A Fuel Cell Propulsion System for a Mini - UAV

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Presentation Outline

- Introduction
- Mission specification
- Feasibility Study
- Preliminary Design (with AAA)
- Mini-UAV lay-out
- Conclusions

Introduction (1)

- Mini-UAV propulsion : various
- Acoustic & IR --- > batteries
- RMA study : a stack of fuel cells integrated in the Mini-UAV (1.5 m spanwidth)

Introduction (2)

Dragon Eye
Mini-UAV
(USA – US Navy)
2001

Our starting point : Dragon Eye (US)

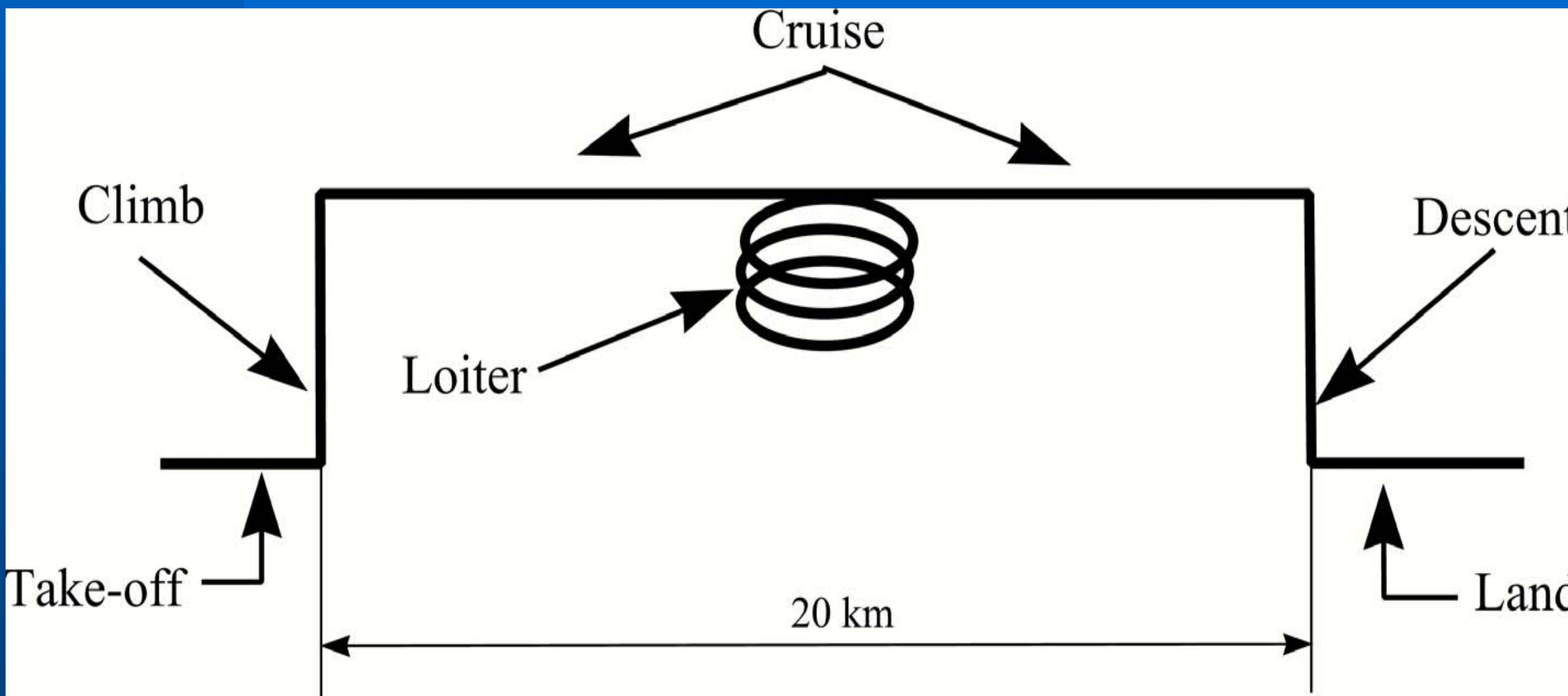
Characteristics :

- Span : 1,14 m
- Speed : 18 m/s
- Endurance : 45 - 60 min
- Electric propulsion with batteries
- Propulsion system mass : 1350 g
- MTOGW : 2150 g
- Payload : ?

Our mission specification

- Payload : 1.0 kg (cam, nav, coms, PS)
- Engines : brushless DC motor with PEMFC
- Performance :
  - Max cruise speed : 16 - 18 m/s
  - Endurance : 50 - 60 minutes
  - Range : ~ 10 km
  - Direct climb to 1.000 ft

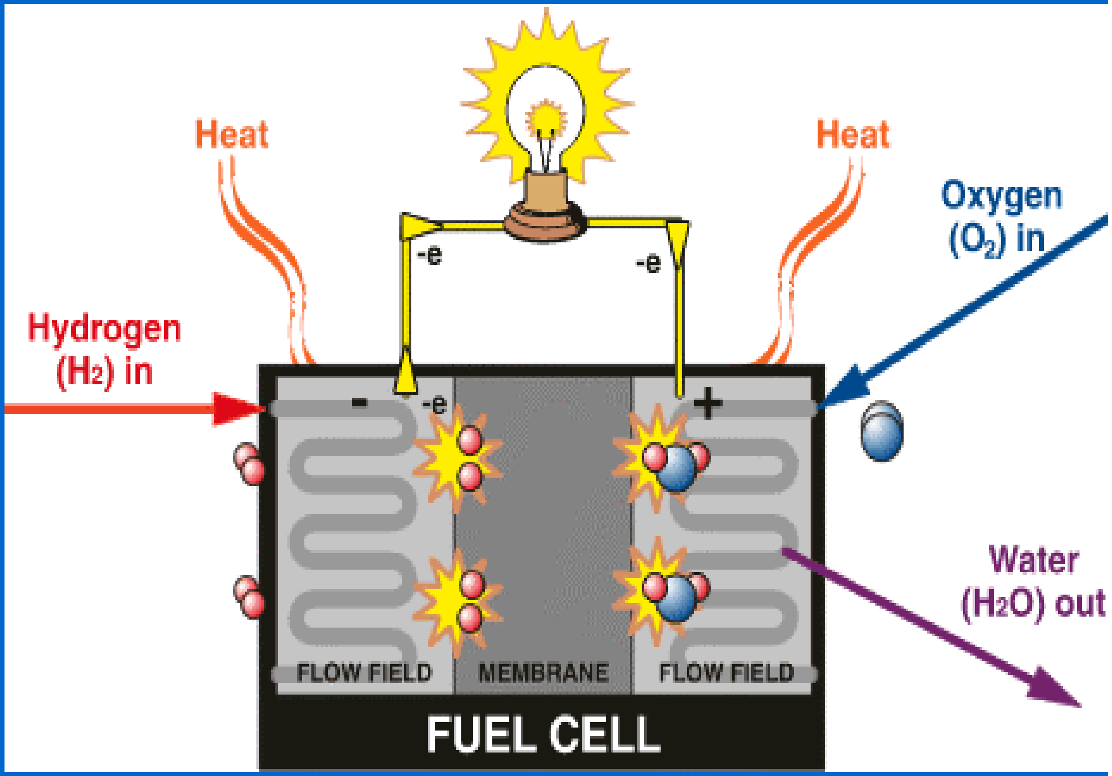
Over the hill mission



FC working principle

Main elements :

- electrodes (+ / -)
- electrolyte
- reactants
- products



Fuel Cells types

Types	SOFC Solide Oxyde Fuel Cell	MCFC Molten Carbonate Fuel Cell	PAFC Phosphoric Acide Fuel Cell	PEMFC Proton Exchange Membrane Fuel Cell	AFC Alcaline Fuel Cell	DMFC Direct Methanol Fuel Cell
Electrolyte	ZrO2/Y2O3	Li2(K2)CO3	H3PO4	membrane polymère	KOH	H2SO4
Température	800-1000°C	650°C	160-210°C	50-100°C	70-100°C	70°C
combustible possible	H2,CO	H2,CO,CH4,méthanol	H2,CO	H2	H2	méthanol

Ideal Selected configuration for tests

- PEMFC of 600 W

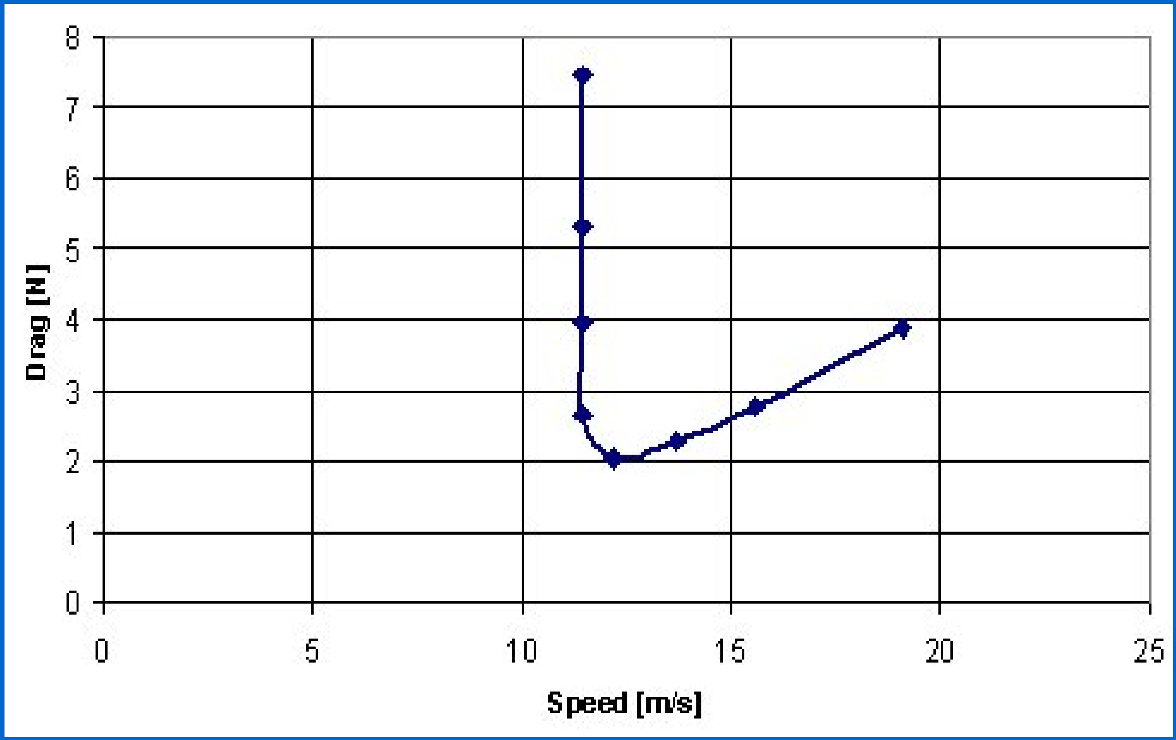
Why ? Major arguments :

- Range of powers & power density & performance
- Functionnal temperature & start-up characteristics
- Fuel used (compactness)

Feasibility Study (1)

a/c drag :

- RMA data
- FX05 profile
- Mass estimation
- Power derived
- Wing area
- Stall speed



Feasibility Study (2)

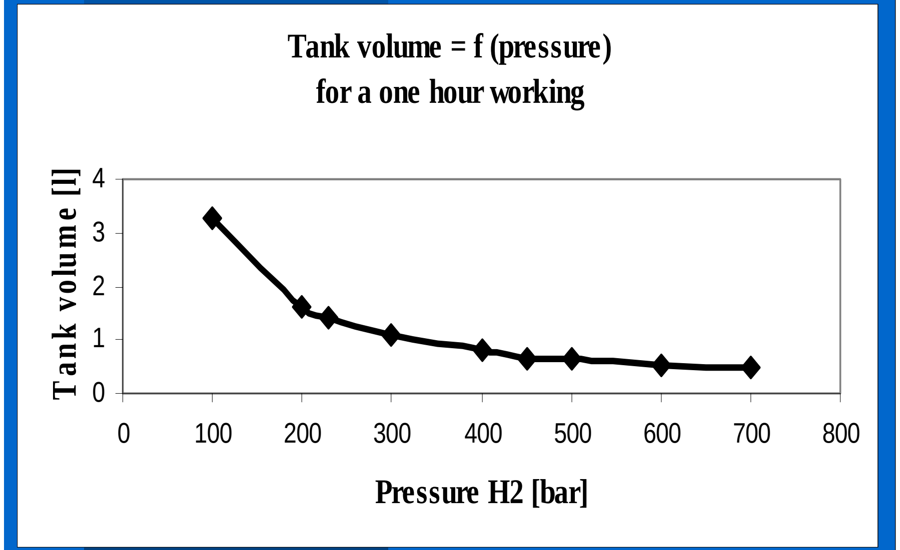
Dimensions of FC :

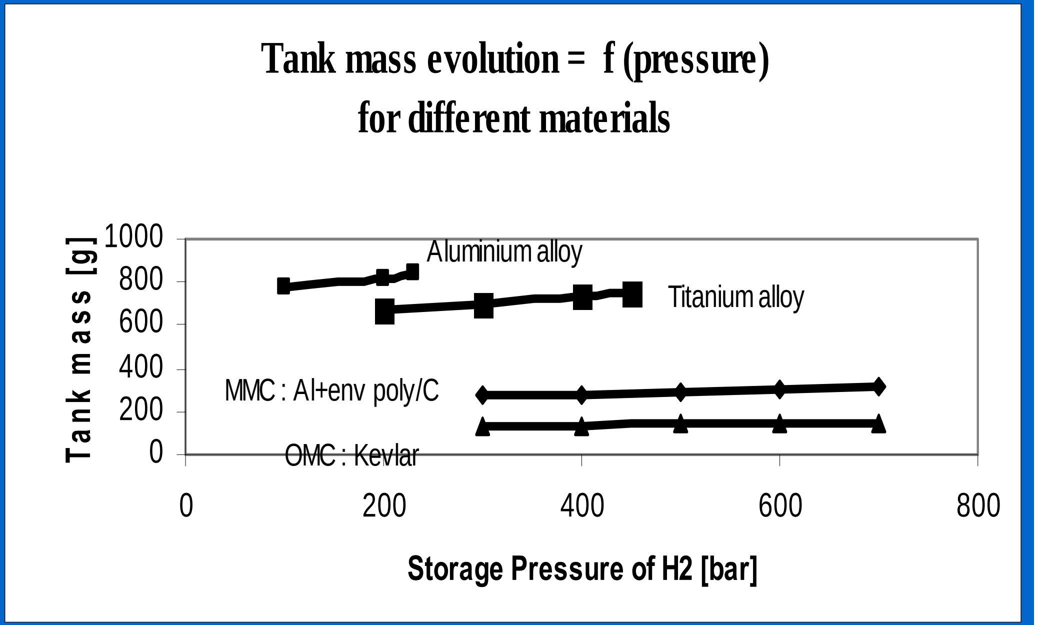
- D & V → required power ~ 400 W
- Power for utilities (10 W camera, 22 W for 24-12V and 13 W for 24-6 V DC-DC convertors) → 50 W
- 450 W PEMFC dim & mass estimation
- Motor voltage fixes the number of cells → length (30 cells x 3 mm + side plates) ~ 160 mm
- Power & Voltage → current (27 A)
- Current & density (.332 A/cm^2) → ϕ_i ~ 40 & ϕ_o ~ 110 mm
- H2 consumption determined ~ 23 g
- GH2 at 300 b → composite tank (60 x 230) ~ 260 g

Feasibility study (3) : Fuel Storage

LH_2 or $GH_2 \rightarrow GH_2$ MP (or other promising storage methods)

Tank size ?





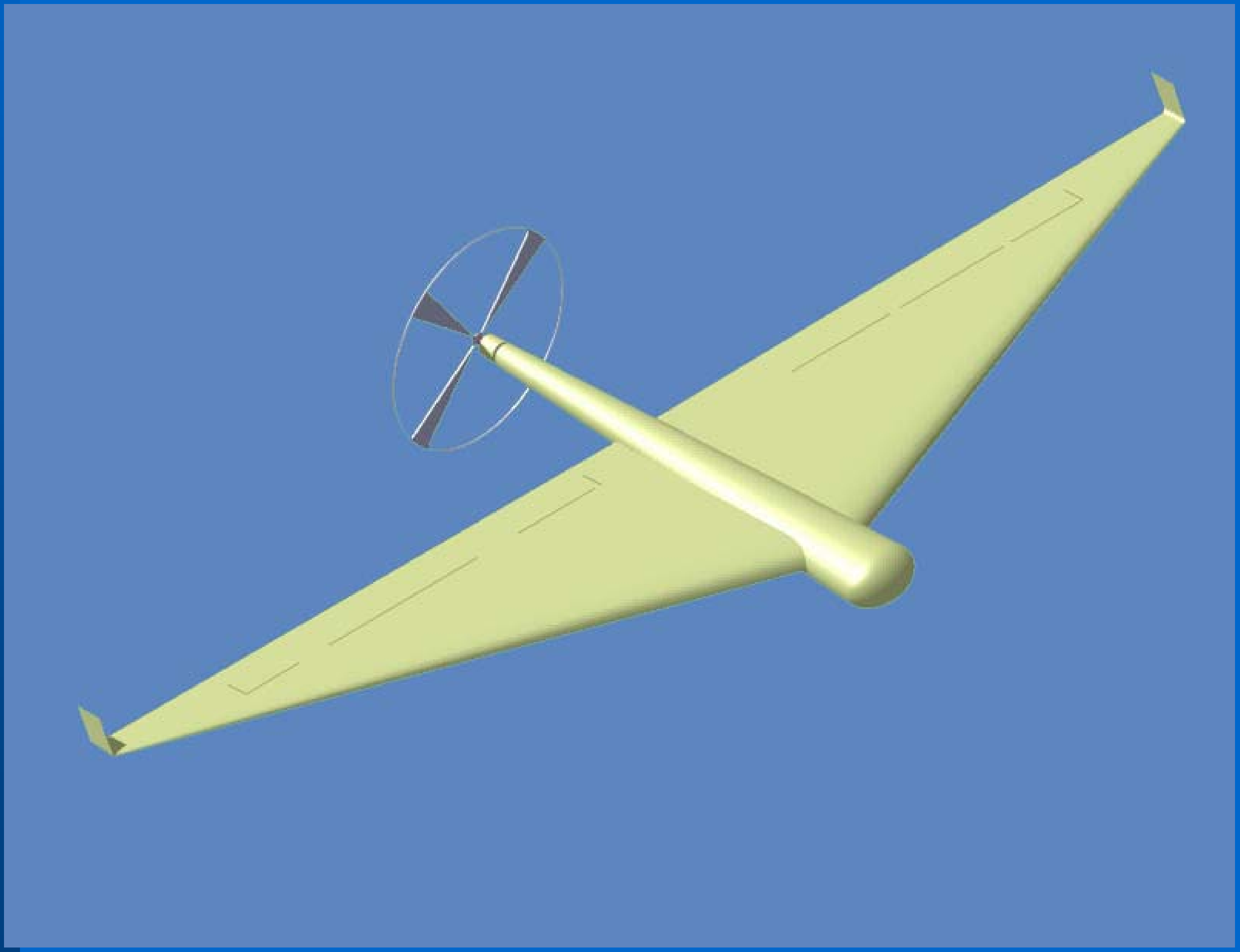
Feasibility Study (4)

Mass description :

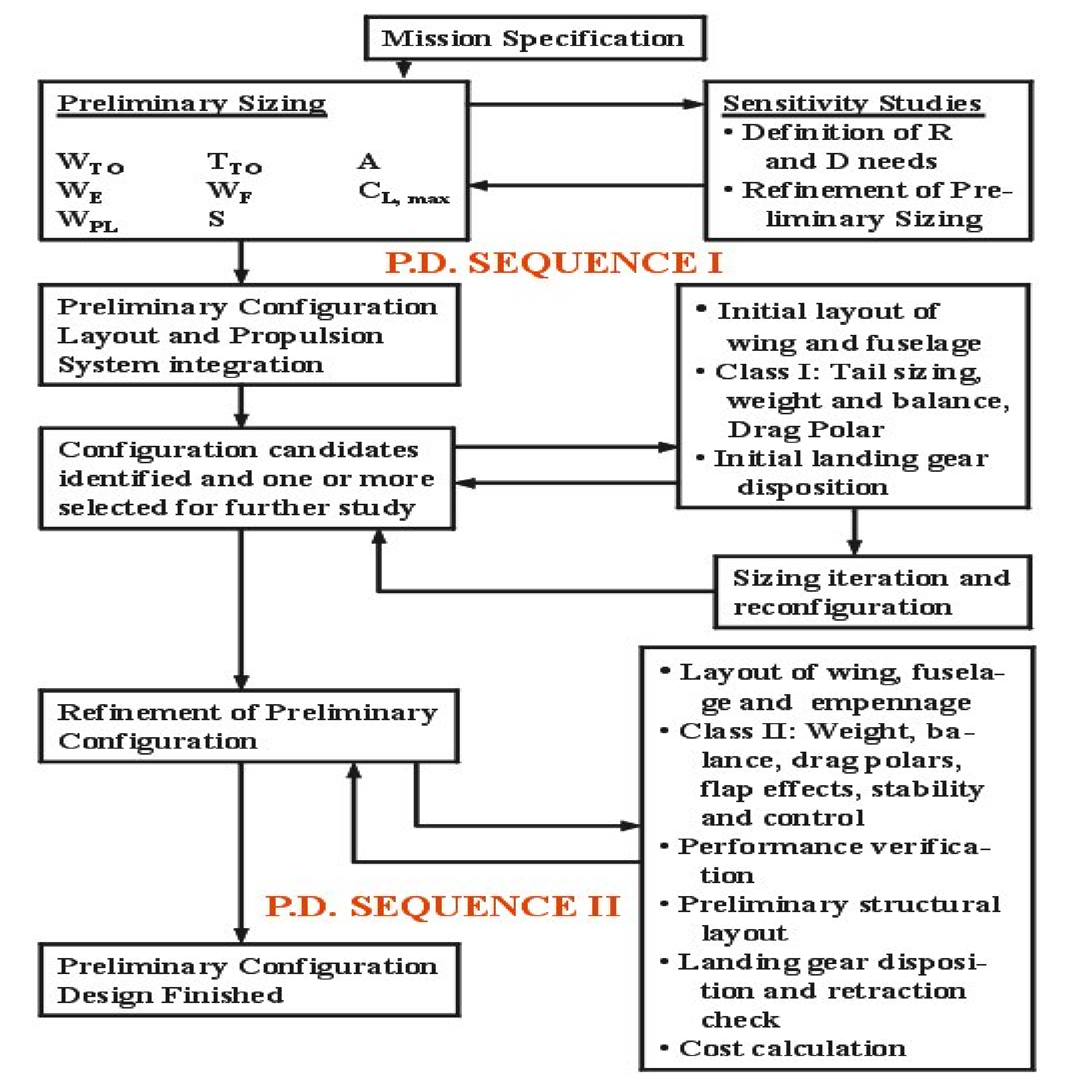
- Mass of PEMFC : 525 g
- Mass of H2-fuel : 25 g
- Mass of full fuel tank : 260 g
- Mass of complete prop syst : 2.160 g
- Mass of payload, fuselage, wings & acc : 950 g
- Total mass : 3,1 kg

Mini-UAV

Configuration : Flying Wing + winglets



Preliminary study (1): iterations !



Preliminary Design (2)

Estimation of TOGW, OEW & MFW (generals of the iterative method) :

- TOGW = OEW + FW + Pay
- OEW = WE + TfoW + Crew
- Correlation : log TOGW = A + B log WE
- If A & B known → determine mission fuel fractions (Mff) & iterate
- With also : FW = (1 - Mff) (1 + Mf,res) TOGW
- Mff ??? A & B ???

Preliminary Design (3)

Determination of Mff :

- Fuel fraction method for Mff (x of the Mffi)
- Fuel unintensive segments (statistical data)
- Fuel intensive segments (Breguet eq. for R & E)
- FC → Breguet eq N/A → hand calculation
- Mff= 0.9919

Preliminary Design (4)

Determination of A & B :

- Correlation : log TOGW = A + B log WE
- Problem : statistics N/A to UAV (mini !!)
- Own data base with electrical UAV & mini
- Small error for our PEMFC but PD 1
- A = 0.1937 & B = 1.0094

Preliminary Design (5)

Results :

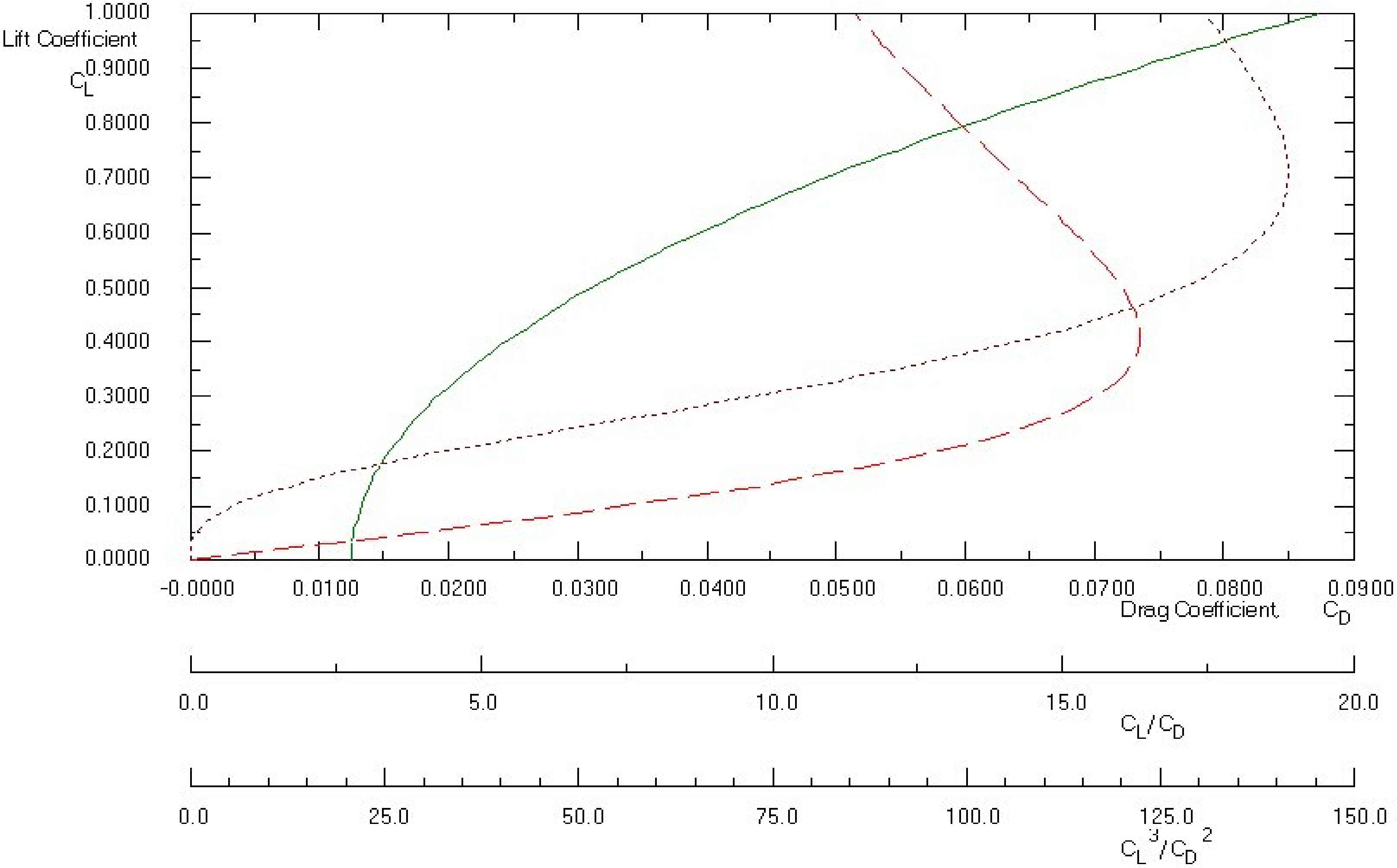
- TOGW = 3.97 kg
- WE = 2.92 kg
- FW = 32 g
- Compared with 3.1 kg, 2.1 kg and 23 g

Preliminary Design (6)

Estimation of the drag polar :

- $CD = Cdo + \Delta Cdo + CL^2/(AR\ e\ \pi)$
- $Cdo = f / Sw$ (parasite area (f) method)
- Rationals : log Swet = c + d log TOGW or log f = a + b log Swet (a, b, c & d based on Cf)
- AGAIN PROBLEM (due to FW configuration)
- Other method : for FW, Swet/Sw ~ 2.1 (with SM)
- FW data → AR = 5 & e = 0.85
- Try various Sw → Sw = 0.45 m^2 → CD
- $CD = 0.0125 + 0 + 0.0749\ CL^2$

Preliminary Design (7)

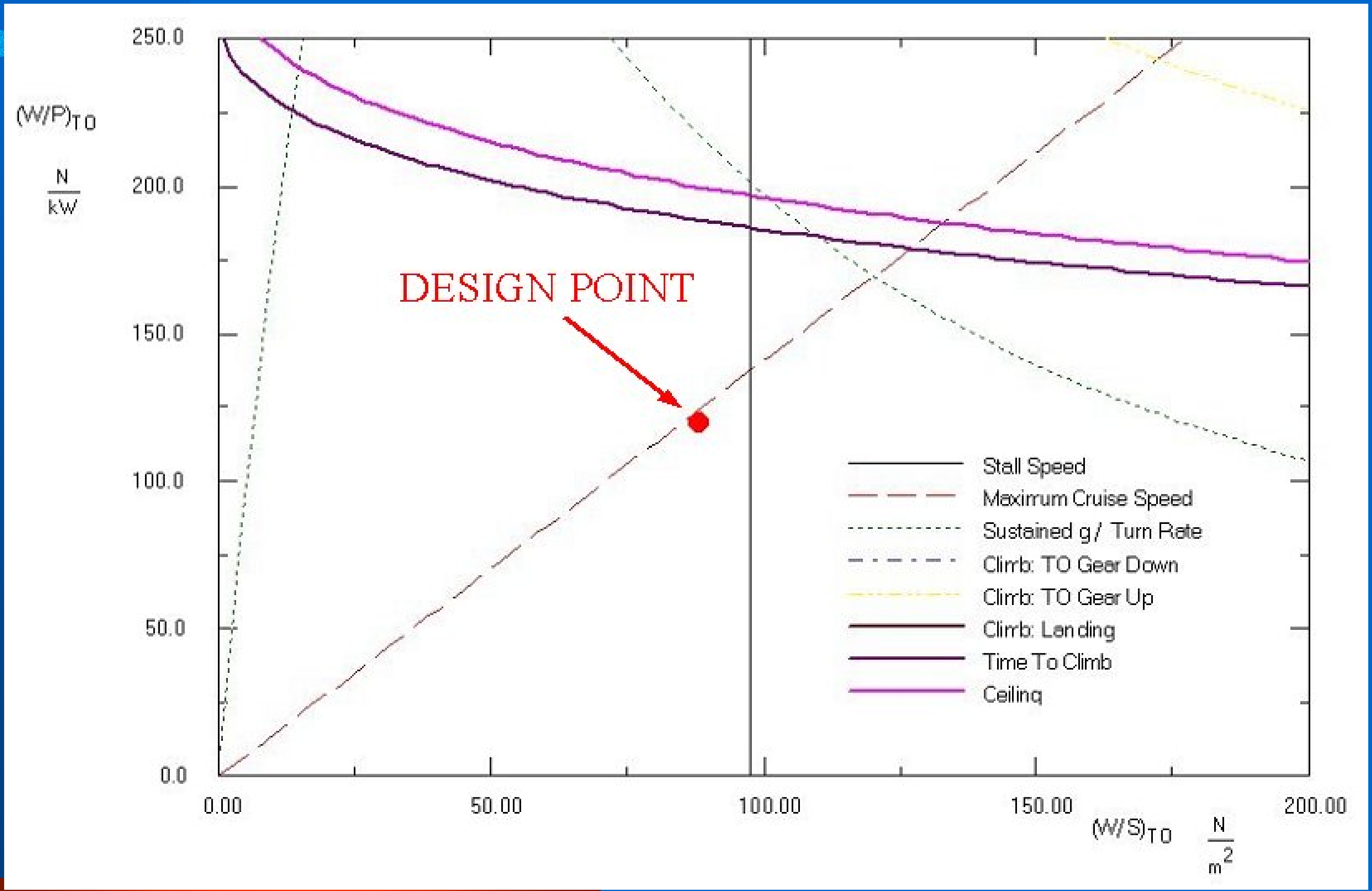


Preliminary Design (8)

Performance sizing :

- Restrictions on W/S at TO & W/P at TO
- Catapult launch & ventral or “net” ldg
- Vs in cruise & MTOGW : 12.1 m/s
- Climb : grad (Mil Specs) & Tclb of 2’
- Max cruise speed at MTOGW
- Maneuvering distance : nmax = 2.0 at MTOGW

Preliminary Design (9)



Preliminary Design (10)

Performance sizing :

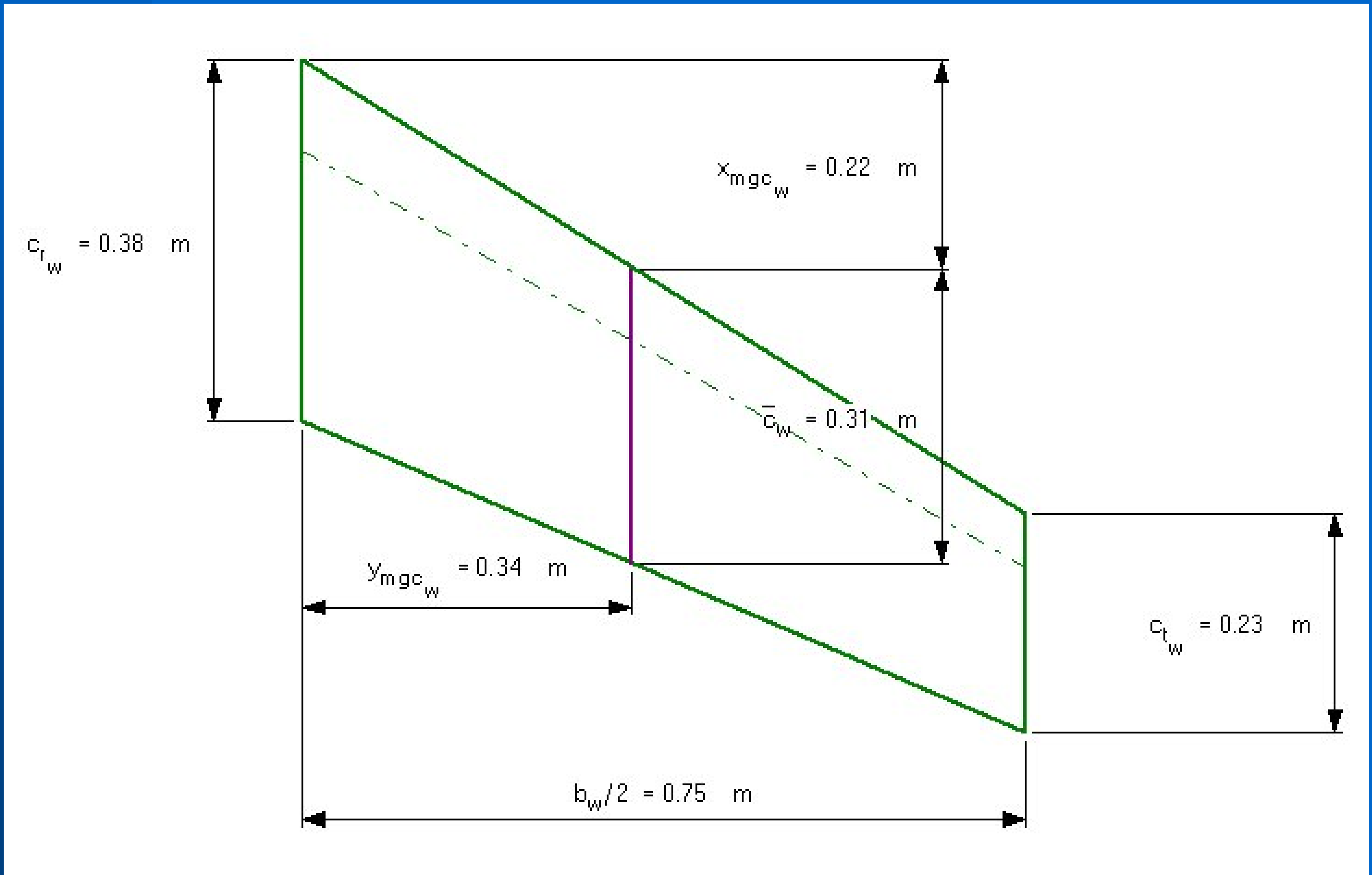
- Try different Sw in order to increase performance and minimize engine
- Final results : (W/S)TO = 86 N/m² & (W/P)TO = 120 N/kW
- Power of the PEMFC = 325 W + 50 for acc
- We had selected one of 450 W → SF = 1.2

Selection of the wing (1)

Wing profile :

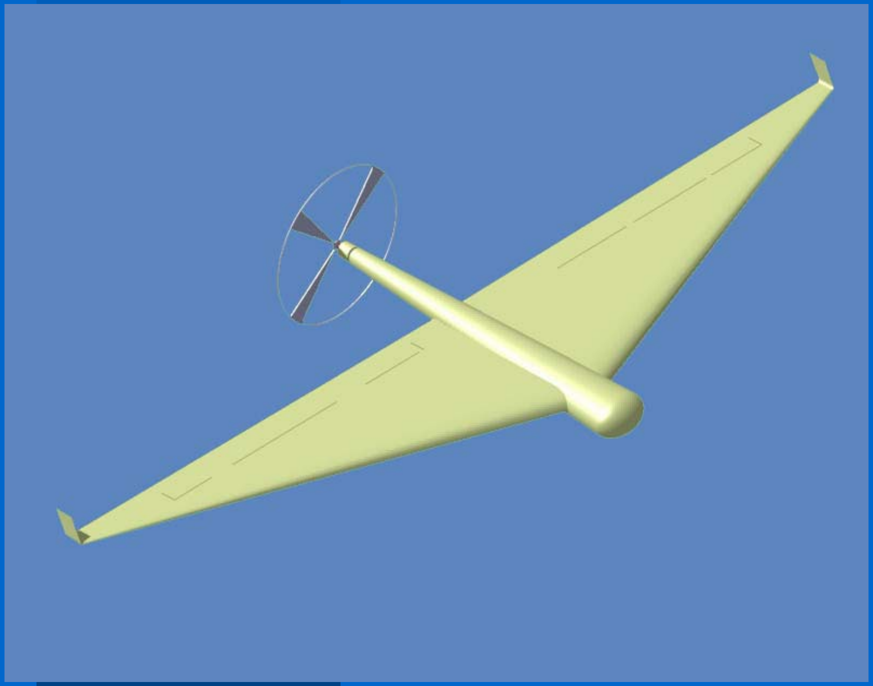
- Need of a fuselage (integrated in the planform)
- Clmax in accordance with sizing requirements
- Clmax ~ 1
- High taper ratio in order to decrease trim drag but “neglectible” here
- ¼ chord sweep (stability with 2-cambered profile)
- Eppler 325, AR = 0.6, Λ = 30° (Clmax = 0.96)

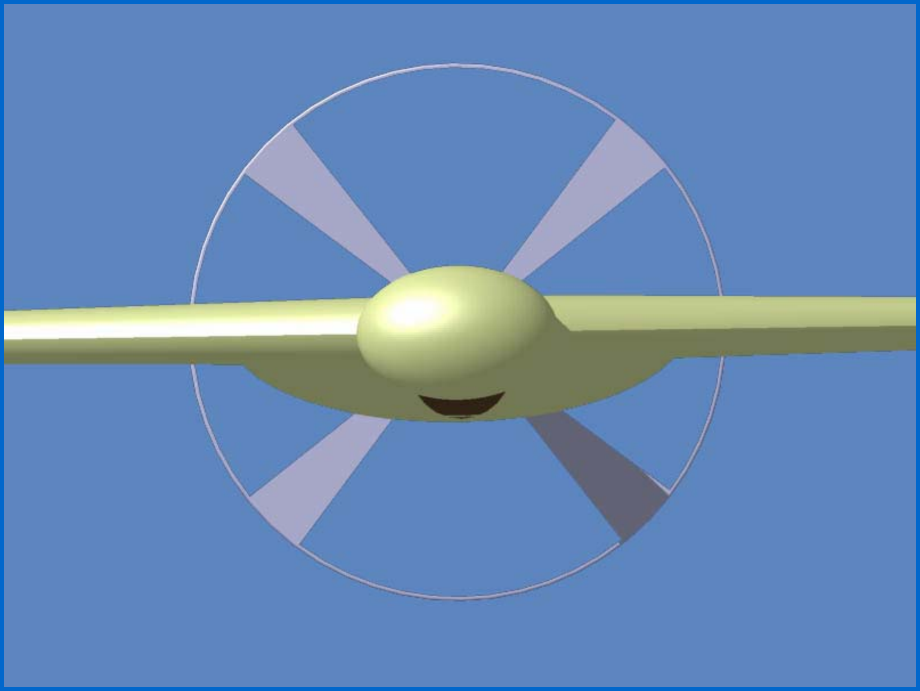
Selection of the wing (2)



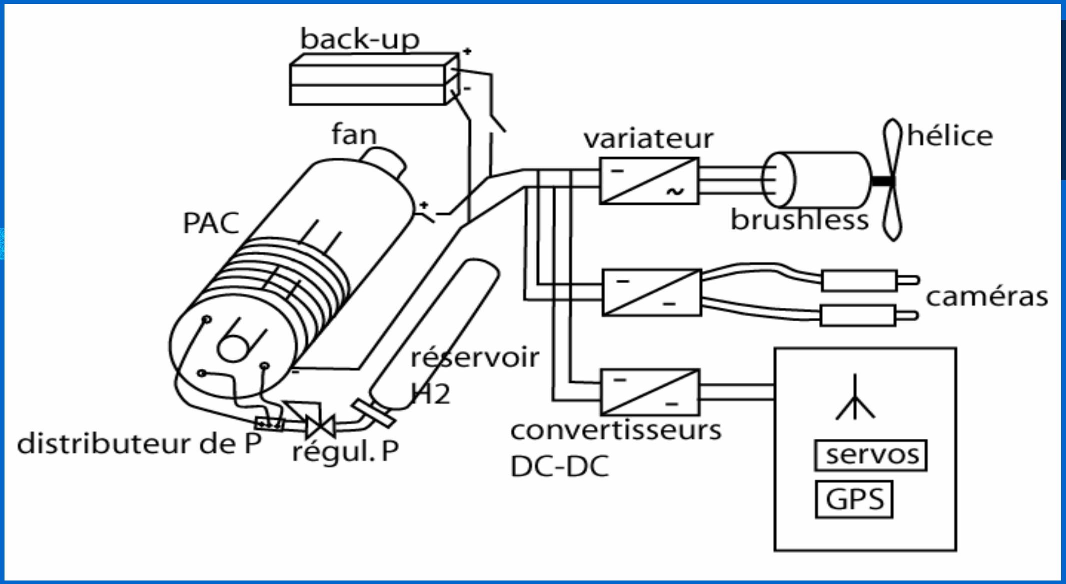
Mini-UAV

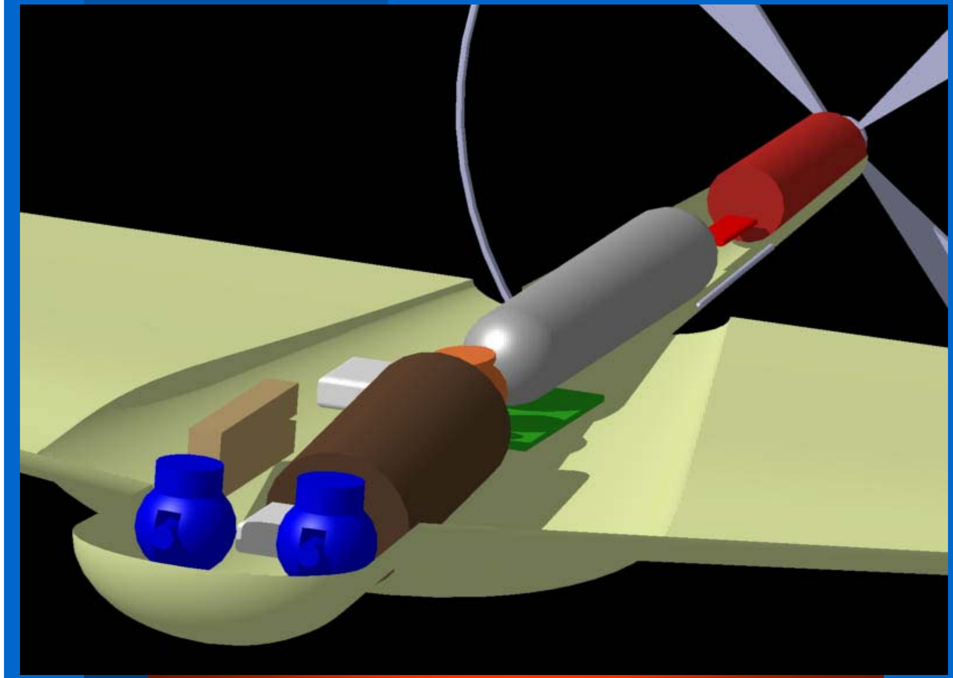
Configuration : flying wing with winglets

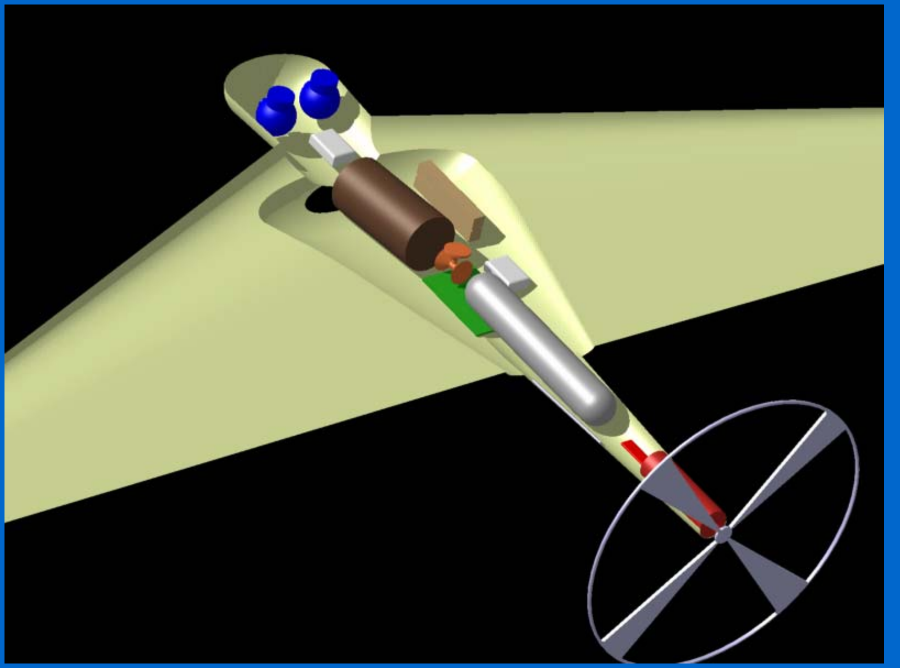




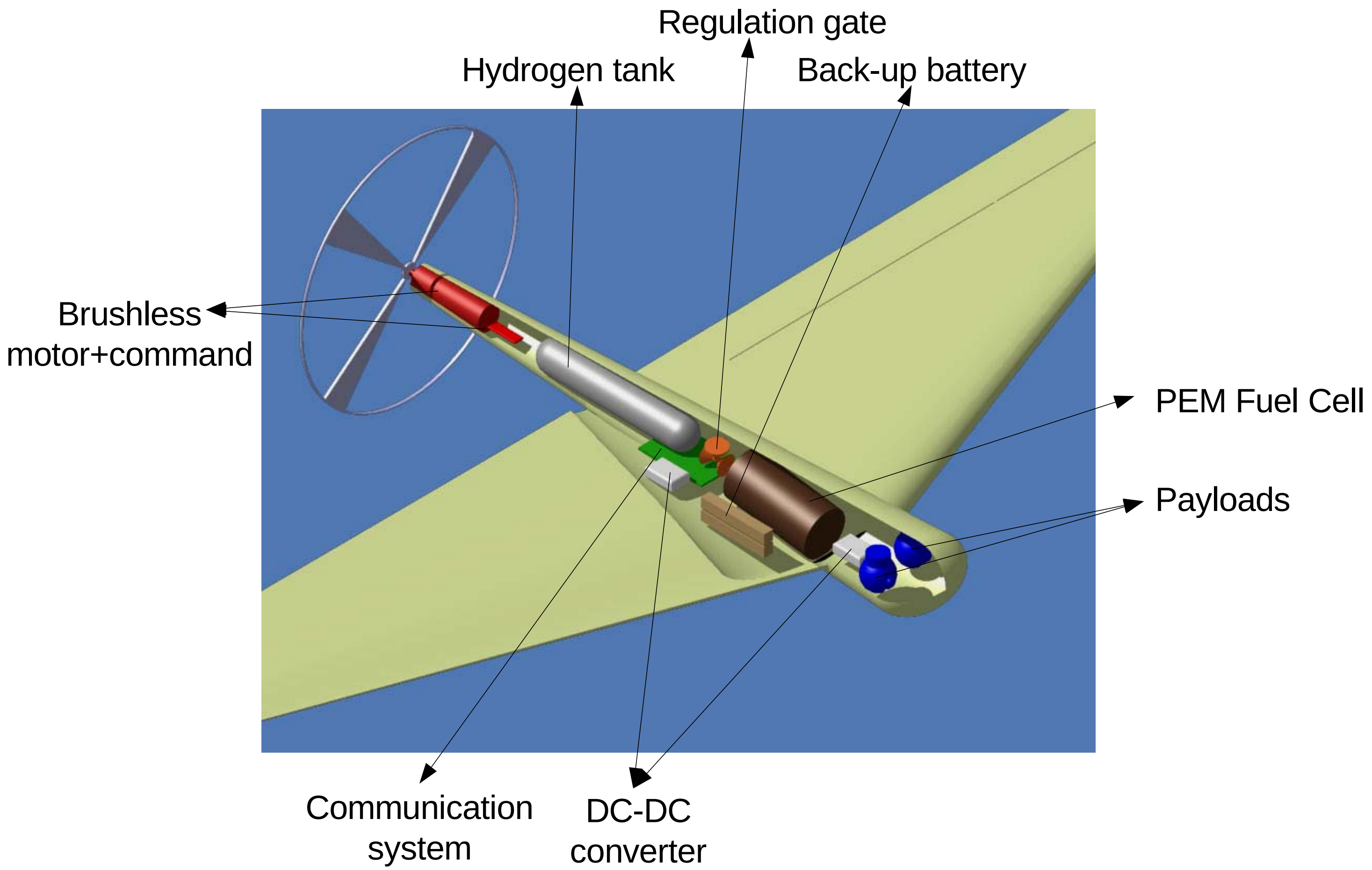
Internal Elements : energy distribution





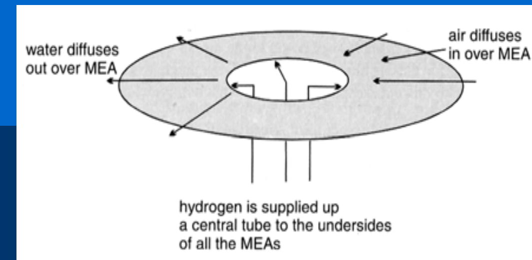


Internal architecture



PEMFC stack by Novars GmbH

- PEMFC of 600W
- Vc = 0,6V , Vtot = 24V (40 cells)
- mass = 780g
- ∅ = 110mm
- L = 200mm ↓



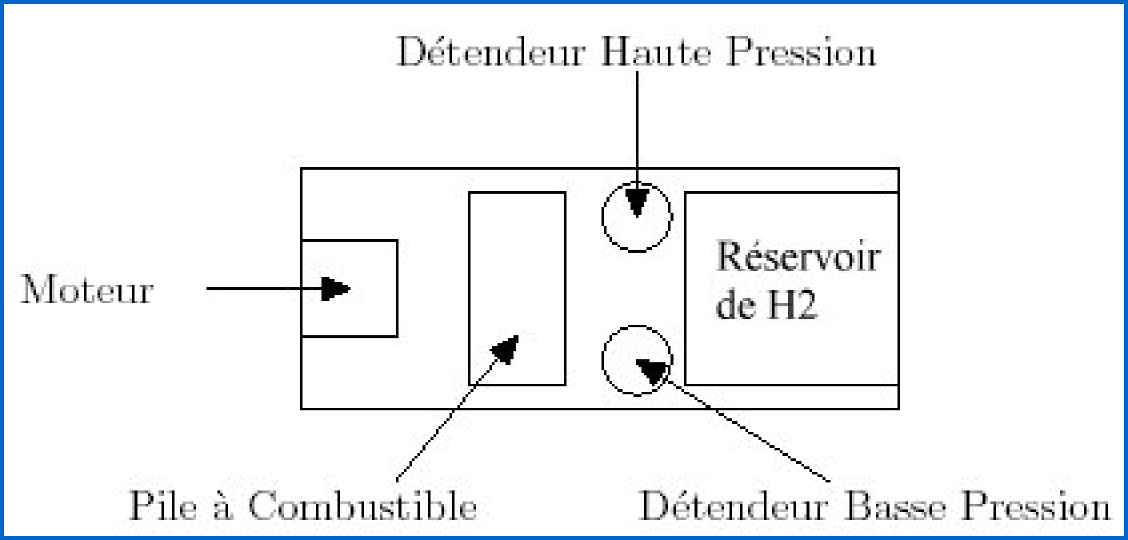
Special architecture

Complete system :
220 Wh/kg energy density
2,27 kg mass system

Longitudinal Stability

StM :

- 4.8 cm
- 16.4 %

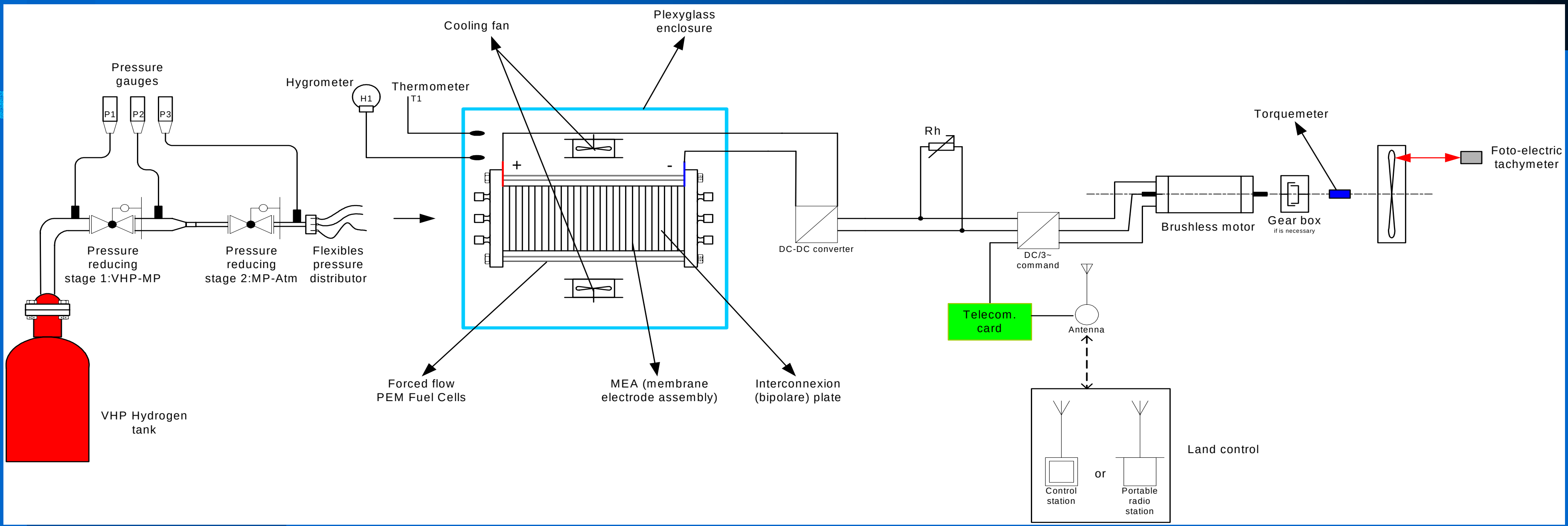


Comparison with the Dragon Eye

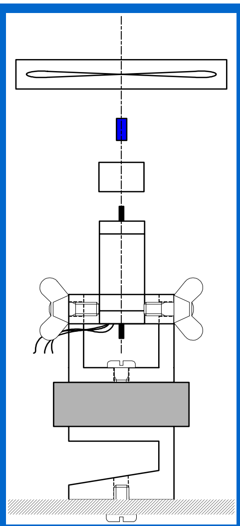
	Dragon Eye	MAV PAC
Wingspan [m]	1,14	1,5
Speed [m/s]	18	18 max
Range [min]	60	60
Masses [g]		
Propulsion System	1350	2620
Complete Aircraft	2150	3950
Power [W]	300	450

The test bed at RMA

- **Schematic**



Thrust measurement system



Our Fuel Cell

<u>**Technical datas**</u>

PEMFC stack of 500 We

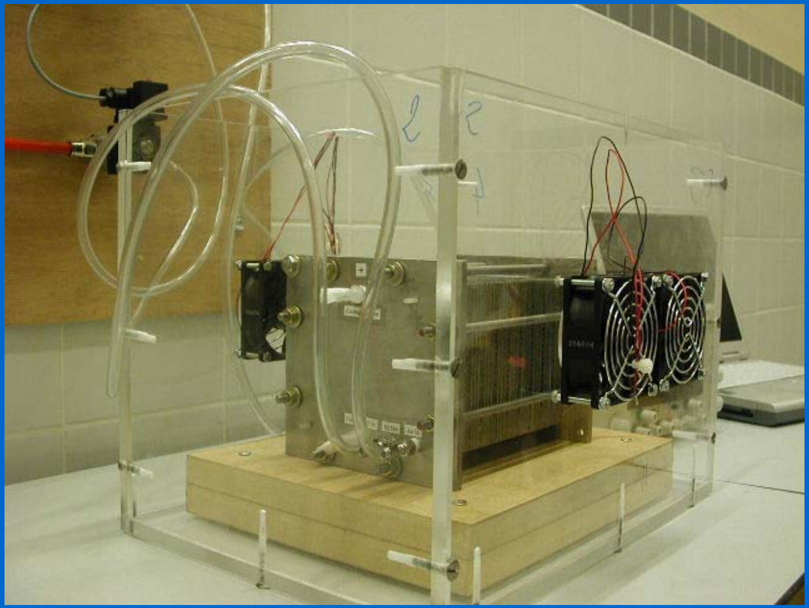
32 cells and Vc=0.625V so Vtot=20 V

A current of 25A is available

The mass is about 6kg (power density 3 x lower)

Cooling system:

- **<200We forced air by 4 fans**
- **>200We forced air+distilled water system**



Conclusions (1)

- 1st : Basic calculations in order to check the feasibility
- Compatible PEMFC are available ($!!)
- 2nd : More detailed calculations (AAA)
- Planform determined & stability possible
- Test Bench : Acquire knowledge about small PEMFC in practice

Conclusions (2)

- **Improve current systems (fueling,storage,etc.) & control the required mass & volume of the whole propulsion system**
- **Miniaturise the complete propulsion system in a future exercice**
- **Increase the power density of complete FC propulsion system**
- **Future : other FC options**
- **Thanks to a few students from Fr & NI**

Questions ?