3) Good performances

So, we did a list in which we can find several information about those engines (mass, power, efficiency). Three of them have been selected:

1) Simotic GP 1LA with 2 poles: better efficiency
2) Simotic GP 1LE1 with 2 poles: lower mass but power too ppor
3) Simotic SD 1LE1503 with 4 poles: very powerful but heavy too

That is why we have decided to take the first one: the most complete one, without drawbacks. This table below sums up its main characteristics (in red: the one we took)

Engine	Simotic GP 1LA		
Poles	2	4	6
Max mass (in kg)	211	196	214
Power (in kW)	37	30	22
Efficiency (in %)	92,5	92,3	90,9

Table 9: Simotic GP 1LA characteristics

It was a difficult task because there was nothing from which we could be inspired. In the actual aeronautical sector, there are not electrical engines dedicated for aircraft. Only one engine is made for this, developed by Siemens, creating a power of 260 kW, for a plane between 50 and 100 passengers.
In the following part, we also use the APS3200 as APU with those characteristics:

APU	APS3200
Weight (kg)	140
Length (cm)	125
Width (cm)	85
Height (cm)	76
Power (KVA)	90
Power (kW)	72

Table 10: APU characteristics

That will help for our calculations. This part will be divided into two parts: first, the hybridization feasibility, and then the calculations of different configurations to see the benefits of hybridization for each of them.

II. Can we really put the electrical engine into the plane ?

First possibility: put this engine directly in the SaM146, into the compressor, on the second stage or behind. Simotic GP1LA dimensions are as follows:

Simotic GP	L	H	AD	AB
environ (en mm)	400	110	195	220

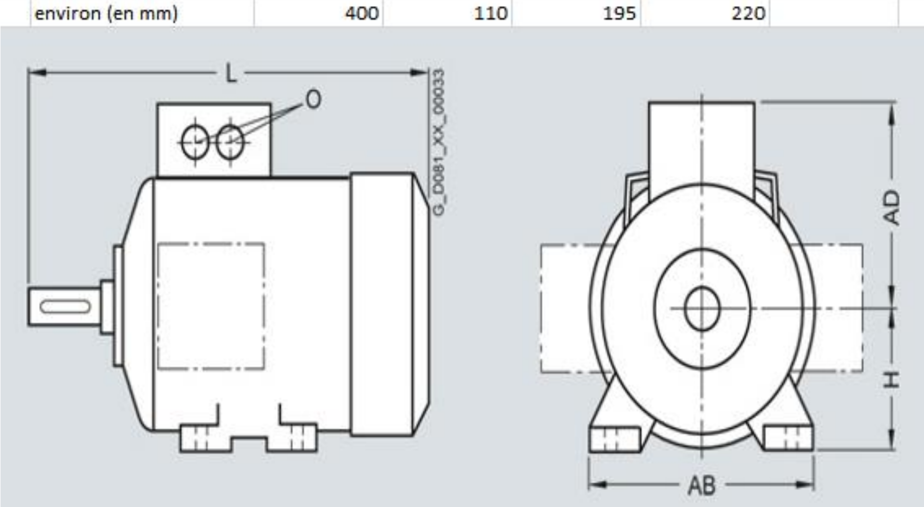


Figure 11: Simotic GP 1LA size

Knowing that SaM146's dimensions are 2.2 meters long and 1.22 meters wide, it has been possible to make a picture of it with a scale of 1/10.

Please refer to <u>Appendix 2</u>: First thought of integration of the electrical motor

Plus:
- Possibility to use the SaM146 to start the electrical engine.
- No need to create a space for the engine into Bee-Plane fuselage

Minus:
- Even if it is still turbofan's « cold » section, it is probably too hot for electrical systems
- Not 100% sure that it will not reduce turbofan performances

Second possibility: put the GP1LA before, link to the front part.

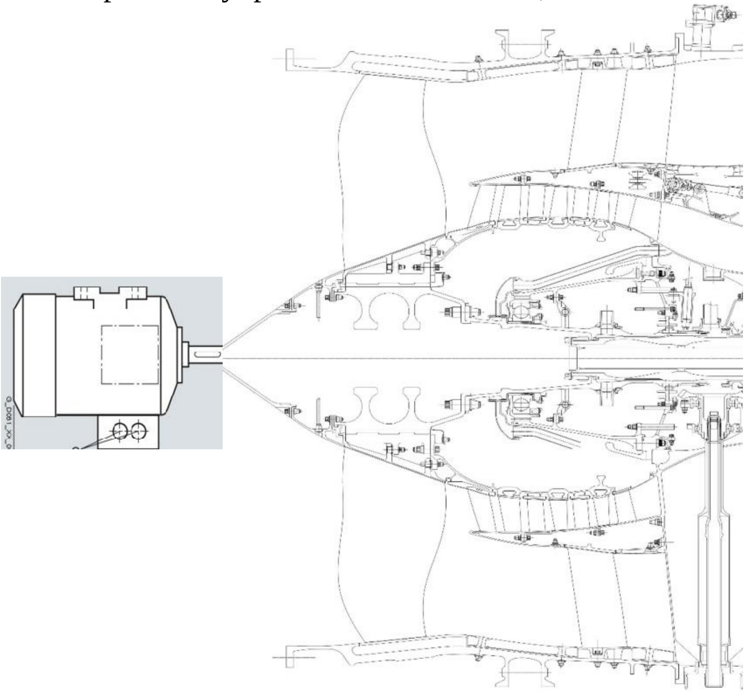


Figure 12: Second hybridization possibility (scale : 1:10)

Plus:
- The turbofan is still use to drive the electrical engine.
- Still no placement problems because it is a little engine, will not change the fuselage and doesn't block the air inlet

Finally, we choose the second one, because it has same advantages without his disadvantages.

III. Is hybridization worth it or not ?

First of all, different parts of the flight must be explained:
It is divided into four phases:
1) Take-off phase where the aircraft flights from 0 meter to a specific altitude
2) Acceleration phase where altitude doesn't change, only speed varies
3) Climb phase where it goes to his cruising altitude
4) Cruising phase

First of all, different parts of the flight must be explained:

It is divided into four phases:

a- Take-off phase where the aircraft flights from 0 meter to a specific altitude
b- Acceleration phase where altitude doesn't change, only speed varies
c- Climb phase where it goes to his cruising altitude
d- Cruising phase

The hybridization will only be used in the three first phases.

Our study will be focus on 4 Bee plane configuration: 2 Bee-planes with 2 TP400 and one CFM56-3C1, one of those will be turned-off during the climb and 2 Bee-planes with still 2 TP400 and one SaM146 hybridize, again one of those Bee-planes will turn his turbofan on during the climb.
We will use some parameters from other Bee-plane's projects:
A take-off Mach $M_0 = 0.18$, a cruise Mach $M_{7000} = 0.53$, a Maximum Take-Off Weight = 100000 kg, a take-off speed = 69.4 m/s, a cruise speed = 150 m/s, cruise at 7000 meters, angle of climb pre-set.

We also made some suppositions:
Static temperature Ts = 288.1 K, temperature at 7000 m Ts (Z=7000) = 257.65 K, at 2000 m Ts (Z=2000) = 275.15 K =.
Static pressure Ps = 101325 Pa
Gas constant R = 287.04 J/kg, gravity g = 9.81 m/s
For the batteries, we estimate that we have 100 kg of those plus 100 kg of wires.

To turn the electrical motor power and the engine power into a thrust, we used this following formula:

$$Thrust = \frac{Power}{aircraft\ velocity} . \eta_{propulsif}$$

With a power of 8205 kW for the TP400 and 37 kW for the GP-1LA.
By using that, we obtained a thrust for the TP400 of F = 78075 N and F = 148.3 N for the GP-1LA.

The objective of each part is to determine the consumption at the end of it.

In red, you will have the first case of the CFM + 2 TP400, in purple the CFM turned-off during climb + 2 TP400, in blue the SaM146 + 2 TP400 and in green the SaM146 turned-off during the climb + 2 TP400.

a. ***First part of the take-off***

First, we need to calculate the take-off weight with Mach when taking-off: $M_0 = \frac{V_0}{\sqrt{\gamma . R . T_S}}$
With an initial speed of $V_0 = 69.4\ m/s$, $M_0 = 0.20$.

Knowing this Mach, we can calculate the Bee-plane thrust at this moment of the flight:
$F_{0/M_0} = F_{0/0} . (0.568 + 0.25 . (1.2 - M_0)^3) \sigma^{0.6}$, the first number, 0, in F_{0/M_0} shows the altitude and the second one, M_0, shows the Mach number.
$F_{0/0}$ being respectively the TP400 thrust, the CFM thrust and the SaM146 hybridate thrust.

But, at an altitude Z=0, σ = 1, we have:

$$F_{0/M_0} = F_{0/0}.(0.568 + 0.25.(1.2 - M_0)^3$$

With F_{0/M_0} in Newtons.

When, we determine each, it's possible to find the specific consumption with the same Mach, with the formula of the specific consumption evolution: $CS\ (M_0, Z) = CS(Z).(1 + M_0)$, CS in kg/(daN.h). We found the specific consumption for each engine and then we used it to show the consumption per hour: $CH_{0/M0} = F_{0/M0}.CS_{0/M0}$, in kg/h.
By knowing the speed and distance travelled during this phase, we can find how much time did this first part take: $t_{phase\ 1} = \frac{L_{phase\ 1}}{V_{phase\ 1}}.10^3$, we multiply by 10^3, cause our distance $L_{phase\ 1}$, is in km.
Finally, by combining those 2 results, we obtain the fuel consumption during the first part.

$$C_{phase\ 1} = CH_{phase\ 1}.\frac{t_{phase\ 1}}{3600}$$

With this solution, we only find the consumption for each kind of engine (TP400, CFM56, and SaM146). However, the Bee-plane conception is 2 TP400 with one turbofan. That's why, to find the final consumption, we do:

$$C_{phase\ 1} = 2.C_{phase\ 1\ of\ TP400} + C_{phase\ 1\ of\ CFM}$$

or

$$C_{phase\ 1} = 2.C_{phase\ 1\ of\ TP400} + C_{phase\ 1\ of\ SaM}$$

The following picture resumes our results:

C phase 1	235,4869955	kg
Cphase 1	235,487	kg
Cphase 1	223,364	kg
Cphase 1	223,364407	kg

Table 11: Take-off results

b. Second part: the acceleration

In this part we climb to an altitude of 2000 meters.
We continue to follow the same logic from the previous part:
We determine the Mach at 2000 m with M_2000=V_2000/√(γ.R.T_S), here the speed is the one of the cruise, V = 150 m/s.
So, M_2000=0.44.
We still use the same formula for the thrust: F_(2000 〖/M〗_2000)= F_(0/0).(0.568+0.25.(1.2-M_0)^3)σ^0.6
But here, σ = 0.785 at 2000 m (value find in previous project).
For the specific consumption, we can't directly use the law of evolution. First, we must take care about the difference of altitude:

$$CS_{2000/M_0} = CS_{0/M0}.\sqrt{\frac{Ts(Z = 2000)}{Ts(Z = 0)}}$$

And now,

$$CS_{2000/M_{2000}} = CS_{2000/M0}.(1 + M_0)$$

As the previous part, the consumption per hour is now possible to be calculated:

$$CH_{2000/M_{2000}} = F_{2000/M_{2000}}.CS_{2000/M_{2000}}$$

For the distance covered during the acceleration, a climb angle must be considered, equal at 1.53°, like obtained in a previous project.

$$L_{phase\ 2} = V_{phase\ 2}.t_{phase\ 2}.\cos(\alpha) = 58.3\ km$$

And

$$C_{phase\ 2} = CH_{phase\ 2}.\frac{t_{phase\ 2}}{3600}$$

We still do for each case:

$C_{phase\ 2} = 2.C_{phase\ 2\ of\ TP400} + C_{phase\ 2\ of\ CFM}$ or $C_{phase\ 2} = 2.C_{phase\ 2\ of\ TP400} + C_{phase\ 2\ of\ SaM}$

Cphase 2	1976,069097	kg
Cphase 1+2	2211,556093	kg

Cphase 2	1976,07	kg
Cphase 1+2	2211,56	kg

Cphase 2	1765,46	kg
C phase 1+2	1988,82	kg

C phase 2	1765,45848	kg
C phase 1+2	1988,82289	kg

Tableau 12: Acceleration results

c. Third part : the climb

Here, we go from 2000 m to 7000 m. The calculation looks like the second part, but the objective of the turbofan use is to stop it whenever we can. So we tried to stop the CFM/SaM146 during this phase. That's why we have 4 boxes.

So, here we know from our inputs that we are at Mach 0.53. We can easily find the thrust with:

$$F_{7000/M_{7000}} = F_{0/0}.(0.568 + 0.25.(1.2 - M_0)^3)\sigma^{0.6}$$

There, σ = 0.405 at 7000 m.

From those results, we found the specific consumption at 7000 m, still calculated in two times:

$$CS_{7000/M_0} = CS_{0/M0}.\sqrt{\frac{Ts(Z = 7000)}{Ts(Z = 0)}}$$

Then,

$$CS_{7000/M_{7000}} = CS_{7000/M0}.(1 + M_0)$$

Climb being realized at iSO speed, V = 150 m/s, and climb angle is equal at 1.04°, we have:

$$L_{phase\ 3} = V_{phase\ 3}.t_{phase\ 3}.\cos(\alpha) = 242\ km$$

Finally:

$$C_{phase\ 3} = CH_{phase\ 3}.\frac{t_{phase\ 3}}{3600}$$

We continue to take care than we considered we have 2 TP400 and one turbofan:

C phase 3	3736,095646	kg
C phase 1+2+3	5947,651738	kg

C phase 3	1840,5	kg
C phase 1+2+3	4052,06	kg

C phase 3	3309,82	kg
C phase 1+2+3	5298,64	kg

C phase 3	1840,50208	kg
C phase 1+2+3	3829,32497	kg

Tableau 13: Climb results

d. Fourth part : cruise

In that last part, our goal is to determine the flying range of each configurations.
For that purpose, we calculate the maximum fuel mass that the Bee-plane could embark.

$$m_F = 564.10^{-9}.m_{TOW}^2 + 0.2118.m_{TOW} = 26870\ kg$$

We substract from this all the consumptions to find the maximum consumption in cruise phase. We use the TP400 consumption per hour because both turbofan must be turned-off.
By dividing the consumption by the consumption per hour, we have how many times we can fly with this fuel quantity and then:

$$L_{phase\ 4} = V_{phase\ 4}.t_{phase\ 4}$$

Finally, by adding $L_{phase\ 4}$ plus all the other distances, we obtained our flying range:

$$L_{flying\ range} = L_{phase\ 1} + L_{phase\ 2} + L_{phase\ 3} + L_{phase\ 4}$$

And there are our final results:

Ltot	7245,327688	km

Ltot	7632,49	km

Ltot	7460,7021	km

Ltot	7948,29743	km

Table 14: Cruise results

As a first conclusion, we could affirmed one thing: turning-off the turbofan during the climb is interesting. We might too say that the SaM146 hybridize could be privileged.

IV. Flying cases

To have a better view of our study, 3 different cases of flight for each configuration has been made, one for Paris-Nice because we developed it in the flight plan, one of 2000 km and one of 400 km :

TP400 +CFM	Paris - Nice	Case 2	case 3	TP400 + SaM146 hybridate	Paris - Nice	case 2	case 3	
Total distance	686	2000	400	Total distance	686	2000	400	km
C cruise	1156,49	5116,094574	294,6596886	C cruise	1156,49117	5116,0946	294,6596886	kg
C1+2+3	5947,65	5947,651738	5947,651738	C1+2+3	5298,64323	5298,6432	5298,643232	kg
C total	7104,142912	11063,74631	6242,311427	C total	6455,13441	10414,738	5593,302921	kg
TP400 + CFM turned-off during climb	Paris - Nice	case 2	case 3	TP400 + SaM146 hybridate turned-off during climb	Paris - Nice	case 2	case 3	
Total distance	686	2000	400	Total distance	686	2000	400	km
C cruise	1156,491174	5116,094574	294,6596886	C cruise	1156,49117	5116,0946	294,6596886	kg
C1+2+3	4052,058177	4052,058177	4052,058177	C1+2+3	3829,32497	3829,325	3829,324975	kg
C total	5208,549352	9168,152751	4346,717866	C total	4985,81615	8945,4195	4123,984663	kg

Table 15: Performance calulation for different cases

To have those results, we first took the total distance, substract from this all the taking-off distance calculate in previous parts. Then we calculate the cruise time with:

$$t_{cruise} = \frac{D_{cruise}}{V_{cruise}}$$

(D_{cruise} : cruise distance in meters, V_{cruise} : cruise speed = 150 m/s)

Then, by using:

$$C_{cruise} = CH_{cruise}.t_{cruise}$$

We add this last one with take-off consumption ($C_{phase\ 1+2+3}$), we have finally our last result. As you may see, using the SaM146 hybridize makes a gain of almost 220 kg. However, the SaM146 has a lower mass than the CFM56 (420 kg), using hybridization increases mass of approximately 410 kg. Moreover, using hybridization doesn't over such an enormous gain, it will be interesting to use it in the future when an electrical engine more powerful and with the same (or less) mass than the Simotic GP-1LA will appear. For right now, we don't think it's really worth it to hybridize the turbofan

FLIGHT PLAN

I. Introduction

In addition to "hybridization" part and "performances and motorization" part, we have focused on the flight plan for the Bee-plane. The flight studied is the route Paris-Nice.

The main aim of this part is to get at the end a full code, which can be used to calculate and estimate data during a flight, for example the fuel consumption, the range. This code will be handled by the school Centrale Paris, which is working on the subject too. The goal is to test different scenarios which are different from each other and to choose the best one. The altitude, the waypoints (route) can be modified from one scenario to another one.

We have built a XML code to describe the route followed by the Bee-plane but also all the parameters related to the aircraft. Therefore, the first difficulty we met was to get familiar with XML language. For that, we have used some guidebooks found on internet. In parallel, we have looked at the files already created in the past years for this project.

After several researches, we have defined what the code would be composed of. It is articulated around the eight following parts:

1- General information
2- Departure airport
3- Arrival Airport
4- Diverted Airport
5- Operational times
6- Waypoints and route
7- Engines
8- Hybridization

For a better understanding and to make things as clear as possible, Sophie and I have used the Excel tool as support for our work. We have created Excel tables, containing for example "Description" column, storing the precise meaning of each code line.

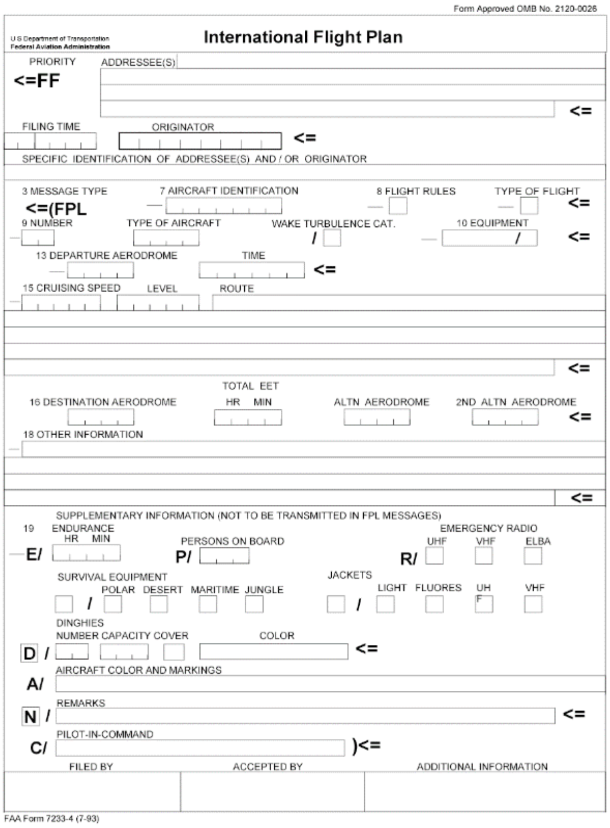
V. Definition

The flight plan is a set of information provided by the pilot before each flight to the aeronautical traffic services authorities. That information allows them to ensure the necessary services during a flight such as flight information, control and warning services and in case of accident, to provide information to the rescuers. Thus, they can manage all flights.

Definition according to ICAO:
"The term "flight plan" is used to mean variously, full information on all items comprised in the flight plan description, covering the whole route of a flight, or limited information required when the purpose is to obtain a clearance for a minor portion of a flight such as to cross an airway, to take off from, or to land at a controlled aerodrome."

Therefore, the flight plan should include all relevant information related to the intended flight such as:

- Aircraft identification
- Aircraft colour
- Rules and type of flight
- Embedded equipment
- The departed airport
- The estimated time of departure of the parking station
- Cruising speed
- Cruise level or altitude
- The route and waypoints
- The destination aerodrome and the estimated total duration
- The diverted airports
- Autonomy
- Passengers and crew number
- Survival equipment aboard



Example of an FAA flight plan form

A flight plan must be turned in to the competent authorities at least sixty minutes before the estimated departure time of the parking station, or for the IFR flight, sixty minutes before the estimated time at which the aircraft will begin its IFR flight. Nevertheless, in some cases, the delay is increased up to three hours if the flight is subject to regulatory actions.
The obligation to provide a flight plan differs from one country to another one. It is compulsory for all international flights or flights with out of sight condition.

There are different types of flight plan:

- PLN flight plan: This is a set of information related to a planned flight.
- FLP flight plan: This is the form considered as “the flight plan”. It is submitted before the flight and describes the entire flight.
- CPL flight plan: “This is a flight plan for a controlled flight operated in accordance with air traffic control authority approvals”.
- RPL flight plan: This is a repetitive flight plan for the IFR flights repeating at least 10 times during a period at regular intervals and with the same basis characteristics (road, radio call sign, departure and arrival airport, etc.)
- AFIL: This is a flight plan provided by radiotelephony to an air traffic organization.

VI. General information

This part is dedicated to providing general information about the flight and the aircraft before going into the details.

First of all, the flight is defined by a name and a number, to know exactly which flight we are talking about.
Please refer to the Annex 1 entitled *Flight part XML code* at the end of the report.

After that, you can find information about the carrier for this specific flight such as the name, different codes and phone number.

To deal with the next two data, we have used two tables from a book (FlightStats DevelopperCenter, FlightStats, Inc).
To define the flight status, we have looked at the table you can find in Annex 2.
We have chosen the letter S for the flight status, meaning "Scheduled".

For the next information, the flight type, we have used a table: please refer to the Annex 3 *Flight type*.
Here, we have selected the letter J: Scheduled Passenger (Normal Service)

The Annex 4 *Aircraft part XML code* displays data about the aircraft: identity, type, figures (number of passengers, Specific Fuel Consumption, weights) but also about the wings, bodies and landing gears.
For example, for the wings, bodies and landing gears, geometric data are given (length, incidence, chord).

The last part is about the equipment of the aircraft. You can refer to the Annex 5 *Equipment part XML code*.
.

VII. Departure – arrival – diverted airports

This part of the code deals with airports related to the flight. Here are reported all important information to simulate the flight and perform calculations. It is the same template for the three types of airports concerned by the flight.

Each airport code is divided into four parts:
- General
- Dates and times
- Resources
- Runway

You can refer to the Annex 6 *General part for Paris-Orly Airport XML code* for this part.

We have focused in this section on codes to make the airport well-identified by the Federal Aviation Administration (FAA), aircrafts pilots and control towers staff.

The **IATA code** is a localisation identifier defined by the International Air Transport Association. It is a three letters code. We can see it on our luggage at the airport.
The **ICAO code** (for the country and the airport) is a location indicator for each airport worldwide composed by four letters given by the International Civil Aviation Organization.
The first letter refers to a continent or a group of states. The second one indicates the country on the continent or group of states. The last two letters identify each airport.

The **FAA** airport **code** is a code given by the FAA to American airports. So we do not have to take this data into account for our case.

In this part, there are also figures to locate the airport precisely such as latitude, longitude and altitude. These data are necessary to be aware of the difference of location between the aircraft and the airport. It is very important for the landing phase.

Another important point is the region time zone. A time zone is a region of the globe that observes a uniform standard time for legal, commercial, and social purposes.
Time zones tend to follow the boundaries of countries and their subdivisions because it is convenient for areas in close commercial or other communication to keep the same time.

Most of the time zones on land are offset from Coordinated Universal Time (UTC) by a whole number of hours, but 30 or 45 minutes offset a few zones.
For Paris-Orly Airport, the time zone is Europe Paris UTC+10. It is the same for the diverted airport (Lyon Saint-Exupéry) and the arrival airport (Nice Côte d'Azur).
This information is essential to manage all the departure and arrival dates and times, especially when a flight is between two different countries. It is needed to have the same time reference.
Other information such as the terminal, the gate and the luggage gate are related to each flight at a specific airport.
Please refer to the Annex 7 *Dates & Times and Resources parts for Paris-Orly Airport XML code*.
The subpart *Runway* (Annex 8) is about the departure runway. Many details are given such as the length, the width, the surface type, the threshold offset, the overrun length and bearings.
In this case, at Paris-Orly airport, to define which runway to use for the flight take-off, one must take the wind speed and direction into account.
.

VIII. Operational times

During a flight, some incidents or program changes can occur due to weather inconvenience or bird strike. That irregular information must be included in the flight plan in real time to inform the competent authorities.

The operational times are all irregular information that occur during a flight such as:

- Cancellation: Flight who has been cancelled for any reason.
- Diversion: Flight directed to land at a different airport (called diverted airport) instead of its scheduled destination.
- Miscellaneous: An irregular operation that is not considered as one of the other identified types listed in the flight plan.
- Place replacement: Any flight that is cancelled or does not operate for some reason. It may be replaced by another flight.
- Incident: If an incident occurs, the pilot must be able to change his flight plan. For example, when one happens, the pilot shall have the ability to enter information on the system to inform the control tower such as:
    - ➢ the kind of the incident,
    - ➢ the date and time of the incident,
    - ➢ a message describing the incident.

- Schedule changes: The schedule might change during a flight due, for example, to weather condition or congestion at the arrival airport. To manage all flights, the flight authorities need to know precisely the schedule of the flight (take-off, landing, etc.).
- Weather changes: That information will be used for the future “Waze” to inform users about the weather conditions.
- Route change: The flight plan needs to know any change of waypoints or route.

In the case of the route LFPO-LFMN, we choose two diverted airports:

ID	Type	Altitude	Latitude	Longitude	Distance from LFPO	Name
LFLL	APT	0 ft / 0 m	45.72581˚	5.09075˚	212 nm	Lyon Saint Exupéry
LFTH	APT	0 ft / 0 m	43.09734°	6.14603°		Toulon-Hyères

Table 16: Characteristics of our diverted airports

The first airport, “Lyon Saint Exupéry”, is located almost in the middle of the route LFPO-LFMN. It can easily be the diverted airport in case of needed diversion.
The second airport, Toulon-Hyères, can be the diverted airport for landing in case of a congestion or problem at the LFMN airport.
In our case, the future “Waze” users will need all that information to prevent and change the route to have the most optimal one.

IX. Waypoints and route

A route is defined by the pilot to connect its destination from his departure aerodrome. Each user needs to respect the constraint of use of each road and each crossing point. For example, some roads are forbidden the week-end.
A route includes an Air Traffic Service route designator, the track to or from significant points (waypoints). They have fixed coordinates and are written with generally five letters. A route begins and ends with the ICAO airport code.

For our study, the route begins at Paris-Orly airport and ends at Nice Côte d’Azur airport.

The main characteristics are:

- Distance: 367 nm / 679 km
- Maximal altitude: 35,000 feet / 10,668 meters
- Number of waypoints: 8
- Route: LFPO AVLON UM976 ATN UZ12 BULOL UM733 OKTET LFMN
  Route explanation:
    - At the airport LFPO, go to waypoint AVLON, where you join airway UM976
    - Continue on UM976 until ATN
    - At ATN, leave airway UM976 and join airway UZ12
    - Continue on UZ12 until BULOL, in this case via an intermediate waypoint MOMIL.
    - At BULOL, leave airway UZ12 and join airway UM733
    - At OKTET, leave airway UM733 and continue direct to the arrival airport LFMN.

ID	Type	Altitude	Latitude	Longitude	Distance from the other waypoint	Distance from the first waypoint	Heading (true)	Name
LFPO	APT	0 ft / 0 m	48.72636°	2.36703°	-	0 nm	-	Paris Orly
AVLON	FIX	31,400 ft / 9,571 m	47.56000°	3.81333°	90 nm	90 nm	140° / 141°	-
ATN	VOR	35,000 ft / 10,668 m	46.80594°	4.25914°	48 nm	139 nm	158° / 158°	-
MOMIL	FIX	35,000 ft / 10,668 m	46.54611°	4.54667°	19 nm	159 nm	143° / 143°	-
BULOL	FIX	35,000 ft / 10,668 m	46.04583°	5.09194°	37 nm	196 nm	143° / 143°	-
GIPNO	FIX	27,900 ft / 8,504 m	45.56000°	5.52917°	34 nm	231 nm	148° / 148°	-
OKTET	FIX	19,500 ft / 5,944 m	44.48500°	6.56944°	78 nm	309 nm	145° / 146°	-
LFMN	APT	0 ft / 0 m	43.65798°	7.21536°	56 nm	366 nm	150° / 151°	Nice/Côte d'Azur

Table 17: Waypoints and their properties

You can find the map with the waypoints in the Annex 9 *LFPO-LFMN route and its waypoints*.

Waypoints indicate the moment when the pilot needs to lower or retract landing gears during a landing or a take-off. Some waypoints allow as well to adjust the engine speed according to the various flight phases.

X. Engines

In this part, we give data about the different engines we have considered for the Bee-plane. The study of performances and hybridization has allowed us to choose the best configuration.

At the beginning, we had the eight different following possibilities:

- two turboprop TP400-D6 engines with the turbofan CFM56-3C1
- two turboprop TP400-D6 engines with the turbofan CFM56-3C1 and an electric engine
- two turboprop TP400-D6 with the turbojet SaM146
- two turboprop TP400-D6 with the turbojet SaM146 an electric engine
- four turboprop PW150A engines with the turbofan CFM56-3C1
- four turboprop PW150A engines with the turbofan CFM56-3C1 and an electric engine
- four turboprop PW150A with the turbojet SaM146
- four turboprop PW150A with the turbojet SaM146 and an electric engine

The final configuration we have chosen is the last one.
The data of the four engines TP400-D6, PW150A, CFM56-3C1 and SaM146 are provided in this part. Please refer to the Annex 10 *Engines part for Paris-Orly Airport XML code*

XI. Hybridization

This section focuses on the electric engine Simotic GP1LA which powers the turbofan SaM146, and on the Auxiliary Power Unit (APU). Please refer to the Annex 11 *Hybridization part for Paris-Orly Airport XML code.*

Project management

To enhance our productivity and to have a good overview of the project, we have resorted to management methods. Through a unique file, we describe our goals and a timeline expectation for the project.

Besides, we kept all the documents on a Dropbox in order to have access to the work of everybody, all the management information, our database and the deliverables. We also organized regular call meetings with Mr Dutertre to explain the work done, our expectations for the following tasks and ask questions. It was also a means to be sure we were going in the right direction. After that, we made a report (annex X) for each meeting, to know where we are and what we have to do for the next call.

I. Division of tasks

The first step was "a state of the art", a phase of preliminary analysis. We have especially studied the existing documents made previously and defined the limits of the project.

Then we decided to focus only on three topics:

Romain Neuville	Confirm the advantages for a mixed propulsion configuration (two TP400-D6 engines and a central turbofan CFM56-3C1)
Benjamin Olier	Study about a possible hybridization of the CFM56-3C1 - benefits calculations
Constance Chirol **Sophie Olias-Zeitschel**	Set-up a complete database to get the final flight plan XML code for a Paris-Nice flight
Stephane Faure	Complete the Simulink to find the range of the Bee-Plane (ditched)

The fourth theme has been given up because the school Centrale Paris had to create a special code XML to solve the range. So, it was not necessary to focus on that even though we have begun to analyse the Simulink.

XII. The Gantt diagram (Appendix 1)

This document is a classic one to manage a project. Based on the expectation matrix, it describes the time needed for each task to be completed, the outputs and also what we did in reality. That is a good way to visualize our delay or our advance. Plus, we added the deadlines for the project and regular meetings.

With some macro, we can easily update the file and use it to see our progress. Moreover, thanks to it, the PO is aware of what we do and of our progress regarding the goals fixed at the very beginning.

Conclusion

In conclusion, we finally realized that the hybridization is not yet the best solution to improve the power efficiency of the Bee-Plane. Indeed fuel savings do not compensate the weight cost of the hybridization. There are many technical inconveniences to save a few more electrical energies, but in the future, thanks to better electrical motors, it could be a great solution to integrate in a plane system.

On the other hand, we have tested several engine configurations for the Bee-Plane and we have determined that the turboprop that makes the most effective plane is the PW150A used in a four-engine version. This turboprop offers the right power level to answer the Bee-plane needs. All calculations were based on the performances of the Bee-plane on all flight phases and scenarios.

The Flight Plan, was an opportunity to learn a new computer language: the XML. The goal of this code is to calculate all the performances characteristics of our plane on the route Paris-Nice.The Flight Plan also needs to be able to change in order to optimize the chosen route with all the community-based data. At the very end, the aim is to create a kind of aeronautical Waze.

Moreover, during this study, we learned a lot on different subjects. It was really interesting to work on such an innovative plane with huge technological potentials and working on a futurist aeronautical project is a chance and constitutes a unique working experience for students like us. Indeed, we have to find a concrete solution for a future innovative project which should be launched in 2050, and we know there is still a lot of work to do to approach this goal. But sincerely we hope our work will help Mr. Dutertre to continue on this innovative aircraft and one dayallow him to set up the Bee-Plane

Feedback

The main difficulties, whatever the subject was, were to find relevant and useful information. Moreover, the team coordination was difficult at the beginning, in fact we never worked together. At the end, the difficulties have been surpassed by the common objective: Creating a futuristic plane, the Bee Plane.

At the beginning, we worked slowly because we didn't completely understand the heading. After a state of the art and several meetings we were able to identify the stakes of this project: a new motor configuration, the hybridization of the turbojet and the flight plan with the aim of testing different engines scenarios. We were now ready to split the work to conduct the project.

At the end of the project we were able to take a step back and estimate the elements we should focus on during the next years:

- Estimate integration feasibility of all those engines;
- Calculate maintenance costs;
- Estimate the profitability of the Bee-plane;
- Estimate the exhaust emissions generated by the Bee-plane.

Besides, these subjects match with our ISPEB school program.

To conclude this feedback, we can say that working on the Bee-plane was challenging because it's an uncommon and unique plane. It was a rewarding experience both on technical and interpersonal skills

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support de cours ESTACA	landing and take-off waypoints

APPENDIXES

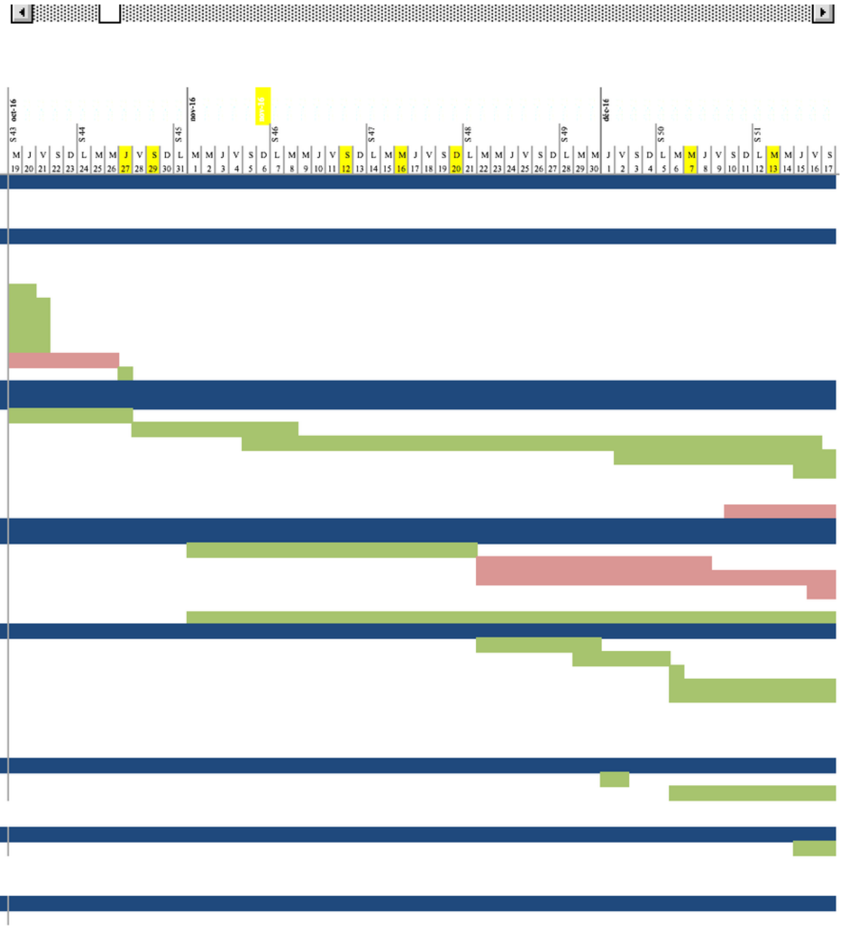
I. Appendix 1: Gantt diagram (extract)

Barre de formule

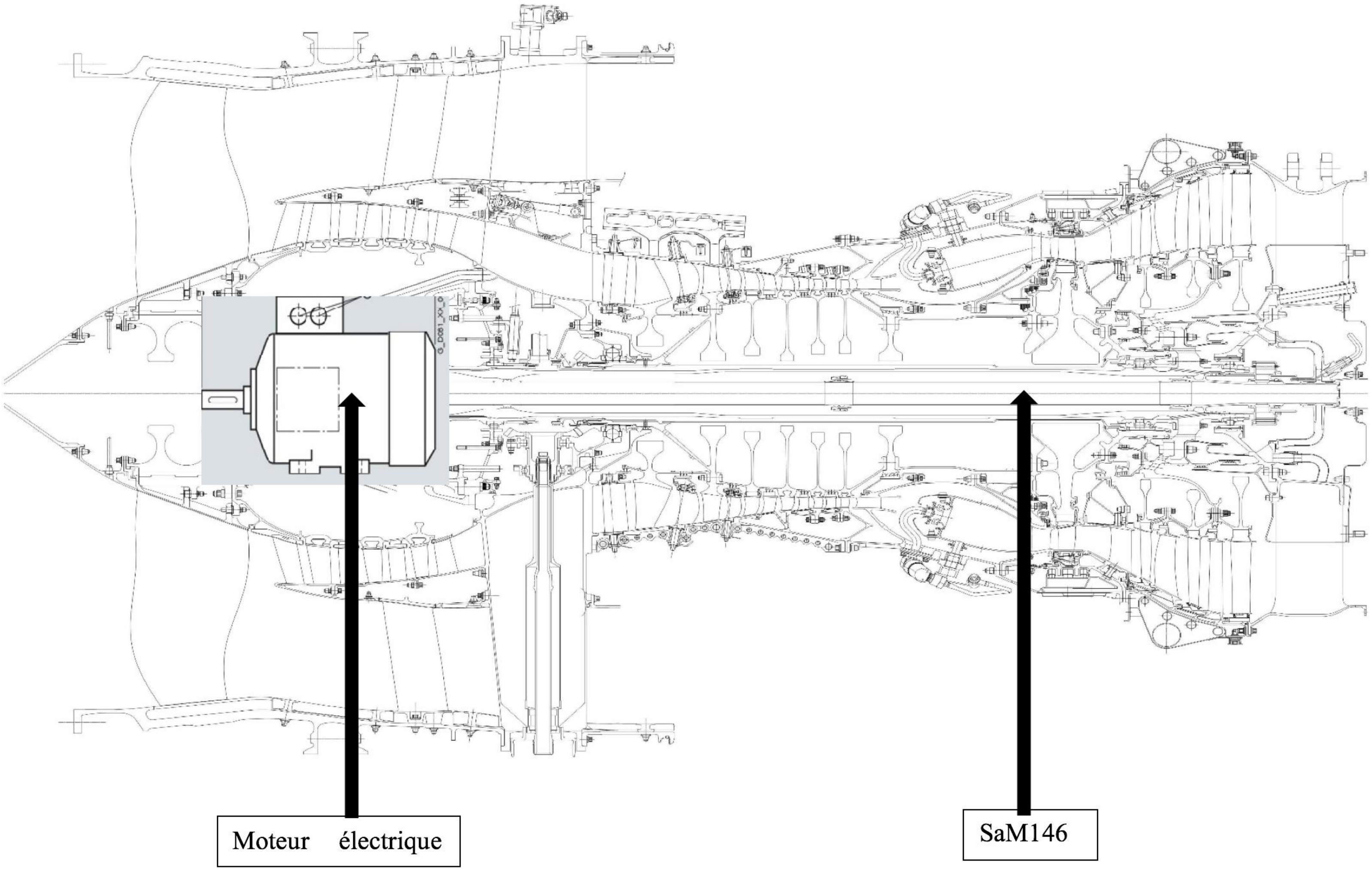
Projet	Bee-plane
Chef de projet	Constance Chirol
Membres	Stéphane Faure, Sophie Olias-Zeitschel, Benjamin Olier, Romain Neuville, Constane Chirol
Jours ouvrés uniquement	OUI
Date de début	03/10/2016

Commentaires : En Jaune les jours où un créneau projet est dédié

	Tâches	Output	Remarques et problèmes	Responsable	Date de début	Durée	Date de fin	Réalisé
1	**Définir le cadre et les enjeux du projet**							
1.1	Définir le cadre du projet				05/10/2016	5	11/10/2016	100%
1.2	Définir les frontières du projet				05/10/2016	5	11/10/2016	100%
1.2	2ème rdv téléphonique avec le tuteur				11/10/2016	1	11/10/2016	100%
2	**Etat de l'art**							
2.1	Etude des travaux existants (trouver toutes les données)	DATA		Sophie	13/10/2016	3	17/10/2016	100%
2.2	Compréhension des fichiers XML existant 1	Base de donnée et repertoire, caractéristique moteur…		Benjamin, Constance	11/10/2016	4	14/10/2016	100%
2.3	Compréhension des fichiers XML existant 2			Stéphane, Romain	12/10/2016	2	13/10/2016	100%
2.4	Documentation sur le Bee-plane			Tous	11/10/2016	8	20/10/2016	100%
2.5	Etude comparative des perfo avion TP400	excel du calcul des perfo.		Constance	13/10/2016	7	21/10/2016	100%
2.6	Etude comparative des perfo avion avec CFM	excel du calcul des perfo.		Romain	13/10/2016	7	21/10/2016	100%
2.6	Etude des Simulink	Word et schéma récapitulatif		Stéphane	13/10/2016	7	21/10/2016	100%
2.7	Faire un FAQ	Word sur dropbox		Sophie	13/10/2016	7	21/10/2016	100%
2.8	Etude faisabilité de l'hybridation du turbofan	Excel ou/et Word	Questionnement sur la faisabilité de cette hybridation	Benjamin	13/10/2016	10	26/10/2016	10%
2.9	CR intermédiaire pour le tuteur	Document format pdf		Tous	27/10/2016	1	27/10/2016	100%
3	**Développer la version biréacteur et performances associées**	**Romain Neuville**						
3.1	Résumé des travaux réalisés par les autres équipes	"Travaux à date du 27.10.pdf"			11/10/2016	13	27/10/2016	100%
3.2	Pros & Cons Biréacteur / quadriréacteur	"Travaux à date du 21.11.pdf"	A première vu la configuration bi est plus avantageuse. A confirmer avec les calculs de perfos		28/10/2016	8	08/11/2016	100%
3.3	Calculs de performances généraux	"Travaux à date du 21.11.pdf"			05/11/2016	30	16/12/2016	100%
3.4	Optimisation de la surface alaire	S=129m²			02/12/2016	24	04/01/2017	100%
3.5	Calculs des régimes moteurs et ranges				15/12/2016	25	18/01/2017	100%
3.6	Choix du profil NACA	NACA 4415			05/01/2016	6	12/01/2016	100%
3.7	Cas du décollage				20/12/2016	33	02/02/2017	100%
3.8	Choix de la motorisation	PW150A			10/12/2016	39	02/02/2017	100%
4	**Choix et intégration du turbofan (voir si on garde ce qui a déjà été fait)**	**Benjamin Olier**						
4.1	Etat des lieux de ce qui a déjà été fait				01/11/2016	15	21/11/2016	100%
4.2	Choix moteur électrique				22/11/2016	13	08/12/2016	100%
4.3	Etude faisabilité de l'hybridation du turbofan	Voir Word			22/11/2016	20	19/12/2016	100%
4.4	Intégration moteur élec dans fan				16/12/2016		13/01/2017	100%
4.5	Comparaison sans/avec/+ batterie				20/12/2016	25	23/01/2017	100%
4.6	Hybridation du turbofan	Voir Excel			01/11/2016	68	02/02/2017	95%
5	**Plan de vol pour waze**	**Sophie Olias-Zeitschel & Constance Chirol**						
5.1	Etat de l'art				22/11/2016	7	30/11/2016	100%
5.2	XML part 1 définition des données à intégrer dans le code				29/11/2016	5	05/12/2016	100%
5.3	Réunion de recadrage pour le XML				06/12/2016	1	06/12/2016	100%
5.4	XML: Departure/arrival runway + engines + diverted airport + operational times				06/12/2016	29	13/01/2017	100%
5.5	XML: Waypoints + hybridation + envoyer première version du code à Centrale				12/01/2016	5	18/01/2016	100%
5.6	Adapter le XML aux 4 scénarios possibles (motorisation) - finir partie hybridation/moteurs du code				12/01/2016	16	02/02/2016	
5.7	Ecriture code XML sous word				01/02/2017	2	02/02/2017	100%
6	**Vérification des résultats avec Centrale**	**Stéphane Faure**						
6,1	Estimation des coeff aéronautiques		A confirmer après calculs de Centrale		01/12/2016	2	02/12/2016	100%
6.2	Etude de la consommation				06/12/2016	10	19/12/2016	100%
6.3								
6.4								
7	**Création du rapport**							
7.1	Ecriture du rapport	CR			15/12/2016	36	02/02/2017	5%
7.2								
7.3								
7.4								
8	**Création du poster résumé**	**Stéphane Faure**						
8.1	Faire poster	Page A3			09/01/2017	5	28/01/2017	80%



II. Appendix 2: First thought of integration of the electrical motor



III. Appendix 3: Consumption for 4 Bee-plane configurations

CFM+TP400

Phase 1 CFM			Phase 1 TP400		
Mach	0,203963574		Mach	0,20396357	
F0/0,18	85579,10409	N	F0/0,18	63634,7822	N
Cs0/0,18	0,710338508	kg/(daN.h)	Cs0/0,18	0,46376677	kg/(daN.h)
CH0/0,18	6079,013316	kg/h	CH0/0,18	2951,16973	kg/h
CHphase1	6137,006658	kg/h	CHphase1	3471,91248	kg/h
Lphase1	2	km	tphase1	64,808814	s
Vphase1	30,86	m/s	Cphase1	62,5029251	kg
tphase1	64,808814	s			
Cphase1	110,4811453	kg			
C phase 1	**235,4869955**	**kg**			
Masse moyenne	**99882,3**	**kg**			
Phase 2 (acceleration) CFM			**Phase 2 (acceleration) TP400**		
Z	7000	m	Z	7000	m
M0 à 7000	0,53		M0 à 7000	0,53	
V0	150	m/s	V0	150	m/s
T(Z=7000)	257,65	K	T(Z=7000)	257,65	K
T(Z=2000)	275,15	K	T(Z=2000)	275,15	K
M0 à 2000	0,440843459		M0 à 2000	0,44084346	
sigma	0,785		sigma	0,785	
F2000/0,512	61509,59023	N	F2000/0,512	45737,2091	N
CS2000/0	0,576587391	kg/(daN.h)	CS2000/0	0,37644316	kg/(daN.h)
CS2000/0,512	0,830772171	kg/(daN.h)	CS2000/0,512	0,54239566	kg/(daN.h)
CH2000/0,512	5110,045583	kg/h	CH2000/0,512	2480,76638	kg/h
Vphase2	90,43	m/s	Vphase2	90,43	m/s
angle climb	1,53	°	angle climb	1,53	°
angle climb	0,026703538	rad	angle climb	0,02670354	rad
tphase2	645,1612903	s	tphase2	645,16129	s
CHphase2	5594,52945	kg/h	CHphase2	2715,96806	kg/h
Cphase2	1002,603844	kg	Cphase2	486,732627	kg
Lphase2	58321,13552	m	Lphase2	58321,1355	m
	58,32113552	km		58,3211355	km
Cphase 2	**1976,069097**	**kg**			
Cphase 1+2	**2211,556093**	**kg**			
Masse moyenne	**98776,48**	**kg**			
Phase 3 (climb) CFM			**Phase 3 (climb) TP400**		
M0 à 7000	0,53		M0 à 7000	0,53	
sigma	0,405		sigma	0,405	
F7000/0,53	39264,68367	N	F7000/0,53	29196,3748	N
CS7000/0	0,557950224	kg/(daN.h)	CS7000/0	0,3642753	kg/(daN.h)
CS7000/0,53	0,853663842	kg/(daN.h)	CS7000/0,53	0,55734121	kg/(daN.h)
CH7000/0,53	3351,884072	kg/h	CH7000/0,53	1627,23427	kg/h
Vphase3	150	m/s	Vphase3	150	m/s
tphase3 (from 2000 to	1612,903226	s	tphase3 (from 2000 to	1612,90323	s
CHphase3	4230,964828	kg/h	CHphase3	2054,00033	kg/h
angle climb	1,04	°	angle climb	1,04	°
	0,018151424	rad		0,01815142	rad
Cphase3	1895,593561	kg	Cphase3	920,251042	kg
Lphase3	241895,6292	m/s	Lphase3	241895,629	m/s
	241,8956292	km		241,895629	km
Cphase1+2+3	3008,67855	kg	Cphase1+2+3 TP400	1469,48659	kg
C phase 3	**3736,095646**	**kg**			
C phase 1+2+3	**5947,651738**	**kg**			
Masse moyenne	**95920,39608**	**kg**			
Phase 4 (cruise) CFM + 2TP400					
Cphase4	20922,34826	kg			
CH cruise	1627,234274	kg/h			
tphase4	12,85761282	h			
Lphase4	6943110,923	m			
	6943,110923	km			
Ltot	**7245,327688**	**km**			

Paris-Nice	686	km
Distance cruise	383,7832353	km
speed	150	m/s
	540	km/h
t cruise	0,710709695	h
C cruise	1156,491174	kg
C1+2+3	5947,651738	kg
C total	7104,142912	kg
case 2	2000	km
Distance cruise	1697,783235	km
speed	150	m/s
	540	km/h
t cruise	3,144043028	h
C cruise	5116,094574	kg
C1+2+3	5947,651738	kg
C total	11063,74631	kg
case 3	400	km
Distance cruise	97,78323527	km
speed	150	m/s
	540	km/h
t cruise	0,181080065	h
C cruise	294,6596886	kg
C1+2+3	5947,651738	kg
C total	6242,311427	kg

CFM+TP400

Phase 1 CFM			Phase 1 TP400		
Mach	0,203963574		Mach	0,203963574	
F0/0,18	85579,10409	N	F0/0,18	63634,78222	N
Cs0/0,18	0,710338508	kg/(daN.h)	Cs0/0,18	0,463766769	kg/(daN.h)
CH0/0,18	6079,013316	kg/h	CH0/0,18	2951,169732	kg/h
CHphase1	6137,006658	kg/h	CHphase1	3471,912485	kg/h
Lphase1	2	km	tphase1	64,808814	s
Vphase1	30,86	m/s	Cphase1	62,50292512	kg
tphase1	64,808814	s			
Cphase1	110,4811453	kg			
Cphase 1	**235,487**	**kg**			
Masse moyenne	**99882,3**	**kg**			
Phase 2 (acceleration) CFM			**Phase 2 (acceleration) TP400**		
Z	7000	m	Z	7000	m
M0 à 7000	0,53		M0 à 7000	0,53	
V0	150	m/s	V0	150	m/s
T(Z=7000)	257,65	K	T(Z=7000)	257,65	K
T(Z=2000)	275,15	K	T(Z=2000)	275,15	K
M0 à 2000	0,440843459		M0 à 2000	0,440843459	
sigma	0,785		sigma	0,785	
F2000/0,512	61509,59023	N	F2000/0,512	45737,20911	N
CS2000/0	0,576587391	kg/(daN.h)	CS2000/0	0,376443158	kg/(daN.h)
CS2000/0,512	0,830772171	kg/(daN.h)	CS2000/0,512	0,542395662	kg/(daN.h)
CH2000/0,512	5110,045583	kg/h	CH2000/0,512	2480,76638	kg/h
Vphase2	90,43	m/s	Vphase2	90,43	m/s
angle climb	1,53	°	angle climb	1,53	°
angle climb	0,026703538	rad	angle climb	0,026703538	rad
tphase2	645,1612903	s	tphase2	645,1612903	s
CHphase2	5594,52945	kg/h	CHphase2	2715,968056	kg/h
Cphase2	1002,603844	kg	Cphase2	486,7326265	kg
Lphase2	58321,13552	m	Lphase2	58321,13552	m
	58,32113552	km		58,32113552	km
Cphase 2	**1976,07**	**kg**			
Cphase 1+2	**2211,56**	**kg**			
Masse moyenne	**98776,5**	**kg**			
Phase 3 (climb) CFM			**Phase 3 (climb) TP400**		
			M0 à 7000	0,53	
			sigma	0,405	
			F7000/0,53	29196,37476	N
			CS7000/0	0,364275298	kg/(daN.h)
			CS7000/0,53	0,557341207	kg/(daN.h)
Cphase1+2+3	1113,084989	kg	CH7000/0,53	1627,234274	kg/h
			Vphase3	150	m/s
			tphase3 (from 2(	1612,903226	s
			CHphase3	2054,000327	kg/h
			angle climb	1,04	°
				0,018151424	rad
			Cphase3	920,2510424	kg
			Lphase3	241895,6292	m/s
				241,8956292	km
			Cphase1+2+3 TP	1469,486594	kg
C phase 3	**1840,5**	**kg**			
C phase 1+2+3	**4052,06**	**kg**			
Masse moyenne	**96868,2**	**kg**			
Phase 4 (cruise) CFM + 2TP400					
Cphase4	22817,9	kg			
CH cruise	1627,23	kg/h			
tphase4	14,0225	h			
Lphase4	7572166	m			
	7572,17	km			
Ltot	**7632,49**	**km**			

Paris-Nice	686	km
Distance cruise	383,783	km
speed	150	m/s
	540	km/h
t cruise	0,71071	h
C cruise	1156,49	kg
C1+2+3	4052,06	kg
C total	5208,55	kg
case 2	2000	km
Distance cruise	1697,78	km
speed	150	m/s
	540	km/h
t cruise	3,14404	h
C cruise	5116,09	kg
C1+2+3	4052,06	kg
C total	9168,15	kg
case 3	400	km
Distance cruise	97,7832	km
speed	150	m/s
	540	km/h
t cruise	0,18108	h
C cruise	294,66	kg
C1+2+3	4052,06	kg
C total	4346,72	kg

Sam146 hybridé + TP400

Phase 1 Sam146			Phase 1 TP400		
Mach	0,203963574		Mach	0,203963574	
F0/0,18	62348,71741	N	F0/0,18	63634,78222	N
Cs0/0,18	0,757293088	kg/(daN.h)	Cs0/0,18	0,463766769	kg/(daN.h)
CH0/0,18	4721,625273	kg/h	CH0/0,18	2951,169732	kg/h
CHphase1	4914,669233	kg/h	CHphase1	3746,38843	kg/h
Lphase1	2	km	Lphase1	2	km
Vphase1	30,86	m/s	Vphase1	30,86	m/s
tphase1	64,808814	s	tphase1	64,808814	s
Cphase1	88,47607894	kg	Cphase1	67,44416415	kg
Cphase 1	**223,36441**	**kg**			
Masse moyenne	**99888,318**	**kg**			
Phase 2 (acceleration) SaM146			**Phase 2 (acceleration) TP400**		
Z	7000	m	Z	7000	m
M0 à 7000	0,53		M0 à 7000	0,53	
V0	150	m/s	V0	150	m/s
T(Z=7000)	257,65	K	T(Z=7000)	257,65	K
T(Z=2000)	275,15	K	T(Z=2000)	275,15	K
M0 à 2000	0,440843459		M0 à 2000	0,440843459	
sigma	0,785		sigma	0,785	
F2000/0,512	44812,8559	N	F2000/0,512	45737,20911	N
CS2000/0	0,614700795	kg/(daN.h)	CS2000/0	0,376443158	kg/(daN.h)
CS2000/0,512	0,88568762	kg/(daN.h)	CS2000/0,512	0,542395662	kg/(daN.h)
CH2000/0,512	4117,019168	kg/h	CH2000/0,512	2480,76638	kg/h
Vphase2	90,43	m/s	Vphase2	90,43	m/s
angle climb	1,53	°	angle climb	1,53	°
angle climb	0,026703538	rad	angle climb	0,026703538	rad
tphase2	645,1612903	s	tphase2	645,1612903	s
CHphase2	4419,322221	kg/h	CHphase2	2715,968056	kg/h
Cphase2	791,9932295	kg	Cphase2	486,7326265	kg
Lphase2	58321,13552	m	Lphase2	58321,13552	m
	58,32113552	km		58,32113552	km
Cphase 2	**1765,4585**	**kg**			
C phase 1+2	**1988,8229**	**kg**			
Masse moyenne	**98893,91**	**kg**			
Phase 3 (climb) Sam146			**Phase 3 (climb) TP400**		
M0 à 7000	0,53		M0 à 7000	0,53	
sigma	0,405		sigma	0,405	
F7000/0,53	28606,31334	N	F7000/0,53	29196,37476	N
CS7000/0	0,557950224	kg/(daN.h)	CS7000/0	0,364275298	kg/(daN.h)
CS7000/0,53	0,853663842	kg/(daN.h)	CS7000/0,53	0,557341207	kg/(daN.h)
CH7000/0,53	2442,017535	kg/h	CH7000/0,53	1627,234274	kg/h
Vphase3	150	m/s	Vphase3	150	m/s
tphase3 (from 2000 to 7000m)	1612,903226	s	tphase3 (from 2000 to 7000m)	1612,903226	s
CHphase3	3279,518351	kg/h	CHphase3	2054,000327	kg/h
angle climb	1,04	°	angle climb	1,04	°
	0,018151424	rad		0,018151424	rad
Cphase3	1469,318258	kg	Cphase3	920,2510424	kg
Lphase3	241895,6292	m/s	Lphase3	241895,6292	m/s
	241,8956292	km		241,8956292	km
Cphase1+2+3	2349,787566	kg	Cphase1+2+3	1474,427833	kg
C phase 3	**3309,8203**	**kg**			
C phase 1+2+3	**5298,6432**	**kg**			
Masse moyenne	**96356,267**	**kg**			
Phase 4 (cruise) Sam146+2TP400					
Cphase4	21571,357	kg			
CH cruise	1627,2343	kg/h			
tphase4	13,256454	h			
Lphase4	7158485,3	m			
	7158,4853	km			
Ltot	**7460,7021**	**km**			

Paris-Nice	686	km
Distance cruise	383,78324	km
speed	150	m/s
	540	km/h
t cruise	0,7107097	h
C cruise	1156,4912	kg
C1+2+3	5298,6432	kg
C total	6455,1344	kg
case 2	2000	km
Distance cruise	1697,7832	km
speed	150	m/s
	540	km/h
t cruise	3,144043	h
C cruise	5116,0946	kg
C1+2+3	5298,6432	kg
C total	10414,738	kg
case 3	400	km
Distance cruise	97,783235	km
speed	150	m/s
	540	km/h
t cruise	0,1810801	h
C cruise	294,65969	kg
C1+2+3	5298,6432	kg
C total	5593,3029	kg

Sam146 hybridé éteint en phase 3 + TP400

Phase 1 Sam146			Phase 1 TP400		
Mach	0,18		Mach	0,18	
F0/0,18	62348,7174	N	F0/0,18	63634,7822	N
Cs0/0,18	0,75729309	kg/(daN.h)	Cs0/0,18	0,46376677	kg/(daN.h)
CH0/0,18	4721,62527	kg/h	CH0/0,18	2951,16973	kg/h
CHphase1	4914,66923	kg/h	CHphase1	3746,38843	kg/h
Lphase1	2	km	Lphase1	2	km
Vphase1	30,86	m/s	Vphase1	30,86	m/s
tphase1	64,808814	s	tphase1	64,808814	s
Cphase1	88,4760789	kg	Cphase1	67,4441641	kg
Cphase 1	**223,364407**	**kg**			
Masse moyenne	**99888,3178**	**kg**			
Phase 2 (acceleration) SaM146			**Phase 2 (acceleration) TP400**		
Z	7000	m	Z	7000	m
M0 à 7000	0,53		M0 à 7000	0,53	
V0	150	m/s	V0	150	m/s
T(Z=7000)	257,65	K	T(Z=7000)	257,65	K
T(Z=2000)	275,15	K	T(Z=2000)	275,15	K
M0 à 2000	0,44084346		M0 à 2000	0,44084346	
sigma	0,785		sigma	0,785	
F2000/0,512	44812,8559	N	F2000/0,512	45737,2091	N
CS2000/0	0,6147008	kg/(daN.h)	CS2000/0	0,37644316	kg/(daN.h)
CS2000/0,512	0,88568762	kg/(daN.h)	CS2000/0,512	0,54239566	kg/(daN.h)
CH2000/0,512	4117,01917	kg/h	CH2000/0,512	2480,76638	kg/h
Vphase2	90,43	m/s	Vphase2	90,43	m/s
angle climb	1,53	°	angle climb	1,53	°
angle climb	0,02670354	rad	angle climb	0,02670354	rad
tphase2	645,16129	s	tphase2	645,16129	s
CHphase2	4419,32222	kg/h	CHphase2	2715,96806	kg/h
Cphase2	791,99323	kg	Cphase2	486,732627	kg
Lphase2	58321,1355	m	Lphase2	58321,1355	m
	58,3211355	km		74,9	km
C phase 2	**1765,45848**	**kg**			
C phase 1+2	**1988,82289**	**kg**			
Masse moyenne	**98893,91**	**kg**			
Phase 3 Sam 146 éteint			**Phase 3 (climb) TP400**		
			M0 à 7000	0,53	
			sigma	0,405	
Cphase1+2+3	880,469308	kg	F7000/0,53	29196,3748	N
			CS7000/0	0,3642753	kg/(daN.h)
			CS7000/0,53	0,55734121	kg/(daN.h)
			CH7000/0,53	1627,23427	kg/h
			Vphase3	150	m/s
			tphase3 (from	1612,90323	s
			CHphase3	2054,00033	kg/h
			angle climb	1,04	°
				0,01815142	rad
			Cphase3	920,251042	kg
			Lphase3	241895,629	m/s
				241,895629	km
			Cphase1+2+3	1474,42783	kg
C phase 3	**1840,50208**	**kg**			
C phase 1+2+3	**3829,32497**	**kg**			
Masse moyenne	**97090,9261**	**kg**			
Phase 4 (cruise) Sam146+2TP400					
Cphase4	23040,675	kg			
CH cruise	1627,23427	kg/h			
tphase4	14,1594086	h			
Lphase4	7646080,66	m			
	7646,08066	km			
Ltot	**7948,29743**	**km**			

Paris-Nice	686	km
Distance cruise	383,783235	km
speed	150	m/s
	540	km/h
t cruise	0,71070969	h
C cruise	1156,49117	kg
C1+2+3	3829,32497	kg
C total	4985,81615	kg
case 2	2000	km
Distance cruise	1697,78324	km
speed	150	m/s
	540	km/h
t cruise	3,14404303	h
C cruise	5116,09457	kg
C1+2+3	3829,32497	kg
C total	8945,41955	kg
case 3	400	km
Distance cruise	97,7832353	km
speed	150	m/s
	540	km/h
t cruise	0,18108007	h
C cruise	294,659689	kg
C1+2+3	3829,32497	kg
C total	4123,98466	kg

IV. Appendix 4: Flight part XML code

	DATA	XML code	Type of data	Description	XXX for us
FLIGHT	Flight Id	<flight_id>XXX</flight_id>	double	The unique identifier for the flight.	
	Flight number	<flight_number>XXX</flight_number>	double	The flight identification number and any additional characters.	
	Carrier	<flight_carrier>XXX</flight_carrier>	string	Details for the operating carrier of the flight (if using the extended options to include inlined references, otherwise the airline details.	
		<flight_carrier_Fs_Code>XXX</flight_carrier_Fs_Code>	double	The FlightStats unique code for the operating carrier to use as a reference for finding the entry in the appendix (unless the extended option to include inlined references is used).	
		<flight_carrier_IATA_code>XXX</flight_carrier_IATA_code>	string	IATA code of the carrier for this flight.	
		<flight_carrier_ICAO_code>XXX</flight_carrier_ICAO_code>	string	ICAO code of the carrier for this flight.	
		<flight_carrier_phone_number>XXX</flight_carrier_phone_number>	double	Carrier phone number for this flight.	
	Flight status	<flight_status>XXX</flight_status>	string		S for Scheduled
	Flight type	<flight_type>XXX</flight_type>	string		J for Scheduled Passenger (Normal Service)
	Flight crew number	<flight_crew_number>XXX</flight_crew_number>	double	Number of flight crew members on-board.	7

V. Appendix 5: Flight status

Value	Description
A	Active
C	Canceled
D	Diverted
DN	Data source needed
L	Landed
NO	Not Operational
R	Redirected
S	Scheduled
U	Unknown

VI. Appendix 6: Flight type

Value	Description
J	Scheduled Passenger (Normal Service)
S	Scheduled Passenger (Shuttle Service)
U	Scheduled Passenger (Service Vehicle)
F	Scheduled Cargo/Mail (Loose loaded cargo and/or preloaded devices)
V	Scheduled Cargo/Mail (Surface Vehicle)
M	Scheduled Cargo/Mail (Mail only)
Q	Scheduled Passenger/Cargo in Cabin
G	Non-scheduled Passenger (Normal Service)
B	Non-scheduled Passenger (Shuttle Service)
A	Non-scheduled Cargo/Mail
C	Charter (Passenger only)
O	Charter (Special handling - Migrants/Immigrants)
H	Charter (Cargo and/or Mail)
L	Charter (Passenger and Cargo and/or Mail)
P	Non-revenue
T	Technical Test
K	Training
D	General Aviation
E	Special (FAA/Government)
W	Military
R	Aditional Flights - Passenger/Cargo
Y	IATA Special Internal (Y)
Z	IATA Special Internal (Z)

VII. Appendix 7: Aircraft part XML code

	DATA	XML code	Type of data	Description	XXX for us
AIRCRAFT	Acid	<aircraft_id>XXX</aircraft_id>		The Acid element contains the aircraft identification/call sign of a flight. This ID is used as the name of the flight both in discussion and in data reduction and analysis. The Acid element has a seven characters maximum. The ID must start with a letter and be followed by one to six alphanumeric characters.	
	Aircraft type	<aircraft_type>XXXX</aircraft_type>		The aircraft type may be preceded by the following indicators: • A digit that indicates the number of aircraft the will be sharing this flight plan. • A letter indicating a weight class or special/experimental equipment an aircraft is using. For example "H/" is used to indicate a heavy aircraft.	
	PAX number	<aircraft_transportable_passengers_number>XXX</aircraft_transportable_passengers_number>	double	Number of passengers transportable on-board for this flight.	220
	SFC	<aircraft_SFC unit="">XXX<aircraft_SFC unit="">	double	Aicraft Specific Fuel Consumption	
	MTOW	<aircraft_maximum_take_off_weight unit="t">XXX</aircraft_maximum_take_off_weight_plane unit="t">	double	Maximum Take-Off Weight value	100
	Fuel Mass	<aircraft_fuel_mass unit="t">XXX</aircraft_fuel_mass unit="t">	double	Fuel mass	30
	Empty Weight	<aircraft_empty_weight unit="t">XXX</aircraft_empty_weight unit="t"> <bee_empty_weight unit="t">XXX</bee_empty_weight unit="t"> <basket_empty_weight unit="t">XXX</basket_empty_weight unit="t">	double	Bee-plane empty weight Bee empty weight Basket empty weight	68.6 46.1 22.5
	Wings	<Wings> <wing> <side_wing>XXX</side_wing> <NACA>XXX</NACA> <length_wing unit="m">XXX</length_wing> <weight_wing unit="kg">XXX</weight_wing> <incidence_wing unit="rad">XXX</incidence_wing> <junction_plane_wing unit="m">XXX</junction_plane_wing> <chord_root unit="m">XXX</chord_root> <chord_tip unit="m">XXX</chord_tip> <dihedral unit="rad">XXX</dihedral> <leading_edge_angle unit="rad">XXX</leading_edge_angle> <raccord_element_wing unit="m">XXX</raccord_element_wing> <rotation_wing unit="rad">XXX</rotation_wing> </wing> </Wings/>		Code part providing data about the wings of the Bee-plane such as NACA airfoil, wings parameters (length, weight, incidence, junction with the fuselage), chord root and tip, dihedral, leading edge angle, raccord element and rotation.	
	Bodies	<Bodies> <body> <weight_body unit="kg">XXX</weight_body> <barycentre_body unit="m">XXX</barycentre_body> <length_body unit="m">XXX</length_body> <semi_horizontal_axis unit="m">XXX</semi_horizontal_axis> <semi_vertical_axis unit="m">XXX</semi_vertical_axis> <raccord_plane_body unit="m">XXX</raccord_plane_body> <raccord_element_body unit="m">XXX</raccord_element_body> <rotation_body unit="rad">XXX</rotation_body> </body> </Bodies>		Code part providing data about the body of the Bee-plane such as wieght, barycentre, length, semi horizontal and vertical axis, raccord with the plane and rotation.	
	Landing gears	<Landing_Gears> <landing_gear> <side_landing_gear>XXX </side_landing_gear> <weight_wheel unit="kg">XXX</weight_wheel> <weight_arm unit="kg">XXX</weight_arm> <radius_wheel unit="m">XXX</radius_wheel> <radius_arm unit="m">XXX</radius_arm> <length_arm unit="m">XXX</length_arm> <thickness_wheel unit="m">XXX</thickness_wheel> <junction_plane_landing_gear unit="m">XXX</junction_plane_landing_gear> <rotation_landing_gear unit="rad">XXX</rotation_landing_gear> <raccord_element_landing_gear unit="m">XXX</raccord_element_landing_gear> </landing_gear> </Landing_Gears>		Code part providing data about landing gears of the Bee-plane such as the side, wheels (weight, radius, thickness), arms (weight, radius, length), junction with the plane, raccord element and rotation.	

VIII. Appendix 8: Equipment part XML code

	DATA	XML code	Type of data	Description	XXX for us
EQUIPMENT	IATA code	<equipment_IATA_code>XXX</equipment_IATA_code>	string	The IATA code for the equipment type.	
	Name	<equipment_name>XXX</equipment_name>	string	The descriptive name for the equipment type.	
	Turboprop	<equipment_turboprop>XXX</equipment_turboprop>	boolean	Boolean value indicating if the equipment type uses TurboProp propulsion.	true
	Jet propulsion	<equipment_jet_propulsion>XXX</equipment_jet_propulsion>	boolean	Boolean value indicating if the equipment type uses jet propulsion.	false
	Wide-body airframe	<equipment_wide_body_airframe>XXX</equipment_wide_body_airframe>	boolean	Boolean value indicating if the equipment type is a wide-body airframe.	false
	Regional airframe	<equipment_regional_airframe>XXX</equipment_regional_airframe>	boolean	Boolean value indicating if the equipment type is a regional airframe.	true

IX. Appendix 9: General part for Paris-Orly Airport XML code

	DATA	XML code	Type of data	Description	XXX for us
GENERAL	IATA code airport	<departure_airport_IATA_code>XXX</departure_airport_IATA_code>	string	The IATA code is a localisation identifier defined by the International Air Transport Association. It is a 3 letters code. We can see it on our luggages at the airport.	ORY
	ICAO code airport	<departure_airport_ICAO_code> XXX </departure_airport_ICAO_code>	string	It is a location indicator for each airport worldwide composed by 4 letters given by the ICAO (International Civil Aviation Organization). 1st letter: Continent or a group of states 2nd letter: Indicate the country on the continent or group of states. 3rd and 4th letters: Identify each airport.	LFPO L for continent F for France PO for airport
	FAA code airport	<departure_airport_FAA_code>XXX</departure_airport_FAA_code>	string	Code given by the FAA (Federal Aviation Administration) to American airports.	
	Name	<departure_airport_name>XXX</departure_airport_name>	string	Name of the airport	Paris-Orly
	Main street	<departure_airport_main_street_name>XXX</departure_airport_main_street_name>	string	Name of the airport main street.	Avenue de l'Union
	City name	<departure_airport_city_name>XXX</departure_airport_city_name>	string	Name of the city.	Orly
	City code	<departure_airport_city_post_code>...</departure_airport_city_post_code>	string	Post code of the city.	94310
	District	<departure_airport_district_name>XXX</departure_airport_district_name>	string	District name of the departure airport.	
	State code	<departure_airport_state_code>XXX</departure_airport_state_code>	string	State code number of the departure airport.	
	Country ICAO code	<departure_airport_country_ICAO_code>XXX</departure_airport_country_ICAO_code>	string	ICAO country code of the departure airport.	LF
	Country code	<departure_airport_country_code>XXX</departure_airport_country_code>	string		FR
	Country	<departure_airport_country_name>XXX</departure_airport_country_name>	string	Country name of the departure airport.	France
	Geographic region	<departure_airport_region_name>XXX</departure_airport__region_name>	string	Name of the geographic region name of the departure airport.	Europe
	Region time zone reference	<departure_airport_time_zone_region_name>XXX</departure_airport_time_zone_region_name>	string	Name of the time zone region of the departure airport.	Europe/Paris (UTC+1.0)
	Weather zone	<departure_airport_weather_zone>XXX</departure_airport_weather_zone>	string	Name of the weather zone of the departure airport. The NOAA weather zone (US only) in which the Airport is located.	
	Latitude	<departure_airport_latitude unit="degrees">XXX</departure_airport_latitude>	double	Latitude of the departure airport.	48.72551
	Longitude	<departure_airport_longitude unit="degrees">XXX</departure_airport_longitude>	double	Longitude of the departure airport.	2.359443
	Altitude	<departure_airport_altitude unit="feet>XXX</departure_airport_altitude unit="feet">	double	Altitude of the departure airport. (89m=291.995ft)	291.995

X. Appendix 10: Dates & Times and Resources parts for Paris-Orly Airport XML code

	DATA	XML code	Type of data	Description	XXX for us
DATES & TIMES	Departure date	<departure_airport_date_local>YYYY-MM-DD</departure_airport_date_local>	double	The departure date of the flight in local and UTC time. This value is likely the	
		<departure_airport_date_UTC<YYYY-MM-DD</departure_airport_date_UTC>	double	publishedDeparture or scheduledGateDeparture value, but could be some other	
	Gate opening local time	<departure_airport_opening_gate_time_local>HH:MM:SS</departure_airport_opening_gate_time_loc	double	Time when the boarding at the gate starts at the departure airport.	
	Gate closing local time	<departure_airport_closing_gate_time_local>HH:MM:SS</departure_airport_closing_gate_time_local	double	Time from which the boarding at the gate is finsihed at the departure airport.	
	Taxi duration	<departure_airport_taxi_duration>HH:MM:SS</departure_airport_taxi_duration>	double	Duration of the taxi (from the gate to the runway).	
	Take-Off time	<departure_airport_TO_time_local>HH:MM:SS</departure_airport_TO_time_local>	double	Take-off local time.	
		<departure_airport_TO_time_UTC>HH:MM:SS</departure_airport_TO_time_UTC>	double	Take-off UTC time.	
	UTC offset hours	<departure_airport_UTC_offset_hours>HH:MM:SS</departure_airport_UTC_offset_hours>	double	Offset between UTC and local time.	10
RESOURCES	Terminal	<departure_airport_terminal>XXX</departure_airport_terminal>	string	Terminal reference at the departure airport. ORY: 2 terminals (sud, ouest)	ORY: 2 terminals (South, West)
	Gate	<departure_airport_gate>XXX</departure_airport_gate>	double	Number of the gate at the departure airport for boarding.	
	Check-in desk	<departure_airport_check_in_desk>X</departure_airport_check_in_desk>	double	Numbers of check-in desks at the departure airport for this flight.	

XI. Appendix 11: Runway part for Paris-Orly Airport XML code

	DATA	XML code	Type of data	Description	XXX for us
RUNWAY	Reference	<IF wind=west> <departure_airport_runway_reference=XXX/> <departure_airport_runway_reference>XXX</departure_airport_runway_reference> </IF> <IF wind=east> <departure_airport_runway_reference=YYY/> <departure_airport_runway_reference>YYY</departure_airport_runway_reference> </IF>	string	Reference of the runway used for take-off at the departure airport.	XXX=24 YYY=08
	Length	<departure_airport_runway_length unit="feet">XXX</departure_airport_runway_length unit="feet">	double	Length of the runway.	Runway 24, XXX= 11 975 ft Runway 08, XXX= 10 892 ft
	Width	<departure_airport_runway_width unit="feet">XXX</departure_airport_runway_width unit="feet">	double	Width of the runway.	Runway 24, XXX= 148 ft Runway 08, XXX= 148 ft
	Surface	<departure_airport_runway_runway_surface_type>XXX</departure_airport_runway_surface_type>	double	asphalt or concrete	Runway 24, asphalt Runway 08, concrete
	Threshold Offset	<departure_airport_threshold_offset>XXX</departure_airport_threshold_offset>	double	point le plus près où l'avion peut se poser - longueur de dépassement de la piste	Runway 24, XXX= 0 ft Runway 08, XXX = 0 ft
	Overrun Length	<departure_airport_overrun_length>XXX</departure_airport_overrun_length>	double	"the offset threshold is in place to give arriving aircraft clearance over an obstruction while still allowing departing aircraft the maximum amount of runway	Runway 24, XXX= 197 ft Runway 08, XXX = 1050 ft
	Bearing (true)	<departure_airport_true_bearing>XXX</departure_airport_true_bearing>	double	angle entre le nord géographique (ou nord vrai) (Nv) et la ligne de foi	Runway 24, XXX= 241.81° Runway 08, XXX = 74.36°
	Bearing (mag)	<departurel_airport_magnetique_bearing>XXX</departure_airport_magnetique_bearing>	double	angle entre le nord magnétique (Nm) et la ligne de foi	Runway 24, XXX= 241.33° Runway 08, XXX = 73.88°

XII. Appendix 12: LFPO-LFMN route and its waypoints

XIII. Appendix 13: Engines part for Paris-Orly Airport XML code

					FOR INFO.			
	Data	XML code	Type of data	Description	XXX for CFM56-3C1	XXX for TP400-D6	XXX for SAM146	XXX for PW150A
Right engine	number of engine at the side	<right_side_number>XXX</right_side_number>	string			1		2
	engine side	<side_engine>XXX</side_engine>	string	Engine side of the engine (right, left or middle)		right		
	engine type	<type_engine>XXX</type_engine>	string	engine type (turboprop or turbofan)		turboprop		
	engine model	<model_engine>XXX</model_engine>	string	Engine name (CFM 56, TP400, SAM146)		TP400-D6		
	coordinate of the engine junction with the plane	<junction_plane_engine unit="m">XXX</junction_plane_engine>	double	coordiantes of junction plane/engine				
	coordinate of the barycentre of the engine	<barycentre_engine unit="m">XXX</barycentre_engine>	double	coordinate of the barycentre of the engine				
		<raccord_element_engine unit="m">XXX</raccord_element_engine>	double					
		<rotation_engine unit="rad">XXX</rotation_engine>	double					
Left engine	number of engine at the side	<left_side_number>XXX</left_side_number>	string			1		2
	engine side	<side_engine>XXX</side_engine>	string	Engine side of the engine (right, left or middle)		left		
	engine type	<type_engine>XXX</type_engine>	string	engine type (turboprop or turbofan)		turboprop		
	engine model	<model_engine>XXX</model_engine>	string	Engine name (CFM 56, TP400, SAM146)		TP400-D6		
	coordinate of the engine junction with the plane	<junction_plane_engine unit="m">XXX</junction_plane_engine>	double	coordiantes of junction plane/engine				
	coordinate of the barycentre of the engine	<barycentre_engine unit="m">XXX</barycentre_engine>	double	coordinate of the barycentre of the engine				
		<raccord_element_engine unit="m">XXX</raccord_element_engine>	double					
		<rotation_engine unit="rad">XXX</rotation_engine>	double					
Middle engine	engine side	<side_engine>XXX</side_engine>	string	Engine side of the engine (right, left or middle)			middle	
	engine type	<type_engine>XXX</type_engine>	string	engine type (turboprop or turbofan)	turbofan		turbofan	
	engine model	<model_engine>XXX</model_engine>	string	Engine name (CFM 56, TP400, SAM146)	CFM56-3C1		SAM146	
	coordinate of the engine junction with the plane	<junction_plane_engine unit="m">XXX</junction_plane_engine>	double	coordiantes of junction plane/engine				
	coordinate of the barycentre of the engine	<barycentre_engine unit="m">XXX</barycentre_engine>	double	coordinate of the barycentre of the engine				
		<raccord_element_engine unit="m">XXX</raccord_element_engine>	double					
		<rotation_engine unit="rad">XXX</rotation_engine>	double					
Engine general data	engine length	<engine_length unit="cm">XXX</engine_length>	double	total engine length	260	350	427	
	engine diameter	<engine_diameter unit="cm">XXX</engine_diameter>	double	engine diamter (with nacelle)		92	205	
	engine weight (without nacelle)	<weight_engine_without_nacelle unit="kg">XXX</weight_engine_without_nacelle>	double	engine weight without the nacelle	2300	1890	1680	
	engine weight (with nacelle)	<weight_engine unit="kg">XXX</weight_engine>	double	Weight of dry engine with the nacelle.			2360	
Thrust	take-off thrust	<take_off_thrust unit="kN">XXX</take_off_thrust>	double	take off thrust of the engine	105		79	
	climb thrust	<climb_thrust unit="kN">XXX</climb_thrust>	double	climb thrust of the engine				
	cruise thrust	<cruise_thrust unit="kN">XXX</cruise_thrust>	double	cruise thrust of the engine				
	approah thrust	<approach_thrust unit="kN">XXX</approach_thrust>	double	approach thrust of the engine				
	taxi thrust	<taxi_thrust unit="kN">XXX</taxi_thrust>	double	taxi thrust of the engine				
Specific fuel consumption	take-off SFC	<take_off_SFC unit="kg/kN/s">XXX</take_off_SFC>	double	take off SFC of the engine				
	climb SFC	<climb_SFC unit="kg/kN/s">XXX</climb_SFC>	double	climb SFC of the engine				
	cruise SFC	<cruise_SFC unit="kg/kN/s">XXX</cruise_SFC>	double	cruise SFC of the engine				
	approach SFC	<approach_SFC unit="kg/kN/s">XXX</approach_SFC>	double	approach SFC of the engine				
Ratio and efficiency	overall pressure ratio	<overall_pressure_ratio>XXX</overall_pressure_ratio>	double	Overall pressure ratio of the engine		25		
	bypass ratio	<bypass_ratio>XXX</bypass_ratio>	double	bypass ratio of the engine	4,9	0,8	4,5 at 39000 ft with a speed of M(0,78) in ISA conditions. Else vary between 4 and 7,5.	
	thermal efficiency	<thermal_efficiency>XXX</thermal_efficiency>	double	tharmal efficiency of the engine				
	propelling efficiency	<propelling_efficiency>XXX</propelling_eficiency>	double	propelling efficiency of the engine				
	thermal propelling efficiency	<thermal_propelling_efficiency>XXX</thermal_propelling_efficiency>	double	thermal propelling efficiency of the engine				
MODULES								
Fan/Propeller		<diameters_fan>XXX</diameters_fan>		All diameters of the fan				
	fan diameters	<internal_diameter_fan unit="cm">XXX</internal_diameter_fan>	double			530	122	
		<external_diameter_fan unit="cm">XXX</external_diameter_fan>						
	fan compression ratio	<fan_compression_ratio>XXX</fan_compression_ratio>	double	fan compression ratio				
	blades numbers	<number_of_blades_fan>XXX</number_of_blade_fan>	double	blade numbers of the fan		8	24	
	rotation speed	<rotation_speed_fan unit="tours/s">XXX</rotation_speed_fan>	double	fan rotational speed				
Low pressure compressor	compressor type	<Compressor type_compressor="XXX">	string		LPC	IPC	LPC	
	stage nbr	<number_of_stages_compressor>XXX</number_of_stages_compressor>	double			5		
		<Diameters_Compressor>						
	diameter	<internal_diameter_compressor unit="m">XXX</internal_diameter_compressor>	double					
		<external_diameter_compressor unit="m">XXX</external_diameter_compressor>						
	compression ratio	<compression_ratio>XXX</compression_ratio>	double			3,5		
	blades number	<number_of_blades_compressor>XXX</number_of_blades_compressor>	double					
	outlet temperature	<outlet_temperature_compressor unit="°C">XXX</outlet_temperature_compressor>	double					
	outlet pressure	<outlet_pressure_compressor unit="Pa">XXX</outlet_pressure_compressor>	double					
High pressure compressor	compressor type	<Compressor type_compressor="XXX">	string		HPC	HPC	HPC	
	stage nbr	<number_of_stages_compressor>XXX</number_of_stages_compressor>	double			6		
		<Diameters_Compressor>						
	diameter	<internal_diameter_compressor unit="m">XXX</internal_diameter_compressor>	double					
		<external_diameter_compressor unit="m">XXX</external_diameter_compressor>						
	compression ratio	<compression_ratio>XXX</compression_ratio>	double			7		
	blades number	<number_of_blades_compressor>XXX</number_of_blades_compressor>	double				6 stages	
	outlet temperature	<outlet_temperature_compressor unit="°C">XXX</outlet_temperature_compressor>	double					
	outlet pressure	<outlet_pressure_compressor unit="Pa">XXX</outlet_pressure_compressor>	double					
Combustion chamber	chamber type	<type_chamber>XXX</type_chamber>	string		CC		CC	
	inlet temperature	<inlet_temperature_chamber unit="°C">XXX</inlet_temperature_chamber>	double					
	outlet temperature	<outlet_temperature_chamber unit="°C">XXX</outlet_temperature_chamber>	double					
	inlet pressure	<inlet_pressure_chamber unit="Pa">XXX</inlet_pressure_chamber>	double					
	outlet pressure	<outlet_pressure_chamber unit="Pa">XXX</outlet_pressure_chamber>	double					
High pressure turbine	turbine type	<Turbine type_turbine="XXX">	string		HPT	HPT	HPT	
	stage number	<number_of_stages_turbine>XXX</number_of_stages_turbine>	double			1		
		<Diameters_Turbine>						
	diameter	<internal_diameter_turbine unit="m">XXX</internal_diameter_turbine>	double					
		<external_diameter_turbine unit="m">XXX</external_diameter_turbine>						
	expansion ratio	<expansion_ratio>XXX</expansion_ratio>	double					
	blades number	<number_of_blades_turbine>XXX</number_of_blades_turbine>	double				74, single stage	
	outlet temperature	<outlet_temperature_turbine unit="°C">XXX</outlet_temperature_turbine>	double					
	outlet pressure	<outlet_pressure_turbine unit="Pa">XXX</outlet_pressure_turbine>	double					
Intermediate turbine	turbine type	<Turbine type_turbine="XXX">	string		IPT	IPT	IPT	
	stage number	<number_of_stages_turbine>XXX</number_of_stages_turbine>	double			1		
		<Diameters_Turbine>						
	diameter	<internal_diameter_turbine unit="m">XXX</internal_diameter_turbine>	double					
		<external_diameter_turbine unit="m">XXX</external_diameter_turbine>						
	expansion ratio	<expansion_ratio>XXX</expansion_ratio>	double					
	blades number	<number_of_blades_turbine>XXX</number_of_blades_turbine>	double					
	outlet temperature	<outlet_temperature_turbine unit="°C">XXX</outlet_temperature_turbine>	double					
	outlet pressure	<outlet_pressure_turbine unit="Pa">XXX</outlet_pressure_turbine>	double					
Low pressure turbine	turbine type	<Turbine type_turbine="XXX">	string		LPT	LPT	LPT	
	stage number	<number_of_stages_turbine>XXX</number_of_stages_turbine>	double			3		
		<Diameters_Turbine>						
	diameter	<internal_diameter_turbine unit="m">XXX</internal_diameter_turbine>	double					
		<external_diameter_turbine unit="m">XXX</external_diameter_turbine>						
	expansion ratio	<expansion_ratio>XXX</expansion_ratio>	double					
	blades number	<number_of_blades_turbine>XXX</number_of_blades_turbine>	double					
	outlet temperature	<outlet_temperature_turbine unit="°C">XXX</outlet_temperature_turbine>	double					
	outlet pressure	<outlet_pressure_turbine unit="Pa">XXX</outlet_pressure_turbine>	double					
	outlet flow speed	<outlet_flow_speed unit="m/s">XXX</outlet_flow_speed>	double					

XIV. Appendix 14: Hybridization part for Paris-Orly Airport XML code

	Data	XML code	Type of data	Description	XXX for us
APU	Name	<APU_name>XXX</APU_name>	string	Name of the APU	APS3200
	Weight	<APU_weight unit="kg">XXX</APU_weight>	double	APU weight, unit = kg	140
	Length	<APU_length unit="cm">XXX</APU_length>	double	APU length, unit = cm	125
	Width	<APU_width unit="cm">XXX</APU_width>	double	APU width, unit = cm	85
	Height	<APU_height unit="cm">XXX</APU_height>	double	APU height, unit = cm	76
	Power	<APU_power unit="KVA">XXX</APU_power>	double	APU power, unit = KVA	90
	Power	<APU_power_KW unit="kW">XXX</APU_power_KW>	double	APU power, unit = KW	72
Engine	Name	<motor_name>XXX</motor_name>	string	Motor name	Simotic GP 1LA
	Weight	<motor_weight unit="kg">XXX</motor_weight>	double	Motor weight, unit = kg	211
	Power	<motor_power unit="kW">XXX</motor_power>	double	Motor power unit, unit = kW	37
	Ratio Weight/power	<motor_ratio_weightPower>XXX</motor_ratio_weightPower>	double	Motor ratio weight/power , unit = none	5,7
	Efficiency	<motor_efficiency unit="%">XXX</motor_efficiency>	double	Motor efficiency, unit = %	92,5