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# *La propulsione ibrida nell'aviazione generale: Innovazione e sperimentazione*

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*Chief Technical Officer*

SEMINARI INTERDISCIPLINARI DI CULTURA AERONAUTICA

**II Serie, I Ciclo**

3° incontro

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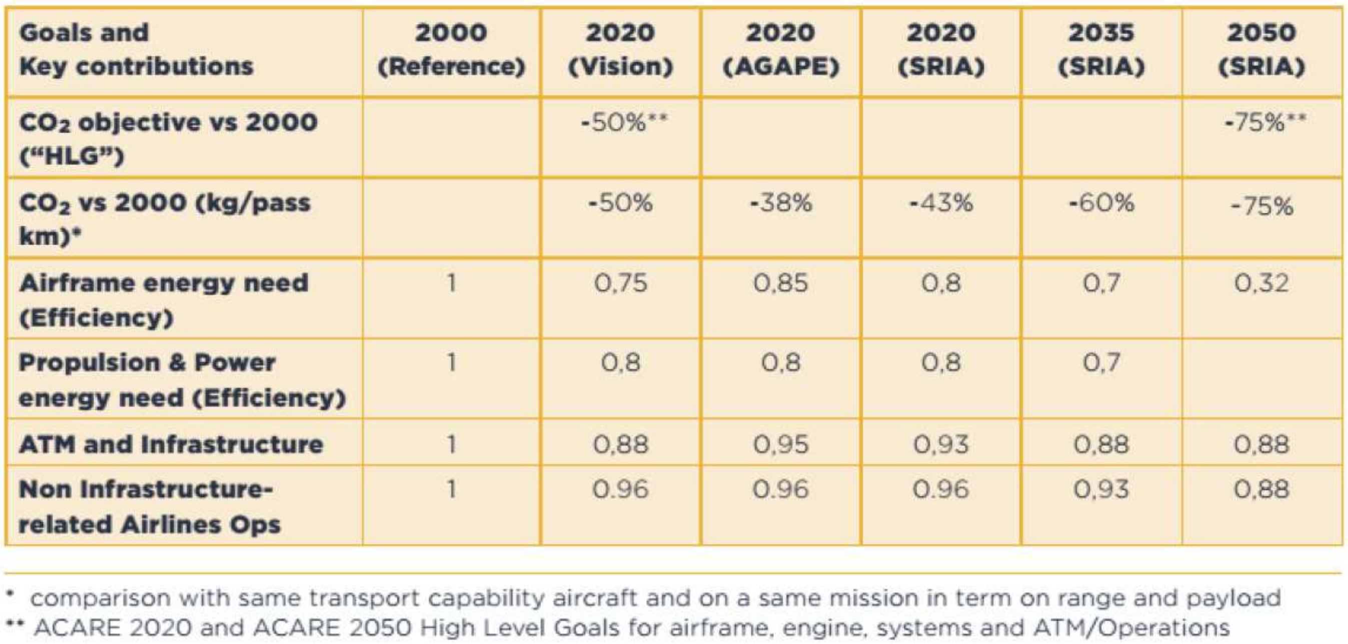
**I VELIVOLI A PROPULSIONE IBRIDA**

*Aula "L. Massimilla", Scuola Politecnica e delle Scienze di Base – P.le Tecchio*

## Contents

# *Motivation for Hybrid-Electric (HE) Aircrafts*

The objective of Flightpath 2050 (Europe's Vision for Aviation) is a reduction of 75% in $CO_2$-emissions per passenger kilometer, a 90% in NOx emissions and a 65% in perceived noise relative to aircraft of the year 2000.



| **Goals and Key contributions** | **2000 (Reference)** | **2020 (Vision)** | **2020 (AGAPE)** | **2020 (SRIA)** | **2035 (SRIA)** | **2050 (SRIA)** |
|---|---|---|---|---|---|---|
| **$CO_2$ objective vs 2000 ("HLG")** | | -50%** | | | | -75%** |
| **$CO_2$ vs 2000 (kg/pass km)*** | | -50% | -38% | -43% | -60% | -75% |
| **Airframe energy need (Efficiency)** | 1 | 0,75 | 0,85 | 0,8 | 0,7 | 0,32 |
| **Propulsion & Power energy need (Efficiency)** | 1 | 0,8 | 0,8 | 0,8 | 0,7 | |
| **ATM and Infrastructure** | 1 | 0,88 | 0,95 | 0,93 | 0,88 | 0,88 |
| **Non Infrastructure-related Airlines Ops** | 1 | 0.96 | 0.96 | 0.96 | 0,93 | 0,88 |

* comparison with same transport capability aircraft and on a same mission in term on range and payload

** ACARE 2020 and ACARE 2050 High Level Goals for airframe, engine, systems and ATM/Operations

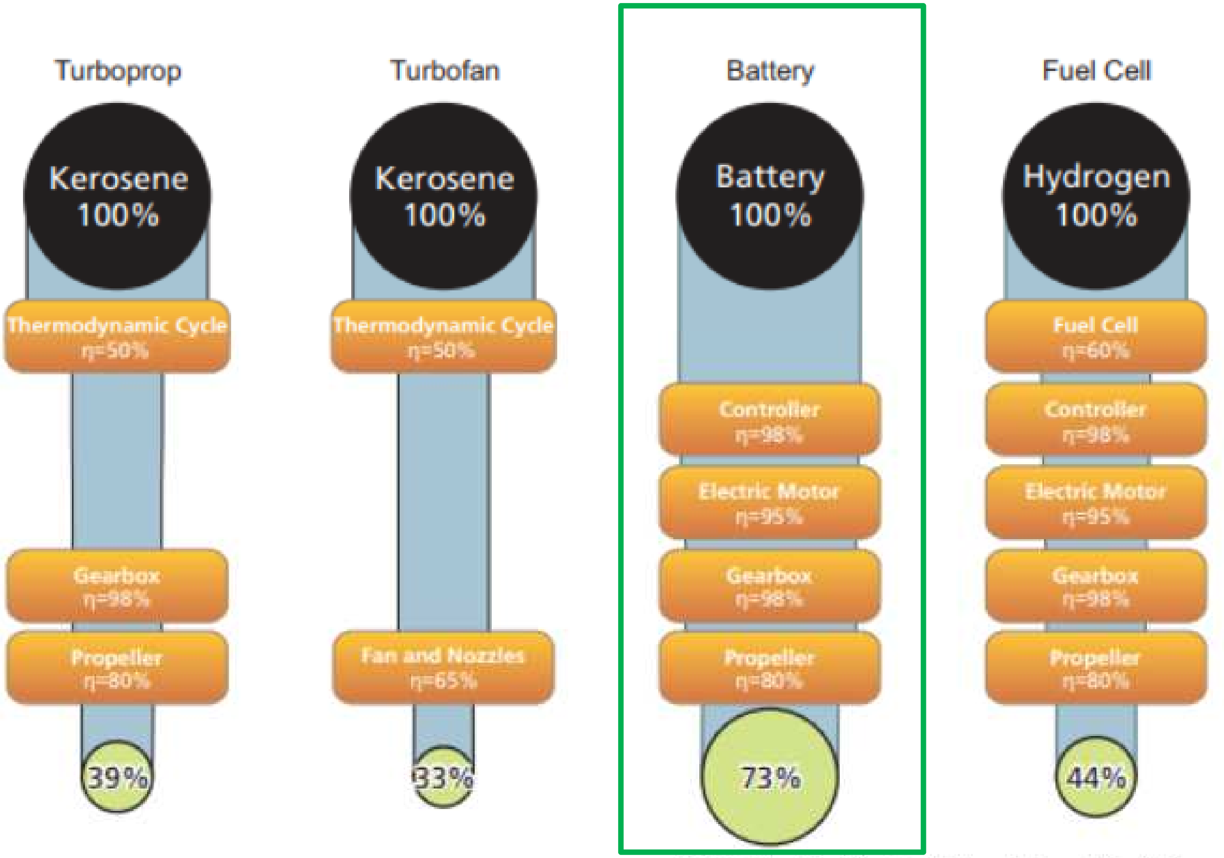
*Advisory Council for Aeronautics Research in Europe (ACARE) emissions reduction and system efficiency goals*

The **electrification** of the propulsion system is seen as one of the few approaches that will feasibly close this gap in the desired time-frame.

# *Motivation for Hybrid-Electric (HE) Aircrafts*

**Total Efficiency**

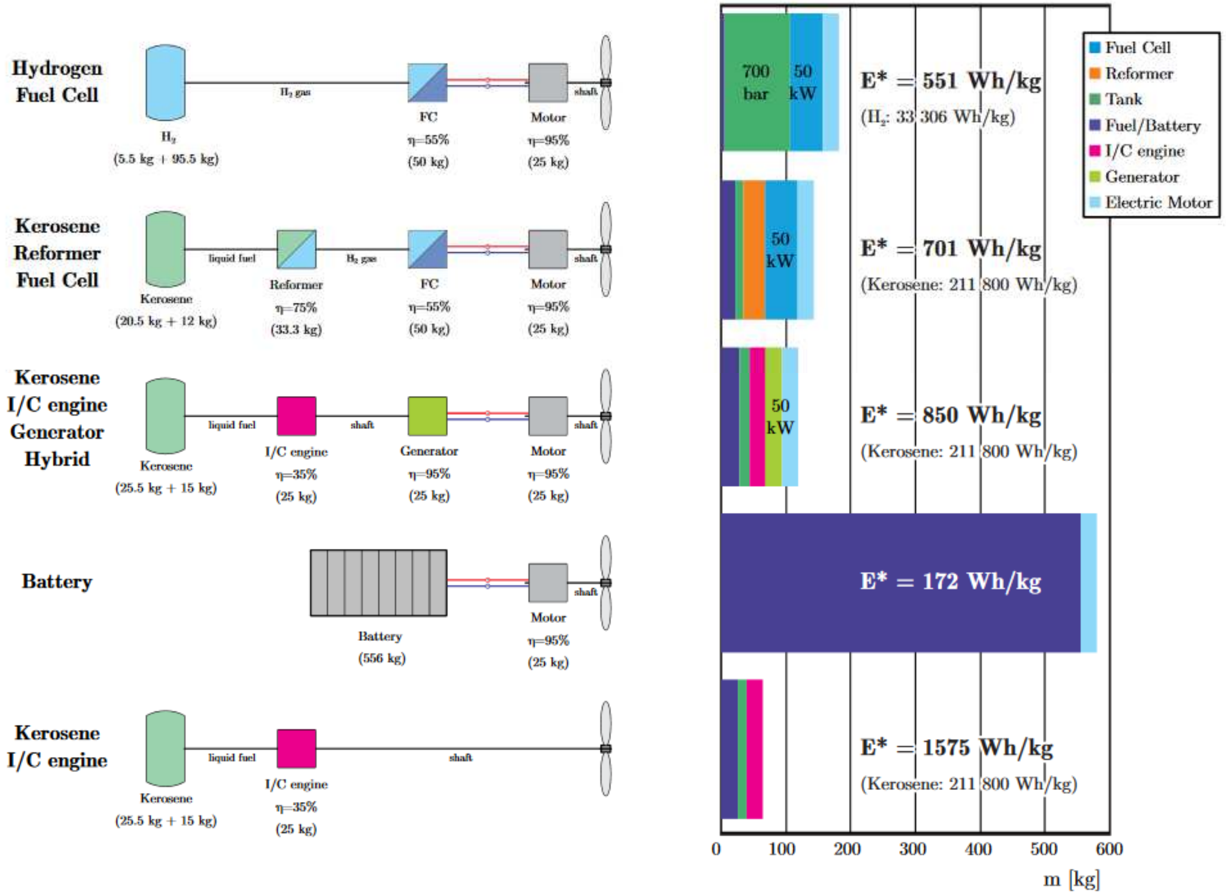
The conversion chain from on-board Energy to Propulsion



*DLR: Electric Flight – Potential and Limitations*

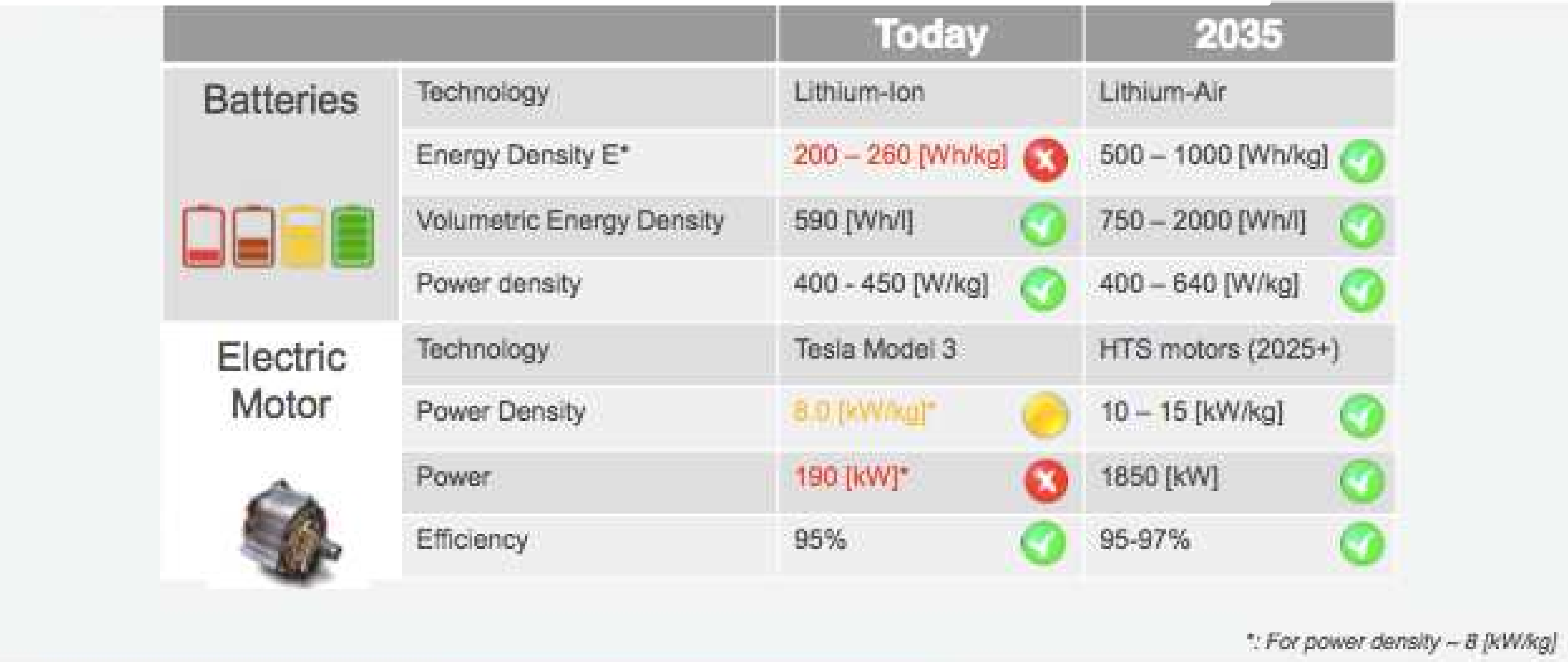
# *Motivation for Hybrid-Electric (HE) Aircrafts*

The results show that the classical internal combustion engine offers the lowest mass and hence an effective specific energy of almost 1600 Wh/kg, which is about 14% of the specific energy content of the raw kerosene fuel.



**ass and equivalent energy density of propulsion systems providing a shaft power of 50 kW for 2 hours.**

# Motivation for Hybrid-Electric (HE) Aircrafts



| | | Today | 2035 |
|---|---|---|---|
| Batteries | Technology | Lithium-Ion | Lithium-Air |
| | Energy Density E* | 200 – 260 [Wh/kg] ✗ | 500 – 1000 [Wh/kg] ✓ |
| | Volumetric Energy Density | 590 [Wh/l] ✓ | 750 – 2000 [Wh/l] ✓ |
| | Power density | 400 - 450 [W/kg] ✓ | 400 – 640 [W/kg] ✓ |
| Electric Motor | Technology | Tesla Model 3 | HTS motors (2025+) |
| | Power Density | 8.0 [kW/kg]* ● | 10 – 15 [kW/kg] ✓ |
| | Power | 190 [kW]* ✗ | 1850 [kW] ✓ |
| | Efficiency | 95% ✓ | 95-97% ✓ |

*: For power density ~ 8 [kW/kg]

**Cryogenic cooling system:**
- Pipe leakage
- Carnot efficiency
- Reliability (99.8% to be achieved)

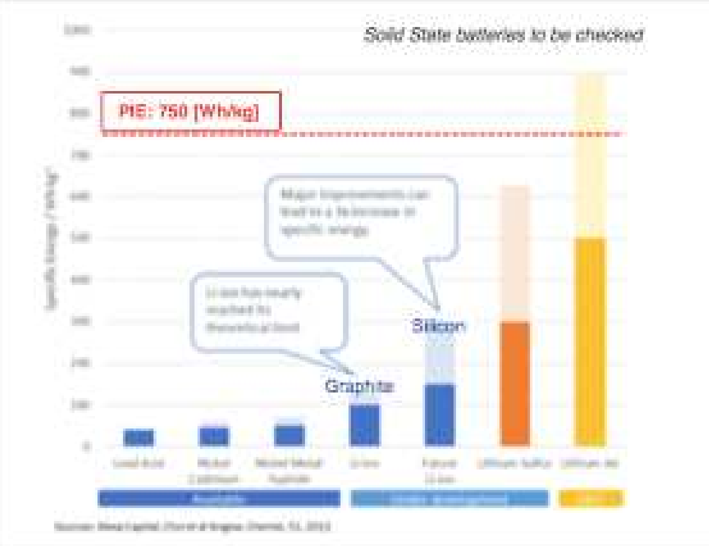
**Current energy densities:**
- Electric machines (motors, generators, inverters, cry-cooling system) E* have to be improved by a factor of 5 to 10

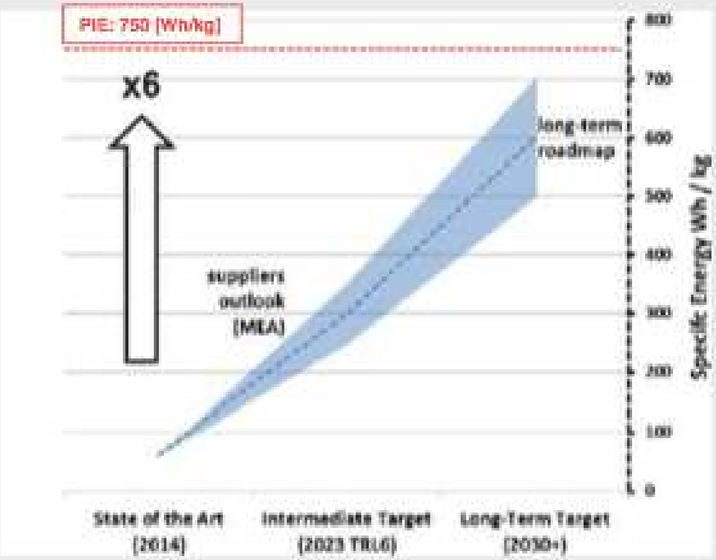
**HTS motors:**
- Feasibility of low loss AC conductors not demonstrated
- Loss of less than 10 W/A-m needed

## Motivation for Hybrid-Electric (HE) Aircrafts

### Lithium Batteries: Energy Density

- The development of hybrid-electric aircraft (HEA) therefore strongly depends on E*
- Energy density of lithium batteries against current technologies:





*Europe-Japan Symposium: Electrical Technologies for the Aviation of the Future*

→ **Lithium availability:** 400 years of output according to US geological Survey
→ **Costs:** Lithium-ion batteries are likely to fall to 100 [$/kWh] by 2020-2025
→ **E*:** Increase of 6% per year up to 250-350 [Wh/kg]

→ **Long term Airbus target for batteries:**
500 >> 700 [Wh/kg] at system level

# Motivation for Hybrid-Electric (HE) Aircrafts

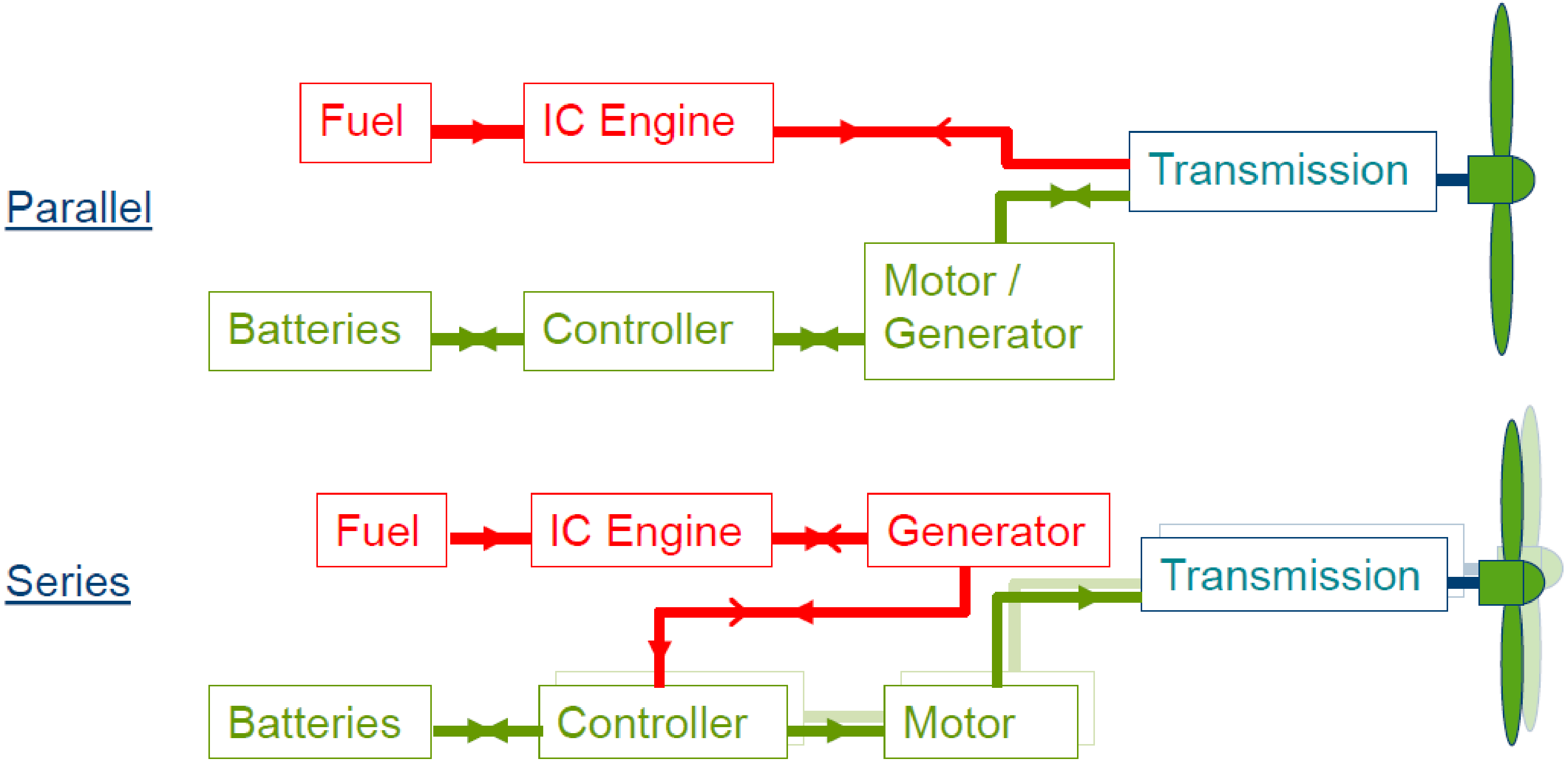
The **expected benefits** of using a hybrid electric power-train in flight vehicles are summarised below:

- Fewer emissions by reducing fuel burn;
- Less atmospheric heat release;
- Reduced noise impact for communities and quieter flight for passenger comfort.
- Better energy conservation and less dependence on fossil fuels.
- Better reliability by substitution of turbo-machinery with electric motors as means of propulsive power producers.
- Parallel redundancy
- Higher peak power.

These benefits would mostly derive from the use of electric energy, that could be (partially) produced by renewable sources.

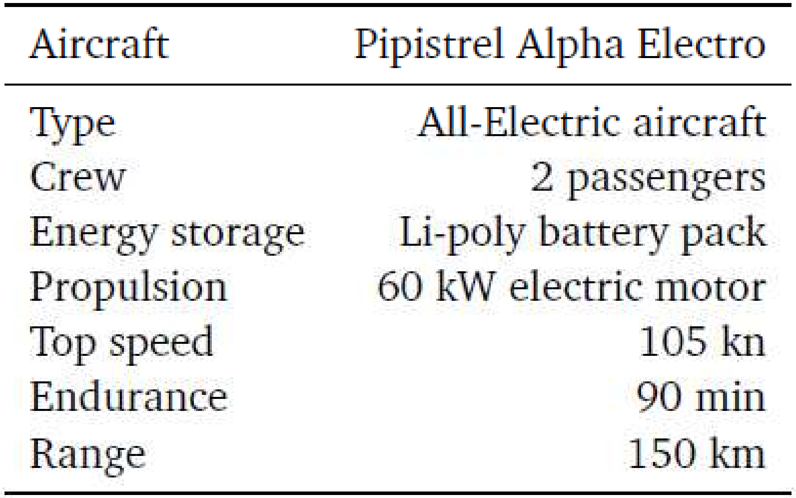
## Hybrid propulsion architectures

Electric motor: very high power-to-weight ratio (5KW/Kg), rapid and precise control – combined with a combustion engine running at peak efficiency



## Review of Aircrafts

**Pipistrel Alpha Electro** is an all-electric high-wing LSA developed by Slovenian company Pipistrel from the prototype WATTsUP.
It is currently available on market and is specifically designed to satisfy needs of flight schools, needing an average endurance of one hour.
17 kWh Li-poly batteries are employed and are rechargeable in less than one hour.

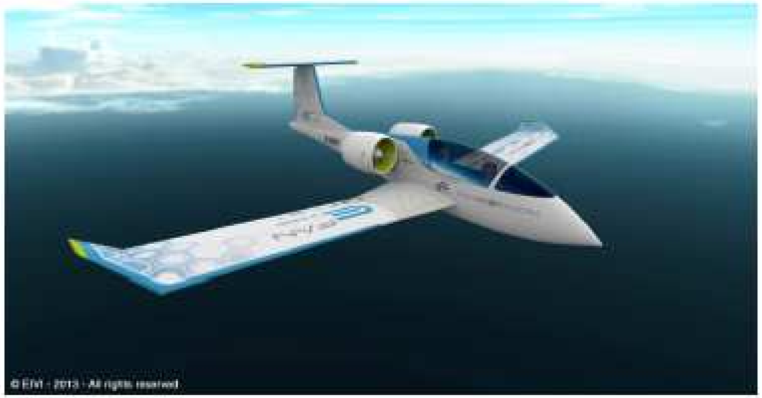


| Aircraft | Pipistrel Alpha Electro |
|---|---|
| Type | All-Electric aircraft |
| Crew | 2 passengers |
| Energy storage | Li-poly battery pack |
| Propulsion | 60 kW electric motor |
| Top speed | 105 kn |
| Endurance | 90 min |
| Range | 150 km |

## Review of Aircrafts

**Airbus E-fan** is an all-electric twin-seat mid-wing experimental that first flew in July 2014; the airplane has an unique feature of a ducted 8-blades propeller and an autonomous landing gear electric system capable of providing extra power through wheels during takeoff.

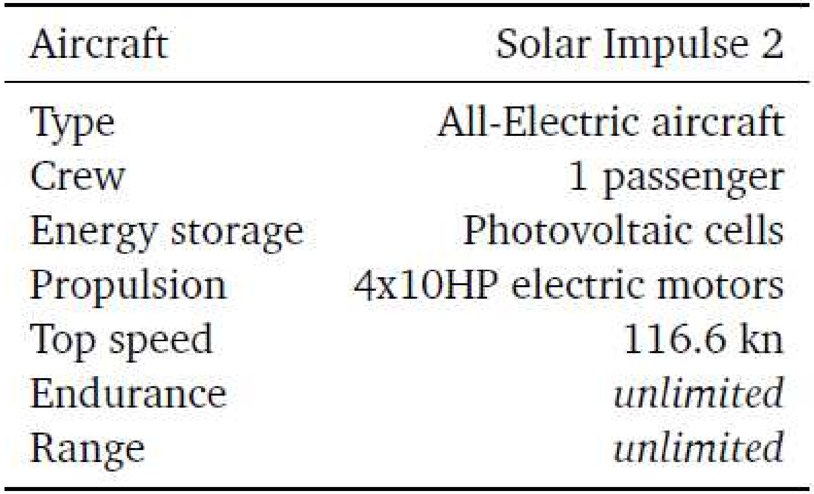
The aircraft was intended for pilot training and mass production was planned to start in 2017 but program was canceled in April 2017.



| Aircraft | Airbus E-fan |
|---|---|
| Type | All-Electric aircraft |
| Crew | 2 passengers |
| Energy storage | Li-poly battery pack |
| Propulsion | 60 kW electric motor |
| Top speed | 105 kn |
| Endurance | 60 min |
| Range | N.Av. |

## *Review of Aircrafts*

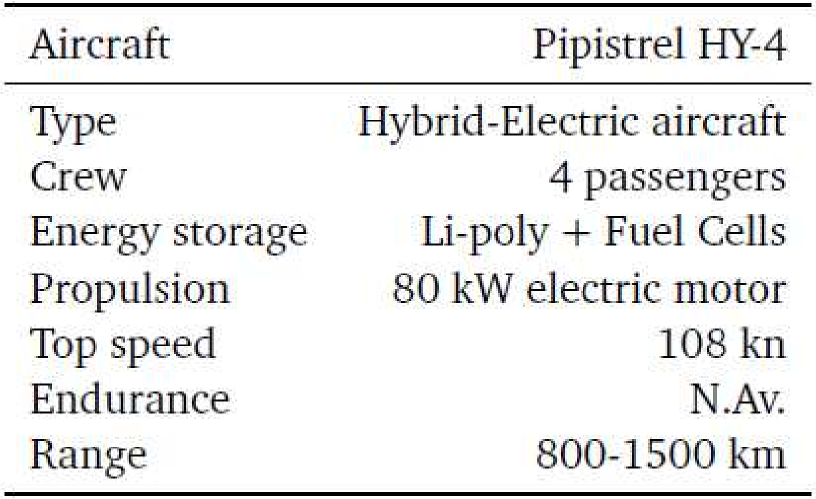
**Solar Impulse 2** is a solar-powered all-electric high-wing aircraft capable of flying virtually *forever*, being entirely powered by solar energy; although a world record aircraft, this **technology is still prohibitive** due to too low photovoltaic cells' specific power, resulting in a very large aircraft size.



| Aircraft | Solar Impulse 2 |
|---|---|
| Type | All-Electric aircraft |
| Crew | 1 passenger |
| Energy storage | Photovoltaic cells |
| Propulsion | 4x10HP electric motors |
| Top speed | 116.6 kn |
| Endurance | *unlimited* |
| Range | *unlimited* |

## *Review of Aircrafts*

**Pipistrel HY-4** is a hybrid-electric twin-fuselage aerotaxi developed by Slovenian company Pipistrel that is powered by a 80 kW electric engine fed by fuel cells. The aircraft is intended to serve as aerotaxi to cover all possible routes in Germany to offer a faster and more flexible transportation solution with zero emissions.



| Aircraft | Pipistrel HY-4 |
|---|---|
| Type | Hybrid-Electric aircraft |
| Crew | 4 passengers |
| Energy storage | Li-poly + Fuel Cells |
| Propulsion | 80 kW electric motor |
| Top speed | 108 kn |
| Endurance | N.Av. |
| Range | 800-1500 km |

## Review of Aircrafts

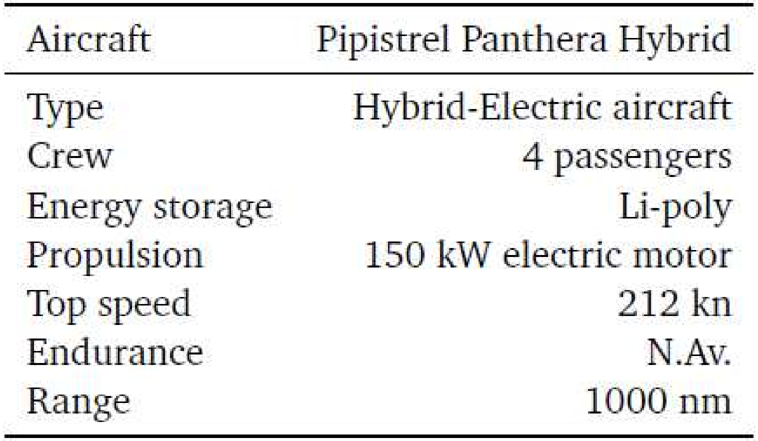
**Extra 330LE** is an aerobatic aircraft developed by Extra Aircraft from the conventional Extra 330L family, in cooperation with Siemens, MT-Propeller and Pipistrel that first flew in July 2016; it is equipped with the Siemens SP260D electric motor, fed by14 Li-ion batteries with a total capacity of 18.6 kWh.

| Aircraft | Extra 330LE |
|---|---|
| Type | All-Electric aircraft |
| Crew | 1 passenger |
| Energy storage | Li-ion |
| Propulsion | 260 kW electric motor |
| Top speed | 182 kn |
| Endurance | 20 min |
| Range | N.Av. |

# Review of Aircrafts

**Pipistrel Panthera Hybrid** is a Hybrid-Electric aircraft under development by Pipistrel as a hybrid version of the already existing Panthera.
The goal of the project is to design an airplane that can be equipped with three different types of propulsion: a conventional version, already on the market, the hybrid-electric version, now under development, and a future all-electric one.

Panthera Hybrid will be powered by a 150 kW electric motor fed by Li-poly batteries charged by Rotax-915 internal combustion engine.



| Aircraft | Pipistrel Panthera Hybrid |
|---|---|
| Type | Hybrid-Electric aircraft |
| Crew | 4 passengers |
| Energy storage | Li-poly |
| Propulsion | 150 kW electric motor |
| Top speed | 212 kn |
| Endurance | N.Av. |
| Range | 1000 nm |

## *Review of Aircrafts*

**NASA X-57 Maxwell** aircraft is a prototype developed by NASA from a Tecnam P2006T with a very high wing loading to reduce drag, using distributed propulsion to increase overall lift due to high-energy flow coming from 6 propellers for each half-wing, with a larger one at the tip to control flow separation to reduce induced drag.

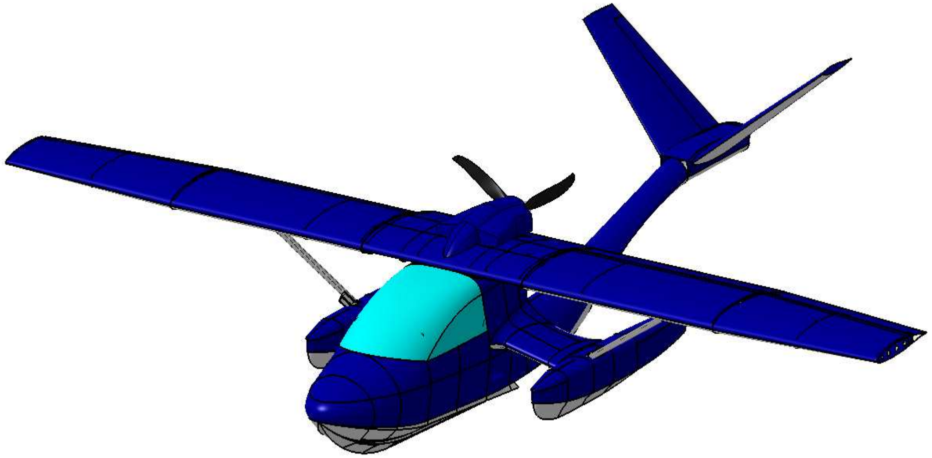
| Aircraft | NASA X-57 Maxwell |
|---|---|
| Type | All-Electric aircraft |
| Crew | 4 passengers |
| Energy storage | Li-ion |
| Propulsion | 14 electric motors |
| Top speed | 150 kn |
| Endurance | 60 min |
| Range | 160 km |

# SEAGULL - The Marin-Air Vehicle for the Millennial Generation

*The SEAGULL is a* ***breakthrough*** *with respect to the current transportation systems, a high performing* ***ultralight amphibian aircraft****,* ***easy*** *and* ***economical****, operating from any infrastructure in complete* ***autonomy****.*

## SEAGULL Main Characteristics

- *Full composite amphibious*
- *Braced wing (through linear actuators)*
- *Automated Folding wing allowing the usage:*
  - *as classical UL aircraft (no folded)*
  - *as sail boat (folded)*
  - *as ship or for ground transport and storage (fully folded aft)*
- *Single engine pusher configuration*
- *Hybrid propulsion system (alternative)*
- *Retractable landing gear*



*Project partially* ***funded*** *by* ***MISE*** *- Italian Ministry of the Economic Development (Law 808/85)*

***Start date:***
*January 2018*
***End date:***
*December 2020*

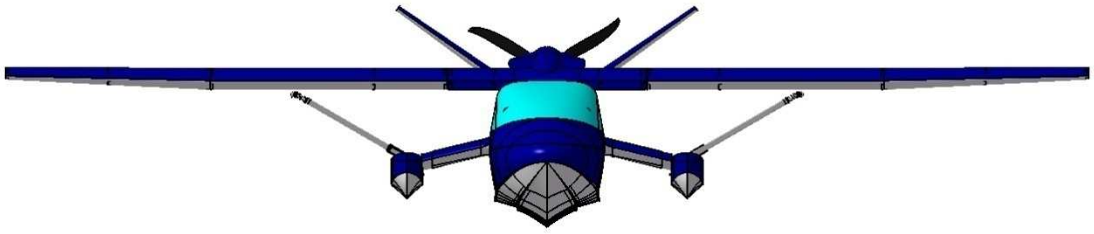
*Financing of* ***1.3M€*** *of which 55% to be returned*

## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

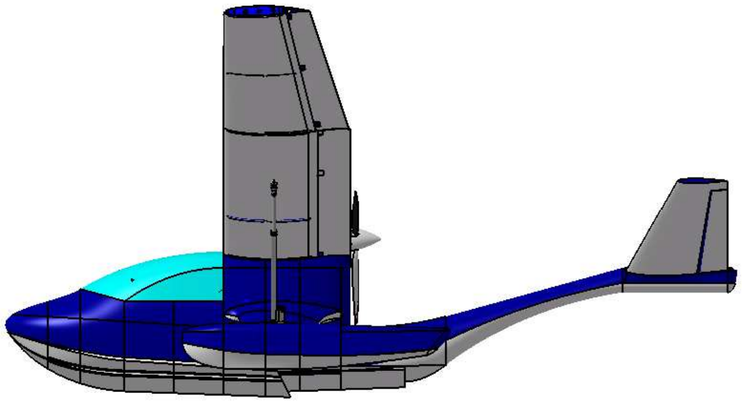
**SEAGULL A/C in 5 words:**

- ✓ **UNIQUE**
- ✓ **INDIPENDENT**
- ✓ **YOUNG**
- ✓ **LIGHT**
- ✓ **ECO-FRIENDLY**

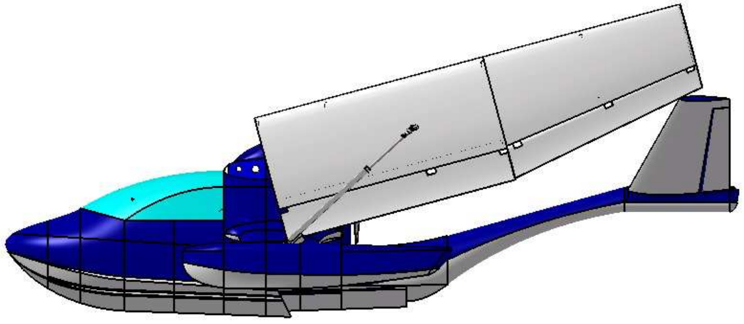
***Ultralight Aircraft configuration***



***Sail configuration***



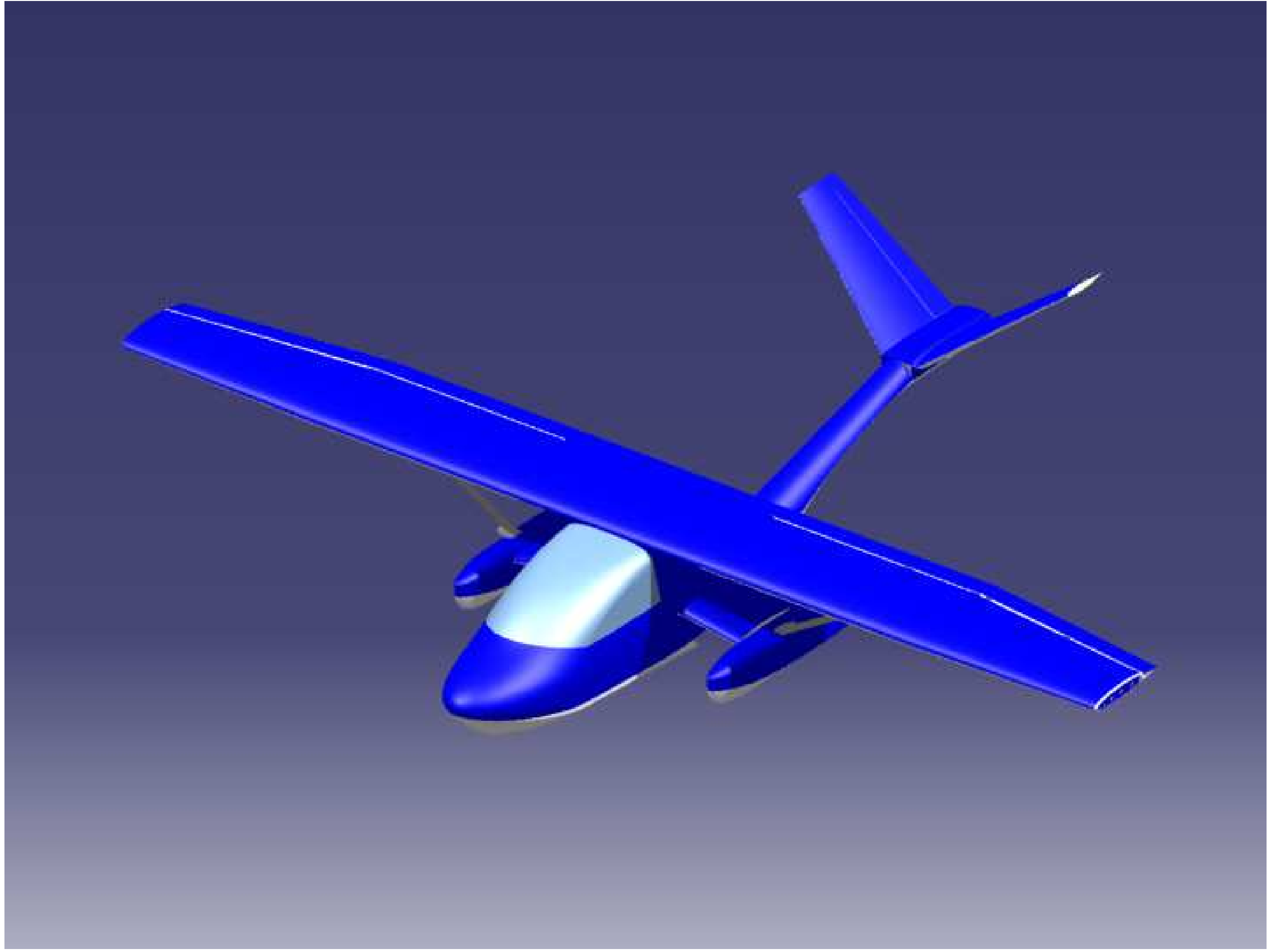
***Mooring Configuration***



# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Folding mechanism simulation

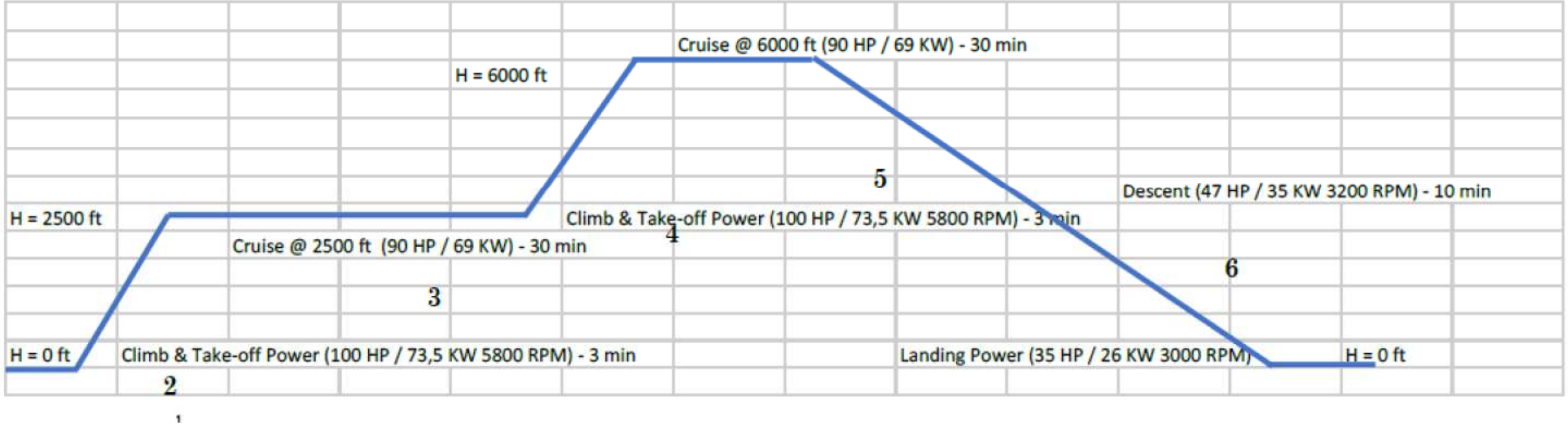
See attached file: Novotech - Folding Simulation Mechanism



## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

### Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

The aim is to asses the potential replacement of a standard piston engine propulsion architecture (i.e. Rotax 912S) with a full electric or hybrid electric configuration.



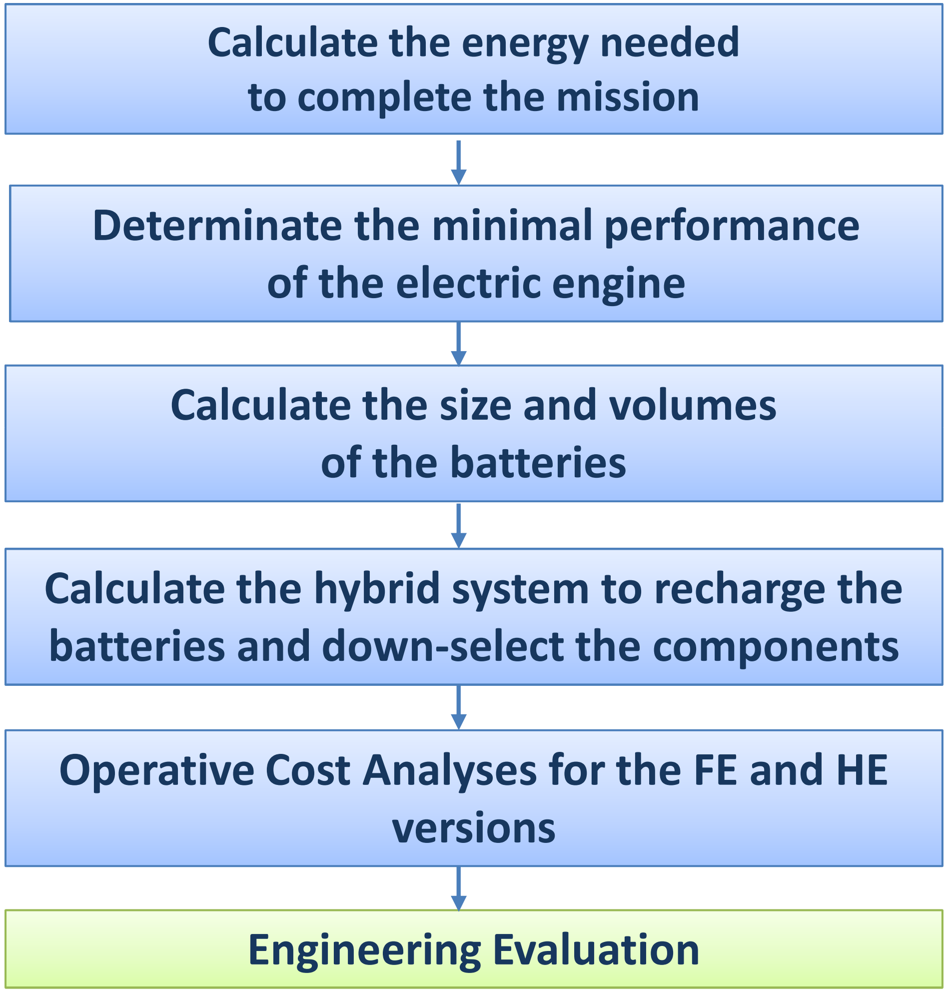
In order to evaluate the energy needed we started from the curves of 3 blades Sensenich 3B0R5 L68C - 68".

It was assumed to vary the rotation speed of the propeller from a minimum of 1900 rpm to a max value of 2800rpm.

It was assumed to work with a pitch of 18,5.

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C



Calculate the energy needed to complete the mission

Determinate the minimal performance of the electric engine

Calculate the size and volumes of the batteries

Calculate the hybrid system to recharge the batteries and down-select the components

Operative Cost Analyses for the FE and HE versions

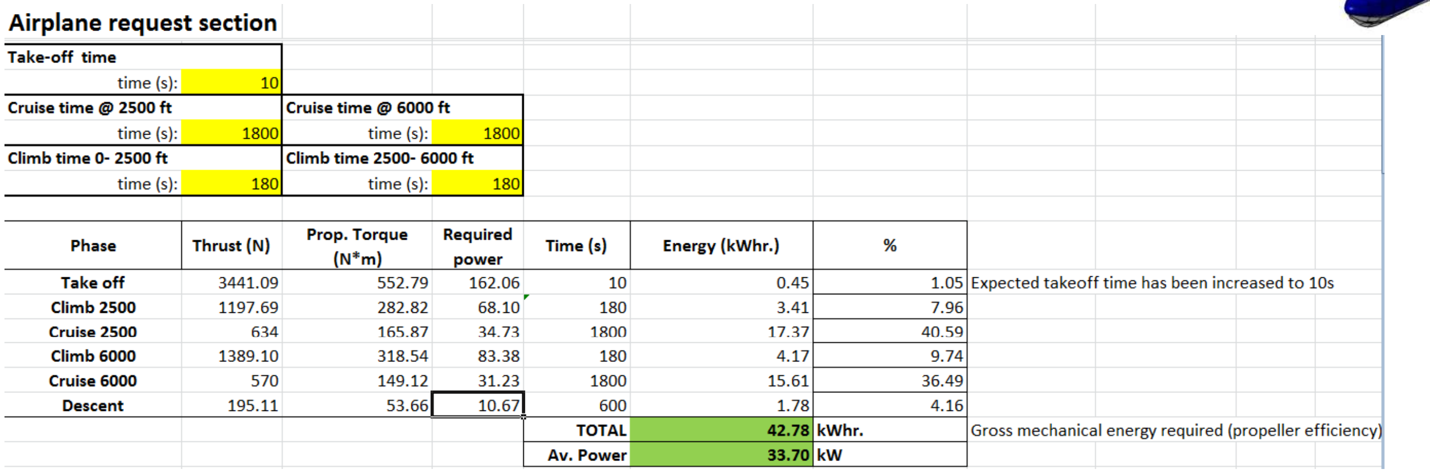
Engineering Evaluation

**Flowchart diagram**

## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

### Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

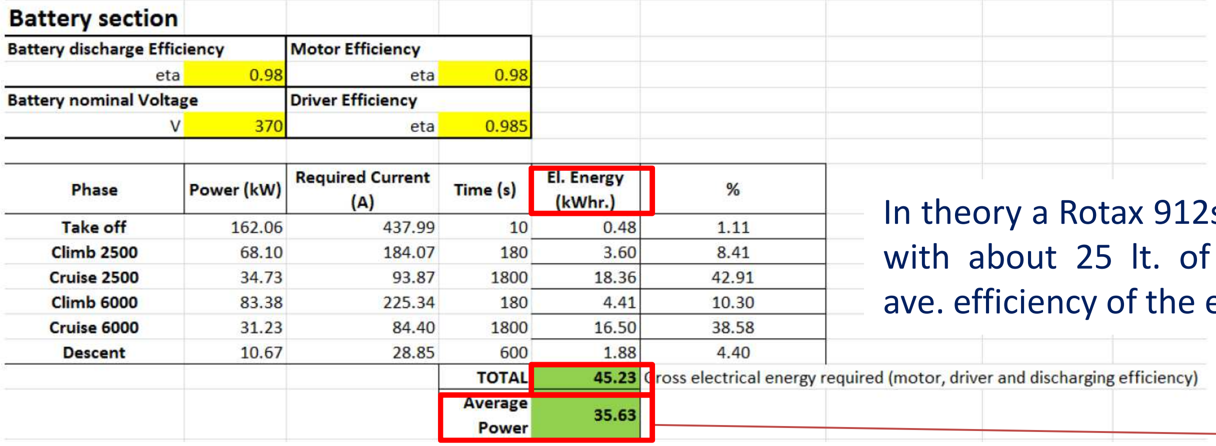
- **Calculate the Energy needed to complete the standard mission @ Vcruise =170km/hr. and pitch 18,5**



**Airplane request section**

| | | | |
|---|---|---|---|
| **Take-off time** | | | |
| time (s): | 10 | | |
| **Cruise time @ 2500 ft** | | **Cruise time @ 6000 ft** | |
| time (s): | 1800 | time (s): | 1800 |
| **Climb time 0- 2500 ft** | | **Climb time 2500- 6000 ft** | |
| time (s): | 180 | time (s): | 180 |

| Phase | Thrust (N) | Prop. Torque (N*m) | Required power | Time (s) | Energy (kWhr.) | % | |
|---|---|---|---|---|---|---|---|
| **Take off** | 3441.09 | 552.79 | 162.06 | 10 | 0.45 | 1.05 | Expected takeoff time has been increased to 10s |
| **Climb 2500** | 1197.69 | 282.82 | 68.10 | 180 | 3.41 | 7.96 | |
| **Cruise 2500** | 634 | 165.87 | 34.73 | 1800 | 17.37 | 40.59 | |
| **Climb 6000** | 1389.10 | 318.54 | 83.38 | 180 | 4.17 | 9.74 | |
| **Cruise 6000** | 570 | 149.12 | 31.23 | 1800 | 15.61 | 36.49 | |
| **Descent** | 195.11 | 53.66 | 10.67 | 600 | 1.78 | 4.16 | |
| | | | | **TOTAL** | **42.78** | kWhr. | Gross mechanical energy required (propeller efficiency) |
| | | | | **Av. Power** | **33.70** | kW | |



**Battery section**

| | | | |
|---|---|---|---|
| **Battery discharge Efficiency** | | **Motor Efficiency** | |
| eta | 0.98 | eta | 0.98 |
| **Battery nominal Voltage** | | **Driver Efficiency** | |
| V | 370 | eta | 0.985 |

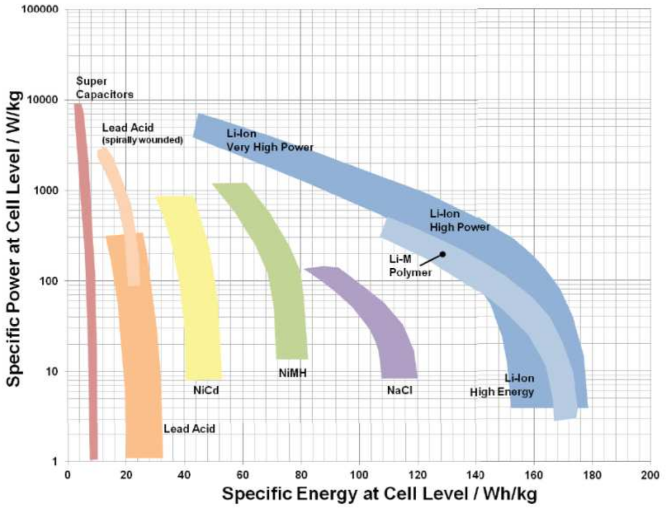
| Phase | Power (kW) | Required Current (A) | Time (s) | El. Energy (kWhr.) | % |
|---|---|---|---|---|---|
| **Take off** | 162.06 | 437.99 | 10 | 0.48 | 1.11 |
| **Climb 2500** | 68.10 | 184.07 | 180 | 3.60 | 8.41 |
| **Cruise 2500** | 34.73 | 93.87 | 1800 | 18.36 | 42.91 |
| **Climb 6000** | 83.38 | 225.34 | 180 | 4.41 | 10.30 |
| **Cruise 6000** | 31.23 | 84.40 | 1800 | 16.50 | 38.58 |
| **Descent** | 10.67 | 28.85 | 600 | 1.88 | 4.40 |
| | | | **TOTAL** | **45.23** | Gross electrical energy required (motor, driver and discharging efficiency) |
| | | | **Average Power** | **35.63** | |

In theory a Rotax 912s can provide 45kWhr. with about 25 lt. of fuel considering the ave. efficiency of the engine of about 0.20.

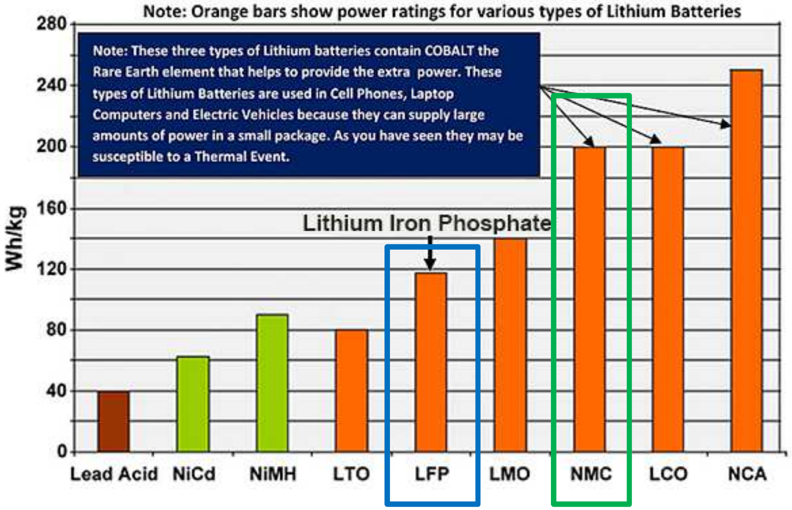
## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Batteries**

Lithium-ion and Lithium-polymers batteries are the most common batteries due to very high performance compared to other technologies available on the market:



Ragone diagram displaying available technologies in 2008.



Note: Orange bars show power ratings for various types of Lithium Batteries

Note: These three types of Lithium batteries contain COBALT the Rare Earth element that helps to provide the extra power. These types of Lithium Batteries are used in Cell Phones, Laptop Computers and Electric Vehicles because they can supply large amounts of power in a small package. As you have seen they may be susceptible to a Thermal Event.

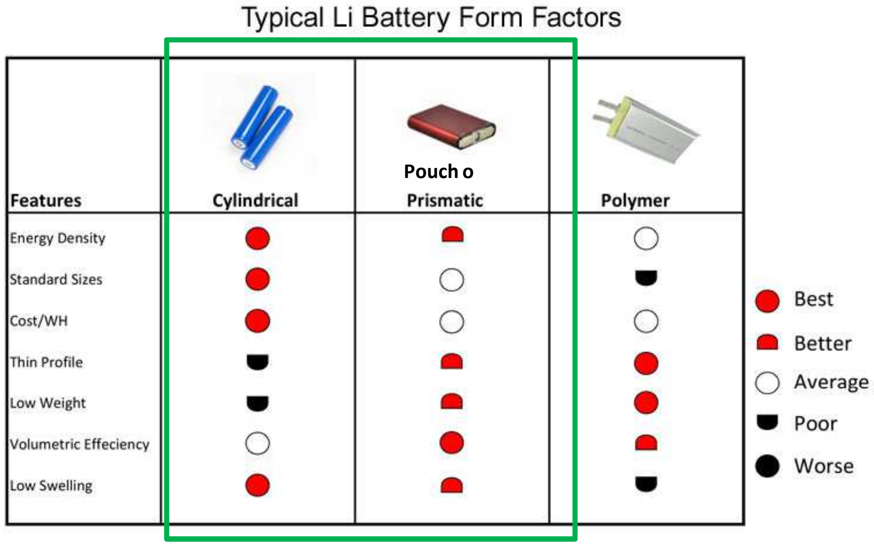
| | LCO | NMC | NCA | LMO | LFP |
|---|---|---|---|---|---|
| **Advantages** | Cycle life, energy density | Excellent energy density | Cycle life, power | Thermal stability, price, energy density | Excellent cycle life |
| **Disadvantages** | Thermal stability | Patent issues | Sensitive to moisture | Cycle life | Energy density, power |
| **Common applications** | Portable electronics | Power tools, EVs | High quality electronics | Power tools | Power tools, stationary energy storage, e-bikes |
| | | $ | | | $$ |

## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

### Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

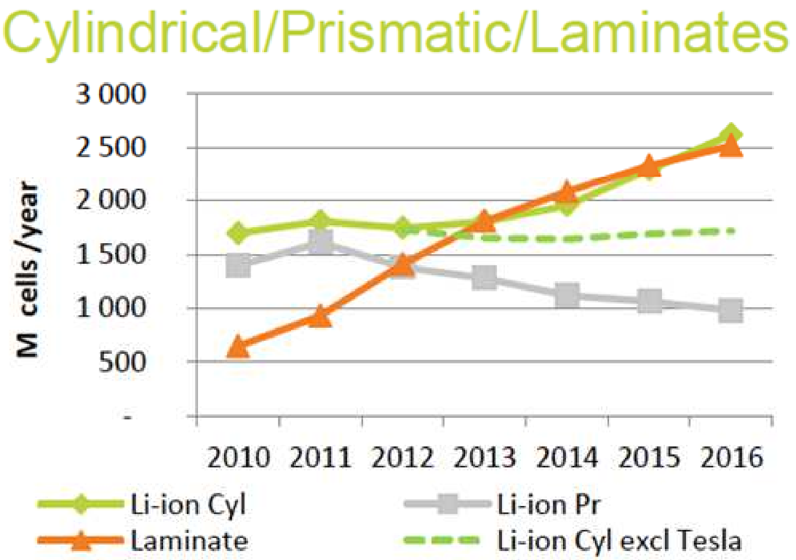
- **Batteries**

Typical Li Battery Form Factors

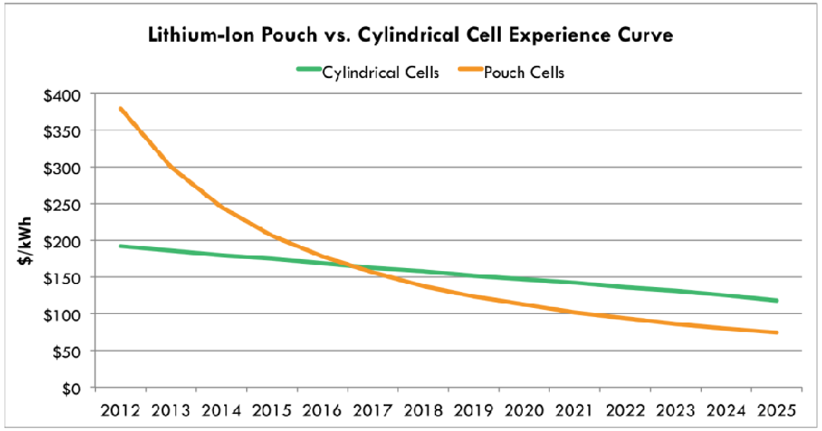


| Features | Cylindrical | Pouch o Prismatic | Polymer |
|---|---|---|---|
| Energy Density | 🔴 | ◓ | ○ |
| Standard Sizes | 🔴 | ○ | ◒ |
| Cost/WH | 🔴 | ○ | ○ |
| Thin Profile | ◒ | ◓ | 🔴 |
| Low Weight | ◒ | ◓ | 🔴 |
| Volumetric Effeciency | ○ | 🔴 | ◓ |
| Low Swelling | 🔴 | ◓ | ◒ |

🔴 Best
◓ Better
○ Average
◒ Poor
⚫ Worse


Cylindrical/Prismatic/Laminates

*Li-ion cylindrical: “Tesla impact”: 150 M cells in 2013, 300M in 2014, 600 M in 2015*


Lithium-Ion Pouch vs. Cylindrical Cell Experience Curve

Source: Avicenne Energy*, ARK Investment Management LLC

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Batteries**

Tipologia 18650 3,2Ah

Tipo Pouch 100Ah

Tipo prismatico rigido Plastica

Tipo prismatico rigido alluminio

Example of compact power module that includes BMS and various security systems of a Tesla model S, the package uses 18650 cells there are approx. 450 batteries from Panasonic.

- Capacity ≈ 5.3kWh
- Weight ≈ 24.5 kg.
- Dimensions [cm] = 68 x 28 x 7.5

Usually similar packages are used in series and in parallel to obtain the desired specifications

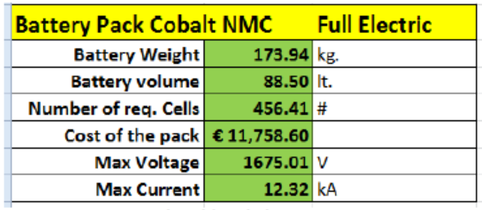
Modulo batteria Tesla model S

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

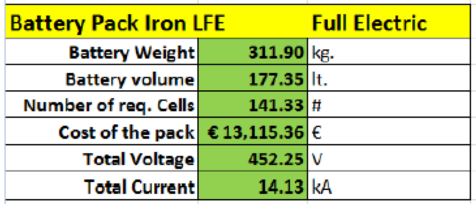
- **Calculate the size and volumes of the batteries**

**FULL ELECTRIC @ 170 km/hr.**



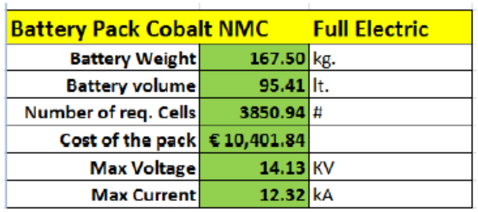
| Battery Pack Cobalt NMC | | Full Electric |
|---|---|---|
| Battery Weight | 173.94 | kg. |
| Battery volume | 88.50 | lt. |
| Number of req. Cells | 456.41 | # |
| Cost of the pack | € 11,758.60 | |
| Max Voltage | 1675.01 | V |
| Max Current | 12.32 | kA |

*Tab.5 Litio cobalto POUCH*



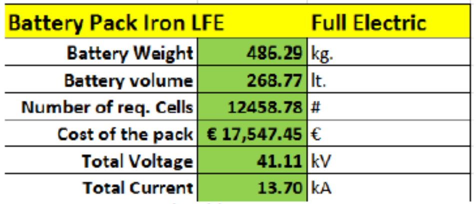
| Battery Pack Iron LFE | | Full Electric |
|---|---|---|
| Battery Weight | 311.90 | kg. |
| Battery volume | 177.35 | lt. |
| Number of req. Cells | 141.33 | # |
| Cost of the pack | € 13,115.36 | € |
| Total Voltage | 452.25 | V |
| Total Current | 14.13 | kA |

*Tab.6 Litio Ferro POUCH*



| Battery Pack Cobalt NMC | | Full Electric |
|---|---|---|
| Battery Weight | 167.50 | kg. |
| Battery volume | 95.41 | lt. |
| Number of req. Cells | 3850.94 | # |
| Cost of the pack | € 10,401.84 | |
| Max Voltage | 14.13 | KV |
| Max Current | 12.32 | kA |

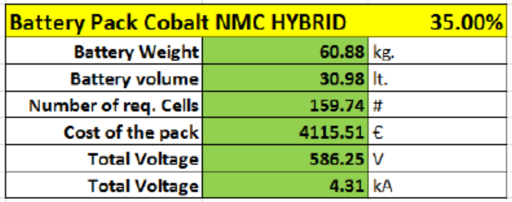
*Tab.7 Litio Cobalto 18650*



| Battery Pack Iron LFE | | Full Electric |
|---|---|---|
| Battery Weight | 486.29 | kg. |
| Battery volume | 268.77 | lt. |
| Number of req. Cells | 12458.78 | # |
| Cost of the pack | € 17,547.45 | € |
| Total Voltage | 41.11 | kV |
| Total Current | 13.70 | kA |

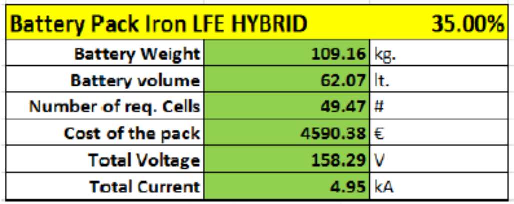
*Tab.8 Litio Ferro 18650*

**HYBRID @ 170 km/hr. @ 35%**



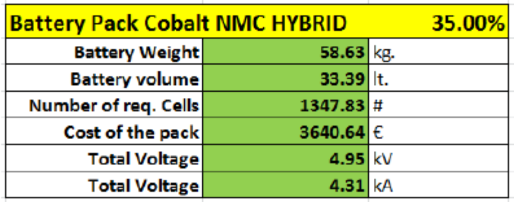
| Battery Pack Cobalt NMC HYBRID | | 35.00% |
|---|---|---|
| Battery Weight | 60.88 | kg. |
| Battery volume | 30.98 | lt. |
| Number of req. Cells | 159.74 | # |
| Cost of the pack | 4115.51 | € |
| Total Voltage | 586.25 | V |
| Total Voltage | 4.31 | kA |

*Tab.13 Litio Cobalto Pouch*



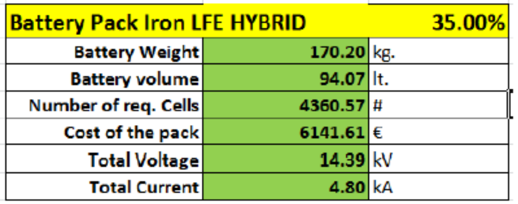
| Battery Pack Iron LFE HYBRID | | 35.00% |
|---|---|---|
| Battery Weight | 109.16 | kg. |
| Battery volume | 62.07 | lt. |
| Number of req. Cells | 49.47 | # |
| Cost of the pack | 4590.38 | € |
| Total Voltage | 158.29 | V |
| Total Current | 4.95 | kA |

*Tab.14 Litio Ferro Pouch*



| Battery Pack Cobalt NMC HYBRID | | 35.00% |
|---|---|---|
| Battery Weight | 58.63 | kg. |
| Battery volume | 33.39 | lt. |
| Number of req. Cells | 1347.83 | # |
| Cost of the pack | 3640.64 | € |
| Total Voltage | 4.95 | kV |
| Total Voltage | 4.31 | kA |

*Tab.15 Litio Cobalto 18650*



| Battery Pack Iron LFE HYBRID | | 35.00% |
|---|---|---|
| Battery Weight | 170.20 | kg. |
| Battery volume | 94.07 | lt. |
| Number of req. Cells | 4360.57 | # |
| Cost of the pack | 6141.61 | € |
| Total Voltage | 14.39 | kV |
| Total Current | 4.80 | kA |

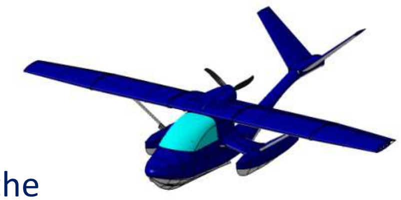
*Tab.16 Litio Ferro 18650*

The sizing of the generation system envisages the use of an endothermic engine that works at a fixed point on a generator and uses a dedicated electronics to work in parallel on the battery pack and the main propulsion engine.

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

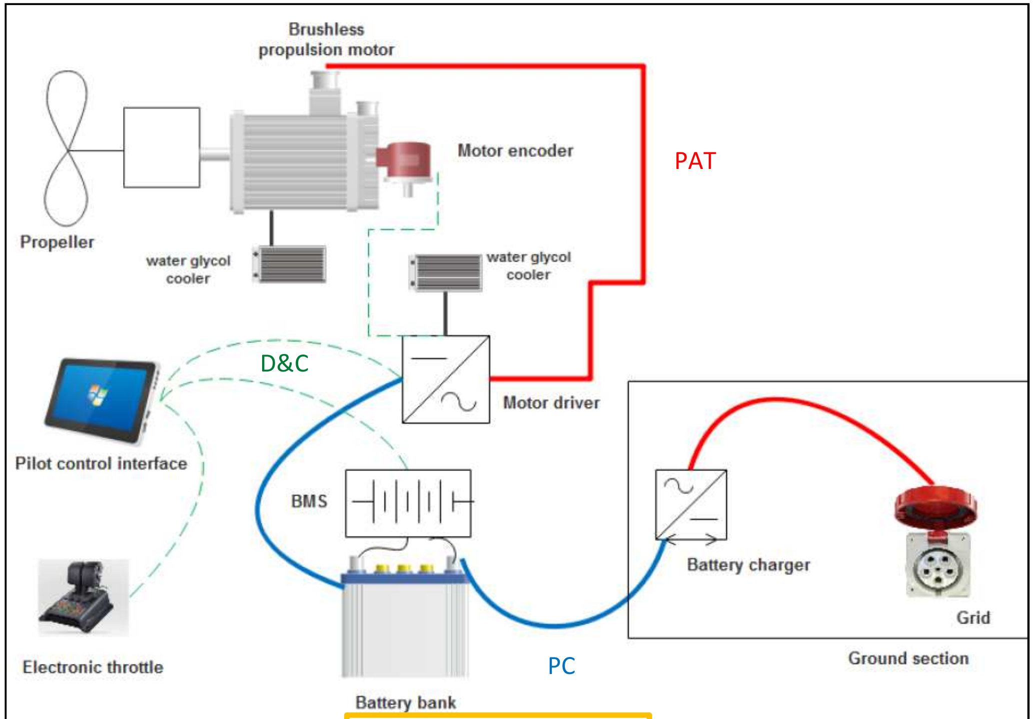
- **Calculate the hybrid system to recharge the batteries and down-select the components**



Energy storage is totally electric so the batteries take the place of the tank and the electric motor takes the place of the ICE.

**Main engine propulsion system**
permanent magnet brushless motors are the ones most suitable for this type of application thanks to their power density (typically up to 5kW/kg).

Moreover, they can are easily overloaded without major problems for several minutes with a factor of up to 2 when cold.



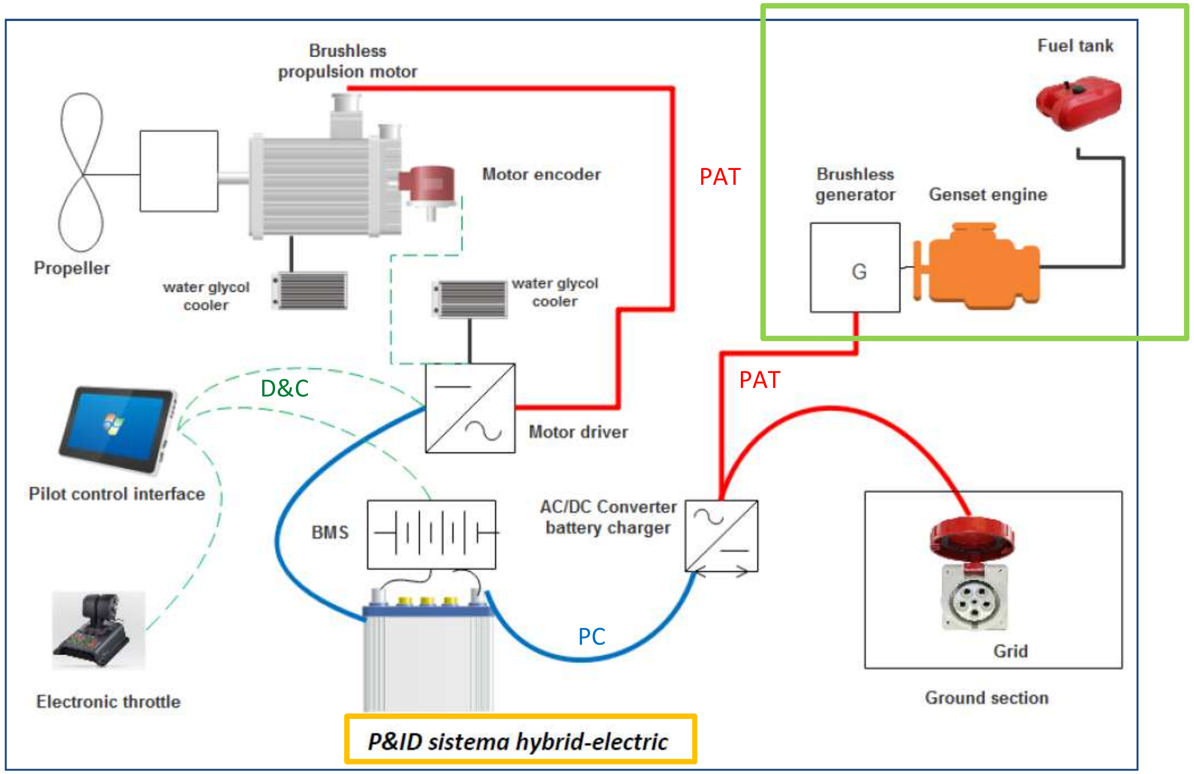
*P&ID sistema full electric*

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Calculate the hybrid system to recharge the batteries and down-select the components**

In the hybrid propulsion system, only a part of the energy needed is stored in the batteries (%), so a power generation system is required to provide the necessary difference during the flight to help recharge of the batteries and provide the necessary redundancies.



**P&ID sistema hybrid-electric**

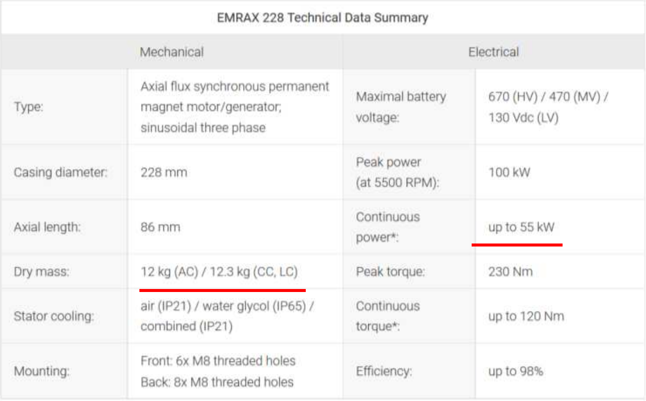
*2018 NOVOTECH Proprietary*

La propulsione ibrida nell'aviazione generale: Innovazione e sperimentazione

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Calculate the hybrid system to recharge the batteries and down-select the components**



EMRAX 228 Technical Data Summary

| Mechanical | | Electrical | |
|---|---|---|---|
| Type: | Axial flux synchronous permanent magnet motor/generator; sinusoidal three phase | Maximal battery voltage: | 670 (HV) / 470 (MV) / 130 Vdc (LV) |
| Casing diameter: | 228 mm | Peak power (at 5500 RPM): | 100 kW |
| Axial length: | 86 mm | Continuous power*: | up to 55 kW |
| Dry mass: | 12 kg (AC) / 12.3 kg (CC, LC) | Peak torque: | 230 Nm |
| Stator cooling: | air (IP21) / water glycol (IP65) / combined (IP21) | Continuous torque*: | up to 120 Nm |
| Mounting: | Front: 6x M8 threaded holes<br>Back: 8x M8 threaded holes | Efficiency: | up to 98% |

* Depends on the rotation speed and thermal conditions.

**SP260D** **SP260D-A**

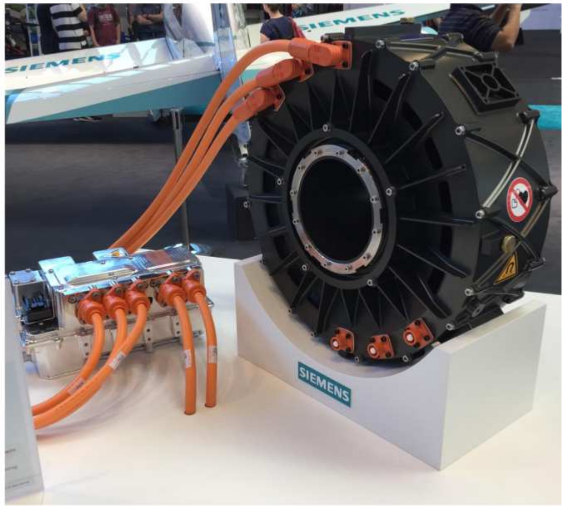
Direct Drive Permanent Magnet
**MTOP** 260 kW @ 2500 RPM
**Torque** 977 Nm
**UDC** 580 V
**Oil cooled** @ 90 °C
**Efficiency** 95%

| | | |
|---|---|---|
| 50 kg | **Weight** | 44kg |
| 5.2 kW/kg | **Power Density** | 5.9 kW/kg |

Developed for maximal Power Density
Redundant 3 Phase Windings

Implemented in Extra 330LE

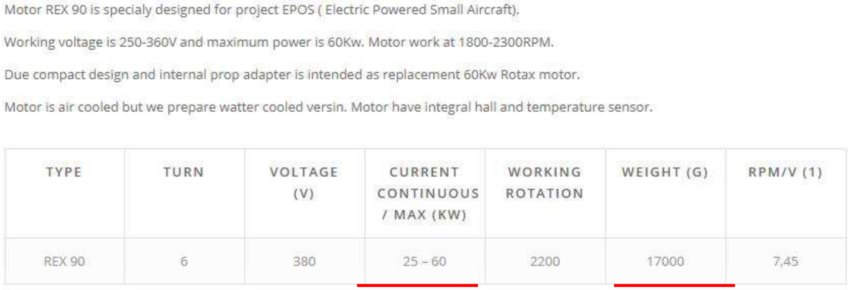
Achievements:
- Electric Aircraft Speed Records
- Electric Aircraft Climbing Records
- First All-Electric Glider Towing



# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Calculate the hybrid system to recharge the batteries and down-select the components**



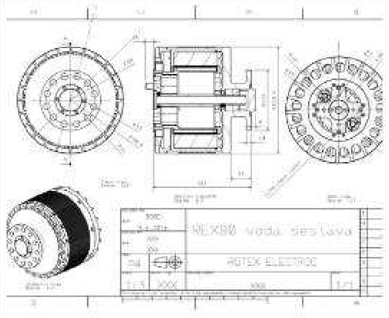
Motor REX 90 is specialy designed for project EPOS ( Electric Powered Small Aircraft).

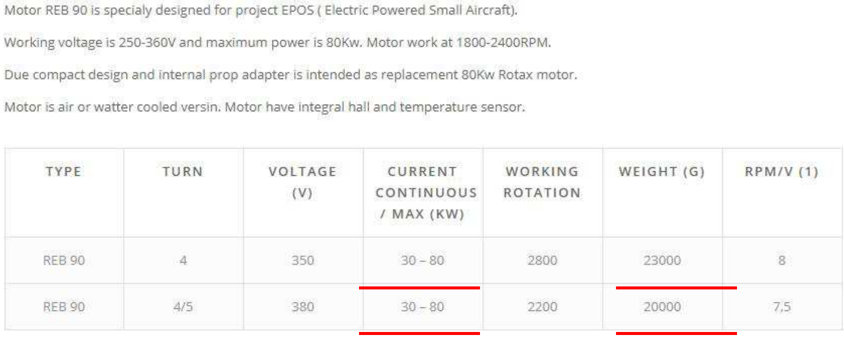
Working voltage is 250-360V and maximum power is 60Kw. Motor work at 1800-2300RPM.

Due compact design and internal prop adapter is intended as replacement 60Kw Rotax motor.

Motor is air cooled but we prepare watter cooled versin. Motor have integral hall and temperature sensor.

| TYPE | TURN | VOLTAGE (V) | CURRENT CONTINUOUS / MAX (KW) | WORKING ROTATION | WEIGHT (G) | RPM/V (1) |
|---|---|---|---|---|---|---|
| REX 90 | 6 | 380 | 25 – 60 | 2200 | 17000 | 7,45 |





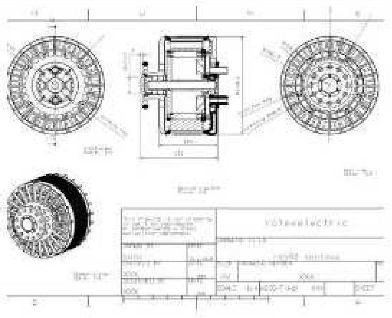
Motor REB 90 is specialy designed for project EPOS ( Electric Powered Small Aircraft).

Working voltage is 250-360V and maximum power is 80Kw. Motor work at 1800-2400RPM.

Due compact design and internal prop adapter is intended as replacement 80Kw Rotax motor.

Motor is air or watter cooled versin. Motor have integral hall and temperature sensor.

| TYPE | TURN | VOLTAGE (V) | CURRENT CONTINUOUS / MAX (KW) | WORKING ROTATION | WEIGHT (G) | RPM/V (1) |
|---|---|---|---|---|---|---|
| REB 90 | 4 | 350 | 30 – 80 | 2800 | 23000 | 8 |
| REB 90 | 4/5 | 380 | 30 – 80 | 2200 | 20000 | 7,5 |



## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

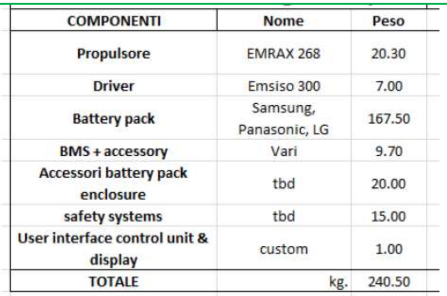
### Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Operative Cost Analyses for the FE and HE versions**

**Profilo di missione Standard @ 170km/hr. pitch 18,5 Batterie 18650**

*Trasmissione diretta motore elica*

Full Electric - Trasmissione diretta motore elica

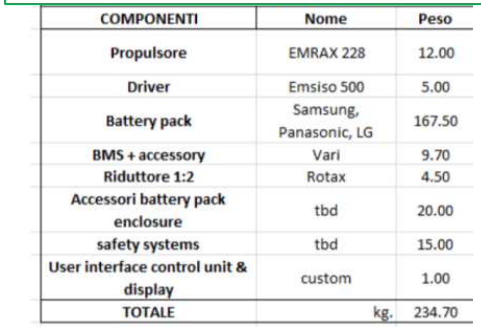


| COMPONENTI | Nome | Peso |
|---|---|---|
| Propulsore | EMRAX 268 | 20.30 |
| Driver | Emsiso 300 | 7.00 |
| Battery pack | Samsung, Panasonic, LG | 167.50 |
| BMS + accessory | Vari | 9.70 |
| Accessori battery pack enclosure | tbd | 20.00 |
| safety systems | tbd | 15.00 |
| User interface control unit & display | custom | 1.00 |
| TOTALE | kg. | 240.50 |

Cost= Δ +33%

*Trasmissione tramite riduttore*

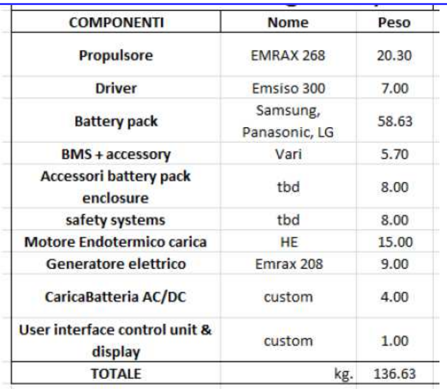
Full Electric - Trasmissione con riduttore



| COMPONENTI | Nome | Peso |
|---|---|---|
| Propulsore | EMRAX 228 | 12.00 |
| Driver | Emsiso 500 | 5.00 |
| Battery pack | Samsung, Panasonic, LG | 167.50 |
| BMS + accessory | Vari | 9.70 |
| Riduttore 1:2 | Rotax | 4.50 |
| Accessori battery pack enclosure | tbd | 20.00 |
| safety systems | tbd | 15.00 |
| User interface control unit & display | custom | 1.00 |
| TOTALE | kg. | 234.70 |

Cost= Δ +12%

Hybrid 35% Electric - Trasmissione diretta motore elica



| COMPONENTI | Nome | Peso |
|---|---|---|
| Propulsore | EMRAX 268 | 20.30 |
| Driver | Emsiso 300 | 7.00 |
| Battery pack | Samsung, Panasonic, LG | 58.63 |
| BMS + accessory | Vari | 5.70 |
| Accessori battery pack enclosure | tbd | 8.00 |
| safety systems | tbd | 8.00 |
| Motore Endotermico carica | HE | 15.00 |
| Generatore elettrico | Emrax 208 | 9.00 |
| CaricaBatteria AC/DC | custom | 4.00 |
| User interface control unit & display | custom | 1.00 |
| TOTALE | kg. | 136.63 |

Cost= Δ +20%

Hybrid 35% Electric - Trasmissione con riduttore

| COMPONENTI | Nome | Peso |
|---|---|---|
| Propulsore | EMRAX 228 | 12.00 |
| Driver | Emsiso 500 | 5.00 |
| Battery pack | Samsung, Panasonic, LG | 58.63 |
| BMS + accessory | Vari | 5.70 |
| Riduttore 1:2 | Rotax | 4.50 |
| Accessori battery pack enclosure | tbd | 8.00 |
| safety systems | tbd | 8.00 |
| Motore Endotermico carica | HE | 15.00 |
| Generatore elettrico | Emrax 208 | 9.00 |
| CaricaBatteria AC/DC | custom | 4.00 |
| User interface control unit & display | custom | 1.00 |
| TOTALE | kg. | 130.83 |

Cost= Δ

# *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

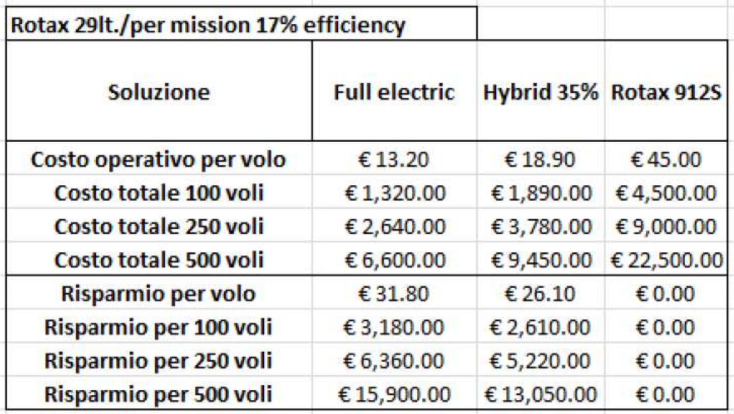
## Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Operative Cost Analyses for the FE and HE versions**

Fuel = 1.55€/lt
Electric energy = 0.28€/KWh

| Phase | lt/h. | Time (s) | lt. |
|---|---|---|---|
| Take off | 27.00 | 10 | 0.08 |
| Climb 2500 | 27.00 | 180 | 1.35 |
| Cruise 2500 | 25.00 | 1800 | 12.50 |
| Climb 6000 | 27.00 | 180 | 1.35 |
| Cruise 6000 | 25.00 | 1800 | 12.50 |
| Descent | 7.50 | 600 | 1.25 |
| | | TOTAL | 29.03 |

*Stima massima del consumo Rotax 912*



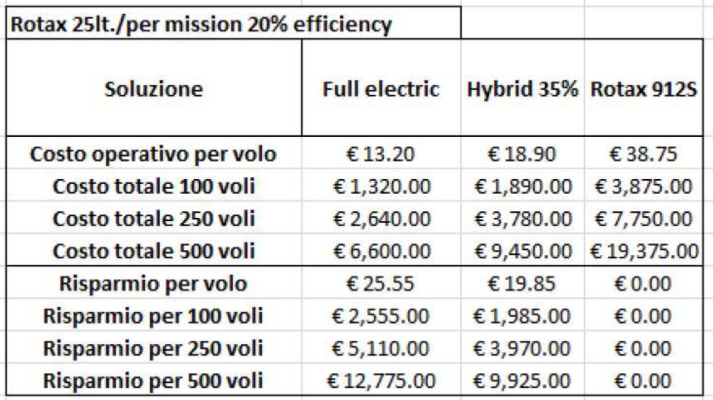
Rotax 29lt./per mission 17% efficiency

| Soluzione | Full electric | Hybrid 35% | Rotax 912S |
|---|---|---|---|
| Costo operativo per volo | € 13.20 | € 18.90 | € 45.00 |
| Costo totale 100 voli | € 1,320.00 | € 1,890.00 | € 4,500.00 |
| Costo totale 250 voli | € 2,640.00 | € 3,780.00 | € 9,000.00 |
| Costo totale 500 voli | € 6,600.00 | € 9,450.00 | € 22,500.00 |
| Risparmio per volo | € 31.80 | € 26.10 | € 0.00 |
| Risparmio per 100 voli | € 3,180.00 | € 2,610.00 | € 0.00 |
| Risparmio per 250 voli | € 6,360.00 | € 5,220.00 | € 0.00 |
| Risparmio per 500 voli | € 15,900.00 | € 13,050.00 | € 0.00 |

45kWhr, η = 0.95.
14kWhr, 9.5lt η = 0.95.
29lt

| Phase | lt/h. | Time (s) | lt. |
|---|---|---|---|
| Take off | 27.00 | 10 | 0.08 |
| Climb 2500 | 27.00 | 180 | 1.35 |
| Cruise 2500 | 21.00 | 1800 | 10.50 |
| Climb 6000 | 27.00 | 180 | 1.35 |
| Cruise 6000 | 21.00 | 1800 | 10.50 |
| Descent | 7.50 | 600 | 1.25 |
| | | TOTAL | 25.03 |

*Stima media del consumo Rotax 912*



Rotax 25lt./per mission 20% efficiency

| Soluzione | Full electric | Hybrid 35% | Rotax 912S |
|---|---|---|---|
| Costo operativo per volo | € 13.20 | € 18.90 | € 38.75 |
| Costo totale 100 voli | € 1,320.00 | € 1,890.00 | € 3,875.00 |
| Costo totale 250 voli | € 2,640.00 | € 3,780.00 | € 7,750.00 |
| Costo totale 500 voli | € 6,600.00 | € 9,450.00 | € 19,375.00 |
| Risparmio per volo | € 25.55 | € 19.85 | € 0.00 |
| Risparmio per 100 voli | € 2,555.00 | € 1,985.00 | € 0.00 |
| Risparmio per 250 voli | € 5,110.00 | € 3,970.00 | € 0.00 |
| Risparmio per 500 voli | € 12,775.00 | € 9,925.00 | € 0.00 |

## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

### Hybrid-Electric or Full Electric feasibility study for SEAGULL A/C

- **Engineering Evaluation (preliminary)**

Results show that the **hybrid version** (35% of electric autonomy) with a small 10lt tank and with a weight slightly higher than the current one is **feasible and convenient** after a certain number of fights.

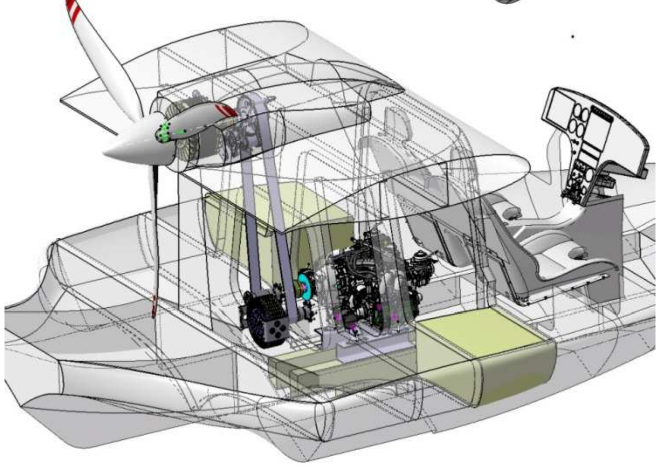
The **full electric** version **not ready yet**, because it implies an additional weight that is higher than 100 kg if compared to the current version. At the same time it gives a higher takeoff thrust from 1.3 times up to 2 times the one obtainable with a Rotax engine.

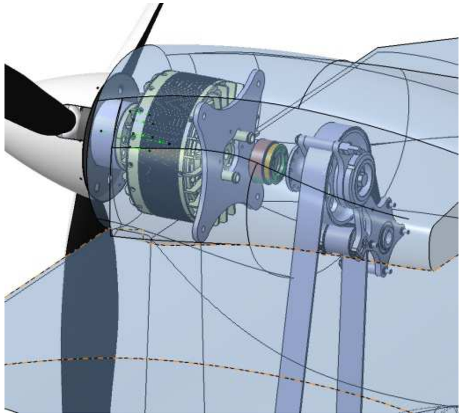
The **cost of the full electric** propulsion system is up to the 33% **higher** with respect to the hybrid electric version.

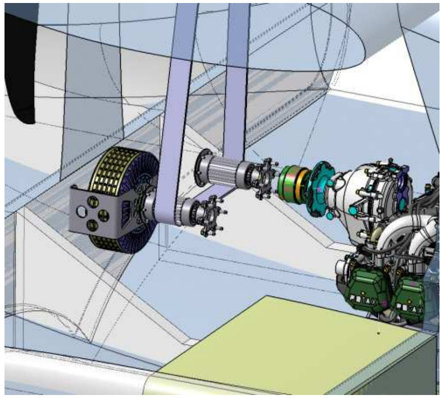
This **preliminary study** doesn't take into account consumptions (even if not significant) of electrical actuators for the movement of the control surfaces, potential optimisation that can be done in terms of performance of the propeller, weight of cooling systems, etc.

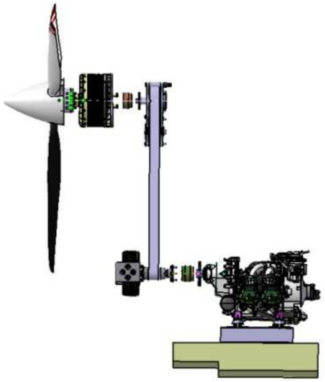
## *SEAGULL - The Marin-Air Vehicle for the Millennial Generation*

### Hybrid-Electric configuration development









# Thank you

## *for your attention*

***If You Want To Go Fast, Go Alone.***
***If You Want To Go Far, Go Together.***

Member of CISQ Federation
RINA
EN 9100
Certified Quality System