HALE UAV PLATFORM OPTIMISED FOR A SPECIALIZED 20-KM ALTITUDE PATROL MISSION

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Abstract

This paper reviews a number of different configurations developed under the umbrella of CAPECON project of 5th Framework Program of the European Union. One of the main goals of the project is to propose a platform, being able to carry on a 500 kg payload of sensors (SATCOM, FLIR, SAR, etc.), operating efficiently and safety at almost 20 km altitude on long endurance missions at the lowest possible cost. Among the requirements there is the necessity to operate at a constant flight speed, to have an unrestricted field of view & sufficiently large volume for sensor's and electronics bays. Comparison between various platforms is included and general conclusions and recommendations are presented.

1. Introduction

This paper presents two projects developed in parallel in ONERA & WUT, which initially differed a lot. Designed from the same set of requirements, the first ONERA configuration was a pure Blended Wing concept whereas the first WUT concept was a CANARD configuration. The paper is focused on different aspects of both projects and shows their evolution during the design process, leading to the proposal of a joint configuration including most of the best features of both configurations. Many different aspects of the two projects are considered and discussed, including general overview of the platform, aerodynamic flight control & stability issues, structure, load & stress analysis, performance, materials, cost & other factors related to the mission fulfillment. Pro & cons of both projects are considered and discussed in detail. Most of the conclusion topics are universal & may be applied to any design UAV process.

CAPECON Project

The CAPECON project (Civil UAV Applications & Economic Effectivity of Potential CONfigurations solutions), done under the hospice of the 5th Framework Program of the European Union, proposes to identify all the potential operational civilian applications of UAVs and to design suited configurations of such systems.

The overall methodology must identify the needs for further technologies, able to design and size systems fulfilling operational requirements and affordable for future customers.

As for all of the 8 concepts initially planned to be defined in the CAPECON project (3 MALE, 3 HALE and 2 rotary vehicles), the design process performed for HALE UAV study has been done in two iterations, the first one proposing a first concept roughly assessed and then refined in the second iteration.

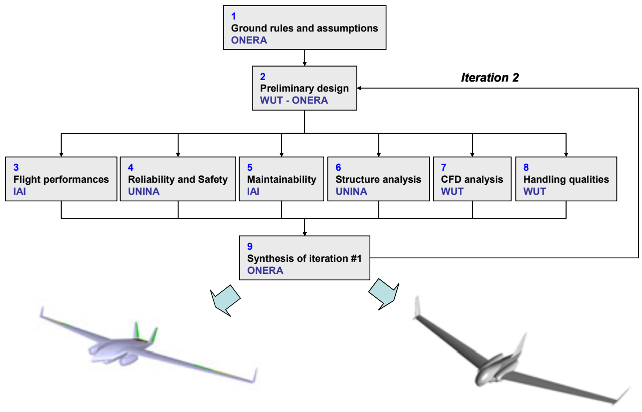

Fig. 1 – Design process

Several others partners have been involved in this two cycle preliminary design process, as mentioned in Fig. 1: IAI (Israël Aircraft Industry) has been in charge of the performance analysis and UNINA (University of Naples - Italy) has done both the structural analysis (FEM analysis) and the reliability and safety assessment. Nevertheless, ONERA (task leader) and WUT were the two main partners of this design process which concluded on the proposal of two different concepts fulfilling the same set of requirements.

In addition, the preliminary design (sub task 2 in Fig. 1) included: sizing, geometrical definition, external layout, structure concept, systems definition, payload integration, internal layout, weight and balance computation.

Requirements consisted in the definition of the nominal operational mission, detailed in term of flight profile (typical egress/ingress bound of 1000 km with 24 h in loiter at 60000 ft, use of conventional runway) and payload equipment (weight, volume, main constraints such as angle of view, electric consumption), typically a SAR radar and an EO/IR sensors.

2. ONERA configuration

Design process description

The perception of what can be the functional and material architectures of Unmanned Aerial Vehicle systems is particularly difficult as the field of functions that such systems can perform is wide and possible technical solutions to design them are diversified. This vast spectrum of choices is particularly noticeable for the air vehicle configuration, for the technologies of the sub-systems, for the concepts of use of the complete system and for the constraints to be taken into account to design it. These constraints extend from technical fields such as technology maturity, to economical fields such as cost or multinational co-operation opportunities.

Regarding this complex system design problem, ONERA started in 1998 a Research Project called HALERTE. Its aim is to help designers in defining a HALE (High altitude Long Endurance) UAV which fulfils operational requirements. It concludes in an advanced research tool modeling a HALE UAV conceptual design approach by formalizing a method of analysis and evaluation of systems.

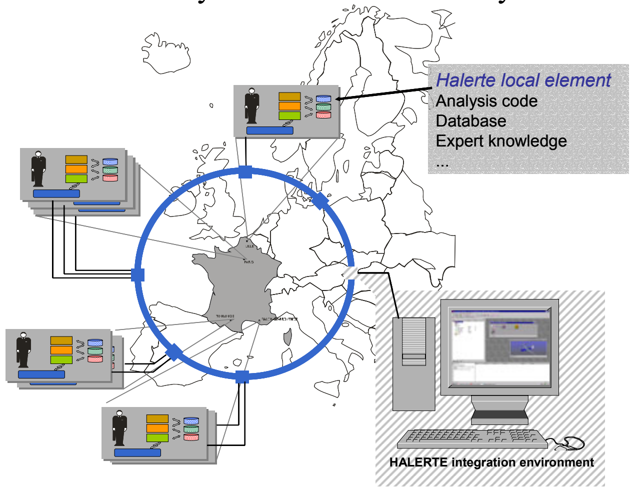

Fig. 2 - ONERA Halerte project collaborative design process

This multidisciplinary engineering methodology for HALE UAV system conceptual design, mainly the core part of the tool implemented, has been used to design the CAPECON project described in this proceeding. The figure 2 shows the block diagram of the process and a view of the integration framework (ModelCenter ® from Phoenix integration) used for this collaborative design process.

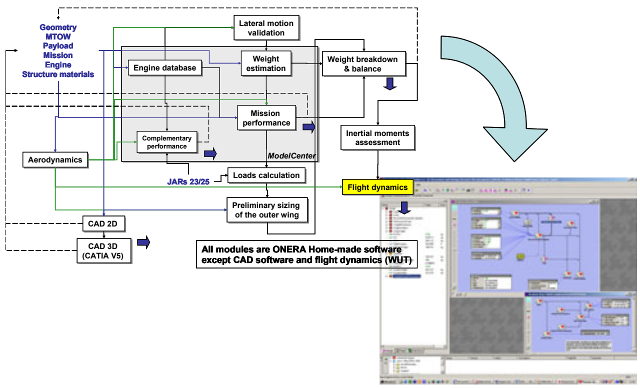

Fig. 3 – Views of the ONERA design process

The following disciplines and topics are integrated into the design process:

- Aerodynamics (a medium-level tools has been used for the airfoils and planform design at loiter flight conditions)
- Weight estimation (semi empirical methods)

- Engine performance estimation (ONERA internal database updated with data provided by the CAPECON partners)
- Loads estimation which are provided by the application of the closest FAR/JAR regulations.
- Flight performance assessment including take off and landing distance, rate of climb at sea level and also mission performance
- Balance estimation for longitudinal trimming
- Inertia moment estimation
- Stability and Flight dynamics (external home-made code from the Warsaw University)
- Primary structure sizing
- Landing gear preliminary sizing
- CAD design at two levels: 2D drawings for geometric analysis and 3D drawings (CATIA V5) to illustrate the concepts designed and also for verifying mainly payload and flight systems arrangement.

Configurations description

Due to the choice of the blended wing configuration, assumed to be close to the "flying wing" kind of vehicle, the design process has been centered on the aerodynamics of such a vehicle. Indeed, as aerodynamics is obviously one of the main disciplines conditioning the performance of the vehicle for a HALE UAV, the additional complexity due to the flying wing kind of configuration interacts mainly on aerodynamic features, essentially in the choice of airfoils, wing planform and twist distribution.
The main assumptions used for the initial selection of the configuration consisted of:

- The twin engines configuration which increases the reliability of the vehicle, aspect also kept in mind by designers for control surfaces and flight systems design and sizing,
- The engine location in nacelle to maximize accessibility for maintenance operations,
- The payload requirements and constraints leading to a volume and a location.

The chosen configuration for both ONERA concepts is a **flying wing without horizontal tail**. The central part of the wing is used mainly to carry equipment such as payloads, data link devices and other avionics systems. Engines are mounted in nacelles located under the outer wings for weight balance, maintenance aspects and aerodynamic efficiency. Two vertical tails (or fin) are used to improve the lateral stability and the yaw control in case of one engine failure. Landing gear is conventional, with additional wheels inserted in downward winglets to improve roll stability on ground after landing. Removable landing gear could be used for take-off.
The first ONERA configuration (OBW-01) has an overall span of 34.5 m for an overall length of 7.8 m. It weights 7 tons for a payload capacity of 700 kg and is powered by two Pratt & Withney PW 535 turbofan engines.

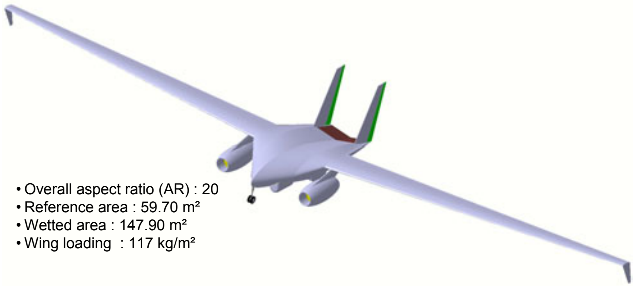

Fig. 4 – View of the first ONERA configuration

This vehicle appeared to be oversized and its main drawback remained mainly in its poor longitudinal stability. Therefore, it presented a great potential in term of performance improvement. It has been decided to modify both the main equipment arrangement and the aerodynamic shape to get the performance level of a lighter and smaller configuration.
A parametric study has been performed in order to determine the new aerodynamic shape, as shown in the Fig. 5.

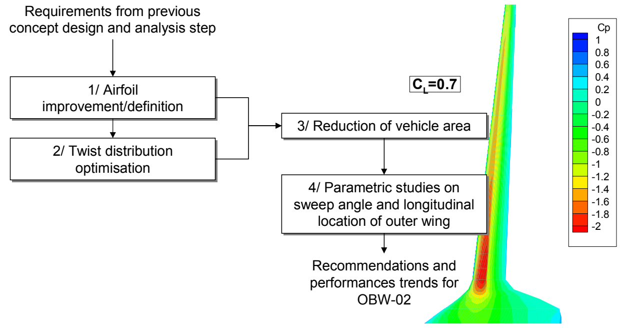

Fig. 5 – Parametric study for aerodynamic shape improvement (use of a home-made code solving the potential equation coupled with a boundary layer computation)

It concludes on the definition of original airfoils (Fig. 6) combined with an improved planform and an optimised twist distribution.

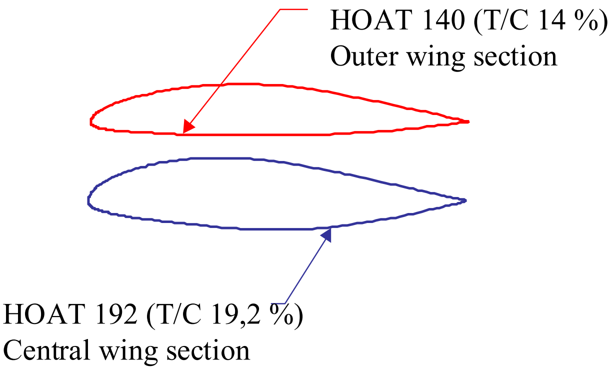

Fig. 6 – Specific airfoils of the OBW-02 concept

This led to a lighter vehicle (OBW-02) with a MTOW of 5.4 tons and powered by the two certified for High altitude flight Rolls-Royce Williams FJ 44-2E. The overall configuration remains similar with several minor shape modifications. Its overall span is now 30.5 m with a reduced Aspect ratio of 18 (for 20 on OBW-01) which contributes to structure weight savings (sized according to CS/FAR 23 regulations). The fuel consumption on the nominal mission used for the sizing decreases from about 3600 kg to 2700 kg of Jet A1. The maximum aerodynamic efficiency reaches 32 (from 27 for the OBW-01) while the vehicle has a permanent positive static margin and presents rather good dynamic behaviour in open loop, which could lead to the use of rather robust but simple and reliable flight control laws.

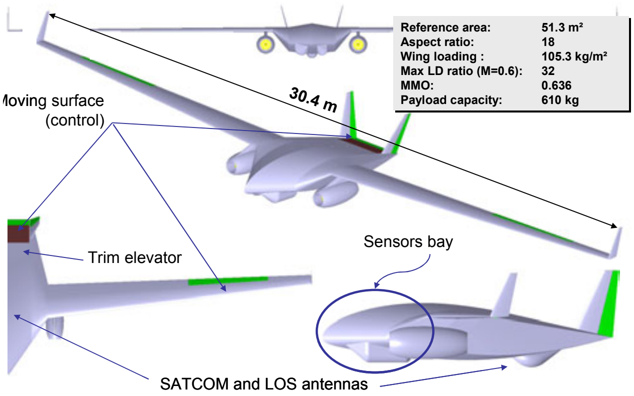

Fig. 7 – OBW-02 concept overview

The following figure gives a comparative view of the wing planform showing the main differences between the two concepts.

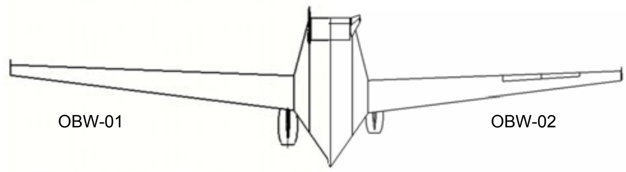

Fig. 8 – Plan forms of the two concepts

The internal arrangement of the main equipment carried by the OBW-02 is shown in Fig. 9. The fuel tanks maximum capacity is 2 800 kg. To improve the shape of the upper surface of the airframe central section a phase array antenna has been selected for the SATCOM antenna. The main payload parts (SAR and IR/EO sensors) are obviously located under wing in the front of the central section.

Parameters	**OBW-01**	**OBW-02**
MTOW	7000 kg	5400 kg
Wing loading	117 kg/m²	105.22 kg/m²
Max LD ratio	27	32
AR	20	18
MMO	0.6	0.636
Initial Climb altitude	50 000 ft	55 000 ft
Absolute ceiling	63 000 ft	63 400 ft
Fuel (nominal mission)	3640 kg	2628 kg
Take off thrust (SLS)	28.5 kN	24.3 kN
Thrust loading	246	222
Payload/wing area	13	12
Payload/take off thrust	27	25

Table 1 – Characteristics of the two successive concepts

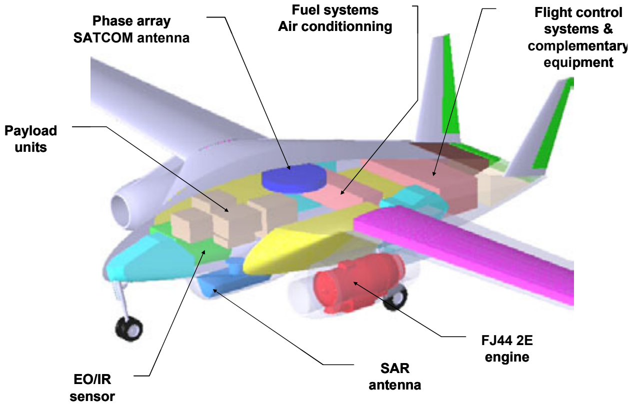

Fig. 9 – Internal view of the OBW-02 concept

3. WUT configuration

General overview

PW-114 aircraft of HALE class was designed by Warsaw University of Technology Team headed by Prof. Zdobyslaw Goraj within the frame of CAPECON project sponsored by European Union under V Framework. PW-114 version was preceded by former versions – PW-111, PW-112 and PW-113 aircraft. The analysis of the PW-111 concept led to a list of main drawbacks which had to be corrected in order to improve the concept. PW-111 was CANARD, naturally unstable configuration. HALE PW-112 received a modified, higher aspect ratio canard. Moreover fuselage and engine nacelle geometry was modified. Lower front fuselage section had to be enlarged because front leg of landing gear was moved forward to the fuselage nose. Previously, front landing gear leg had been located behind EO/IR sensor. Nacelles had to be enlarged after final engine selection. Nevertheless, the configuration was still unstable. Canard was abandoned in the HALE PW-113 configuration. Instead, new, larger outer wing was designed with smaller taper ratio. New configuration analysis revealed satisfactory longitudinal stability. Unfortunately transverse stability appeared not to be satisfactory. Vertical stabilizer with rudder was located at the top of the fuselage. Calculations suggested better qualities for negative dihedral. As a result the PW-114 configuration with negative wing dihedral was endowed with a modified fin in the rear fuselage section together with wingtips to provide sufficient directional stability.

Tailless architecture was based on both the Horten and the Northrop design experience. Global Hawk was considered as a reference point - it was assumed that BW design has to possess efficiency, relative payload (Payload over the total weight) and other characteristics at least the same or even better than that of Global Hawk. FLIR, SAR & SATCOM containers were optimised for best visibility. No one element of aircraft structure limits the sensor's visibility

All payload systems are put into separate modular containers of easy access and quick to exchange, so this architecture can be consider as a "modular".

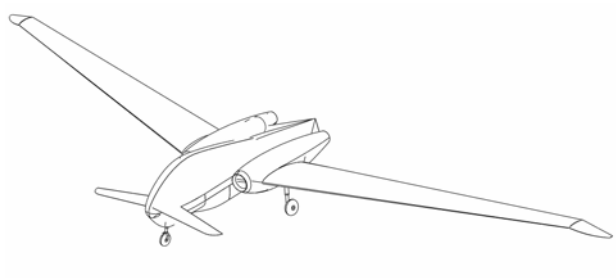

Fig. 10 - HALE PW-111

PW-111 UAV was designed as a canard configuration. Vertical stabilizer was located under rear part of the centre-wing. This configuration provided high manoeuvrability. However it had to be redesigned because of too large loading over the canard and longitudinal instability. Fig.2 shows that independently on the canard area S_C and its lift curve-slope a_C the natural longitudinal stability can be attained when the dimensionless arm L_H/c_a is negative, i.e. when the canard is replaced with a classical tailplane.

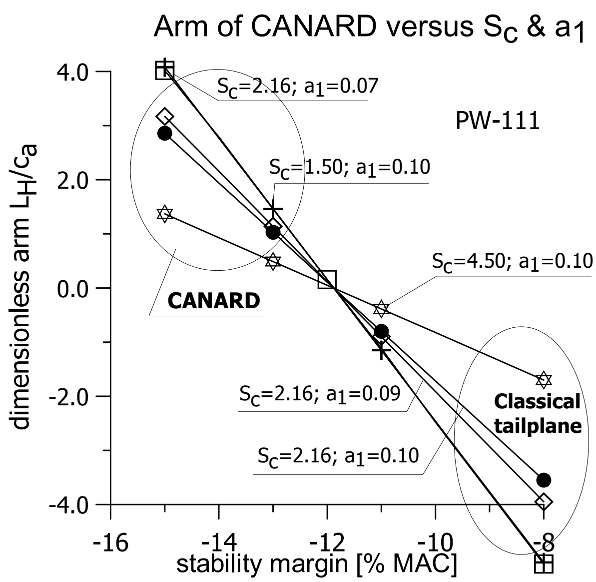

Fig. 11 – An influence of the Canard parameters on the HALE PW-111 longitudinal stability

HALE PW-112 received a modified canard. Moreover fuselage and engine nacelle geometry was modified. Lower front fuselage section had to be enlarged because front leg of landing gear was moved forward to the fuselage nose. Previously, front landing gear leg had been located behind the EO/IR sensor. Nacelles had to be enlarged after the final engine selection.
Canard was abandoned in PW-113 aircraft. Instead, new, larger outer wing was designed with smaller taper ratio. Analysis of this new configuration revealed satisfactory longitudinal stability. Unfortunately transverse stability appeared not to be satisfactory enough. Vertical stabilizer with rudder was located at the top of the fuselage. Calculations suggested better qualities for negative dihedral. The abovementioned modifications leading to the aerodynamic improvement gave PW-114 HALE UAV as a result.
HALE PW-114 is designed as a blended wing configuration, made of metal and composite materials. It is equipped with two engines. Wing control surfaces provide longitudinal balance. Fin in the rear fuselage section together with wingtips provide directional stability. Airplane is equipped with retractable landing gear with controlled front leg that allows operations from conventional airfields.

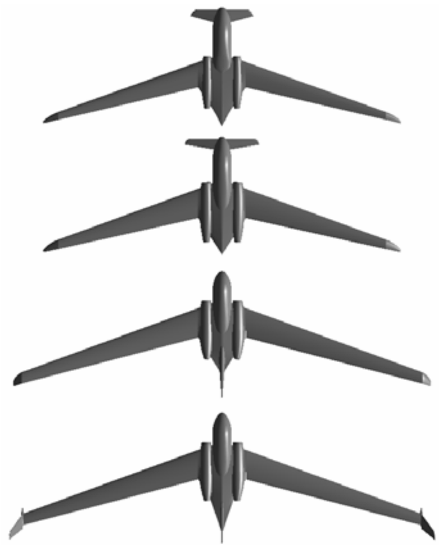

Fig. 12 - Comparison of the configurations (plan views): HALE PW-111 (from top), PW-112, PW-113 and PW-114 (to the bottom)

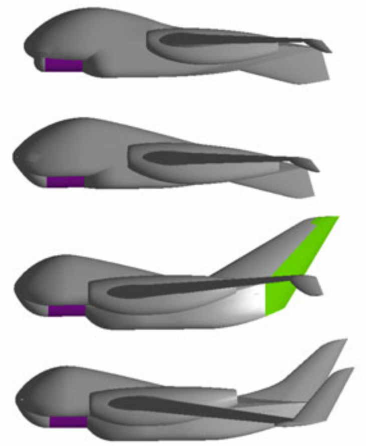

Fig. 13 - Comparison of the configurations (side views): HALE PW-111 (from top), PW-112, PW-113 and PW-114 (to the bottom)

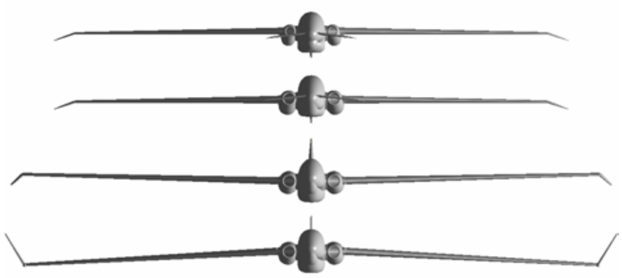

Fig. 14 - Comparison of the configurations (front views): HALE PW-111, PW-112, PW-113 and PW-114

PW-114 HALE UAV description

HALE PW-114 is designed as a blended wing configuration, made of metal and composite materials. It is equipped with two engines. Wing control surfaces provide longitudinal balance. Fin in the rear fuselage section together with wingtips provide directional stability. Airplane is equipped with retractable landing gear with controlled front leg that allows operations from conventional airfields.

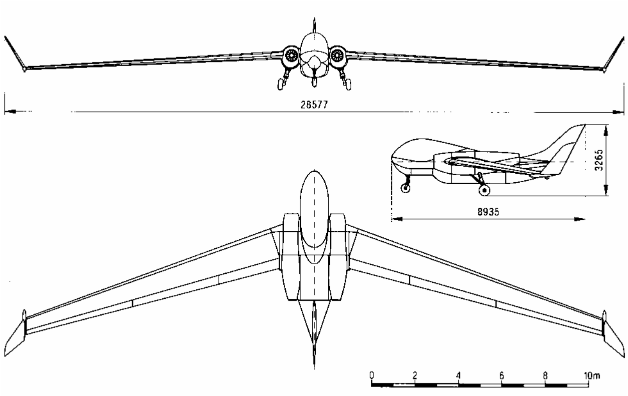

Fig. 15 - HALE PW-114 (three views)

Parameter	Value
Wing span	28 m
Wing area	44,4 m^2
Aspect ratio	17,7
Empty mass	2200 kg
Payload	700 kg
Fuel mass	4150 kg
Take-off mass	6350 kg
Take-off thrust	20,9 kN
Wing loading	143 kg/m^2
Thrust loading	304,1 kg/kN
Payload loading	15,8 kg/m^2
Payload/take-off thrust	33,5 kg/kN

Table 2 – Technical data

Aerodynamic analisys

During design process aircraft has been changing. Some parts was improved, some was rejected because are useless in the new configuration. Aerodynamic calculations for HALE aircraft were made using the VSAERO program, using the potential compressible flow model (subsonic) with boundary layer.

The LRT-17.5 wing section was selected, mainly due to its high CL ($C_{L,MAX}$ = 1.54 at Mach=0.57 and $C_{L,MAX}$ = 1.46 at Mach = 0.62 & Re=2*10^6), needed at loiter regime with Ma=0.6. It enabled to essentially limit the gross wing area.

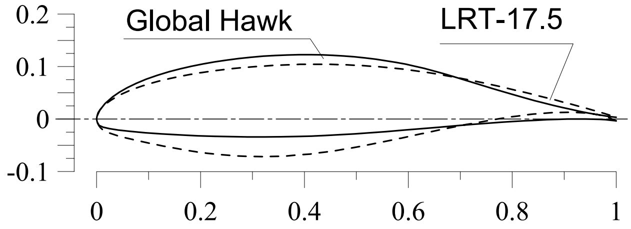

Fig. 16- Airfoil of PW-114 wing compared to the Global Hawk airfoil

Three types of control surfaces were built on HALE wing. Some of them may play the same role like others. It will be presented in this paragraph. Figure below shows division of control surfaces on HALE wing, place of mean aerodynamic chord (MAC) and the location of the centre of gravity.

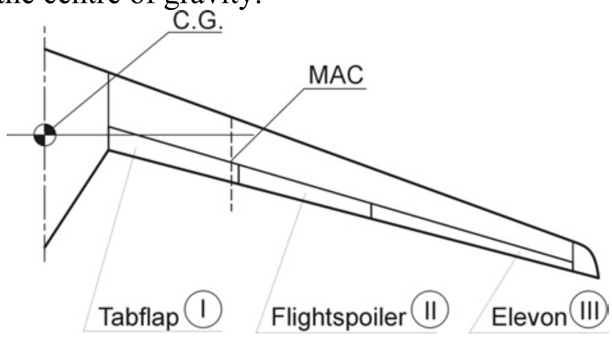

Fig. 17- Control surfaces of HALE wing

Tabflap (tabs + flaps) was used to increase the lift. It was placed near fuselage. Figure below presents deflection of tabflaps for two characteristic position in flight.

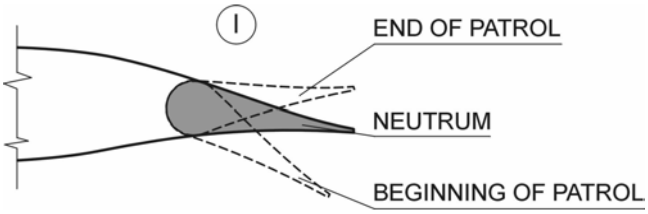

Fig. 18- Tabflap of HALE wing – three characteristic positions

Flightspoiler may work in two ways. It can be used like a brake, to provide braking force (Fig. 19 - left) or for longitudinal control during the last phase of mission (Fig. 19 - centre). Fig. 19 (right), presents range of deflection for brake of HALE wing.

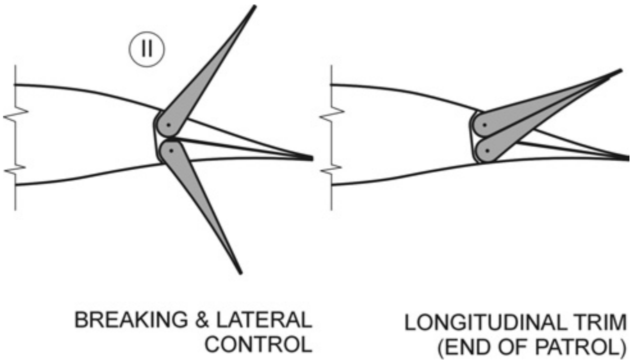

Fig. 19- Brake of HALE wing – two ways/option of work

Elevon may work in two ways too. For longitudinal control the elevon is used like elevator, but for lateral control elevon is used like aileron. Three phase of work and range of deflection was presented on the figure below.

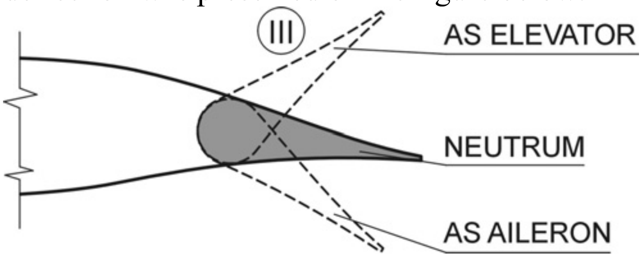

Fig. 20- Elevon of HALE wing - three states of work

The total fuel capacity is 5600l, divided in seven structural fuel tanks.

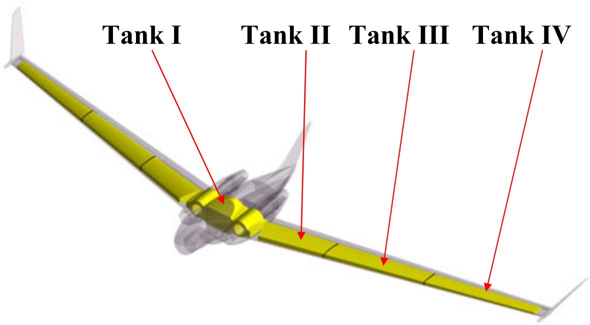

Fig. 21 PW-114 – fuel tanks

The fuel is located in the integral fuel tanks in the wing torsion box and in the fuselage between first and third main frame. Each wing contains three independent tanks and has an independent installation of pipes. Fuel is used from the fuel tanks in the following sequence: from 1st and 4th together, then from 2nd and finally from 3rd.

Central fuselage section's framework consists of seven frames and two longitudinal walls joining frames. The three central main frames are the most loaded components in the whole fuselage structure because they outer semi wing are attached on these frames.

The wholes in main frames are used for engine air intake ducts. Remaining frames and longitudinal walls are made of carbon composite. Brackets for propulsion system installation are installed here. Loaded skins are also made of carbon composite. Upper skin is equipped with eyeholes enabling easy access to avionics and equipment. Lower skin is reinforced by composite longerons.

Moreover bottom fuselage section is installed to the lower skin. Front fuselage section is installed to four brackets on the first main frame. Rear fuselage section with the fin is installed to five brackets on the last frame of the central fuselage section. Bottom and rear fuselage sections are made of carbon-epoxy composite. All fairing, covers and eyeholes are made of composite.

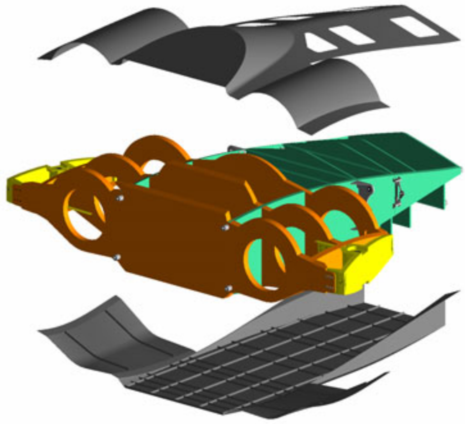

Fig. 14 - Load bearing fuselage structure of PW-114 before composite skins installation

Outer wing structure consists mainly of the torsion box, having two circuits made of carbon-epoxy composite. It takes the torsion moment (Fig.). Upper and lower skins are made as a sandwich structure to provide resistance for buckling. Polyurethane foam is used as filler between layers of the carbon fabric.

Spar walls have sandwich structure made of layers of carbon fabric and polyurethane filler. Carbon roving is used for their flanges. Their walls have sandwich structure made of carbon fabric and polyurethane filler..

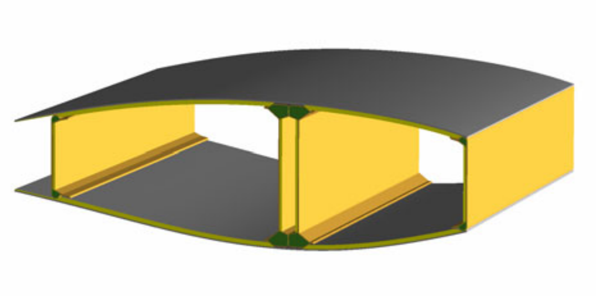

Fig. 15 - Wing section view

4. OBW-O2 – PW 114 basic cross comparison

The two descriptions of the OBW-02 and PW114 related above show that the two configurations, each following one kind of "flying wing"/no horizontal tail architecture, fulfilling the same set of requirements, using the same kind of engines, present similar performance although they differ basically in their architecture (see): the first one uses a low swept wing and reflexed airfoils while the second one uses a classical swept wing with conventional airfoils.

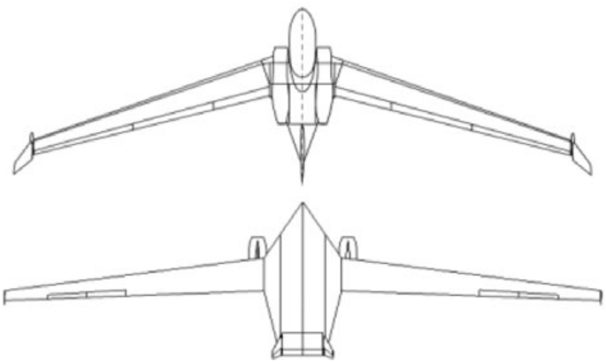

Fig. 22 – Planform of the two concepts

In addition, the location of engines are radically different, the payload is integrated in the OBW-02 while it is more external in the PW114, the tail arrangement differs also and the PW-114 uses flaps to improve its efficiency.
Moreover, the primary structure of the two concepts, in its critical sections which corresponds to the outer wing, uses a similar topology building with high module carbon/epoxy materials. The FEM analysis done has confirmed the initial sizing with an assessment of the structural weights which concludes on similar results for both concepts.
Then, the maintainability, reliability and safety analysis done produced also comparable results, assuming that the two concepts are designed in taken into account numerous basic design rules on those topics.
Thus, beyond this qualitative parallel description, a basic cross comparison, focused on classical criteria relatively to aircraft efficiency, demonstrates however that the two vehicles are very close in term of performance (Table 3 and design criteria as shown in Fig. 23), reliability and maintenance aspects. To ease the comparison, criteria marks have been normalized with the ones estimated for the Global Hawk which is a reference in such a vehicle. It shows also that, according this restricted point of view, first, the two concepts are close, and second, that the conventional architecture seems to be rather more efficient.

Performance		PW114	OBW-02
Absolute ceiling at MTOW	m	19200	19400
Time to climb to 55 000 ft	mn	15	26
Time to climb to 60 000 ft	h	1h36mn	1h36mn
Rate of climb (SLS)	m/s	33	28
BFL	m		810
Take off distance	m	427	650
Landing distance at LW	m	546	610
Landing distance at MTOW	m	852	800

Table 3 – Additional performance of the two concepts

Parameter		Global Hawk	PW114	OBW-02
Take_off thrust	kN	37	26,7	24,3
Wing loading	kg/m²	231,52	98	105,2
Thrust loading	kg/kN	314,1	162,9	222
Payload/wing area	kg/m²	19,9	11,3	12
Payload/take-off thrust	kg/kN	27	18,7	25,2
Fuel fraction		57%	54%	52%
EEW/reference area	kg/m²	83,2	33,8	38,8
EEW/MTOW		32%	34,50%	37%
Payload/MTOW		8,30%	11,50%	11,35%

Table 4 – Design criteria

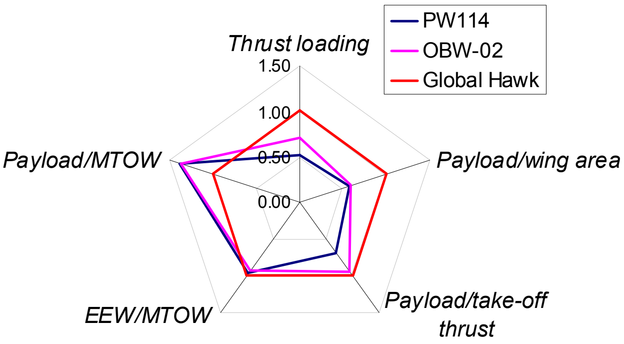

Fig. 23 – Design criteria (referenced to Global Hawk)

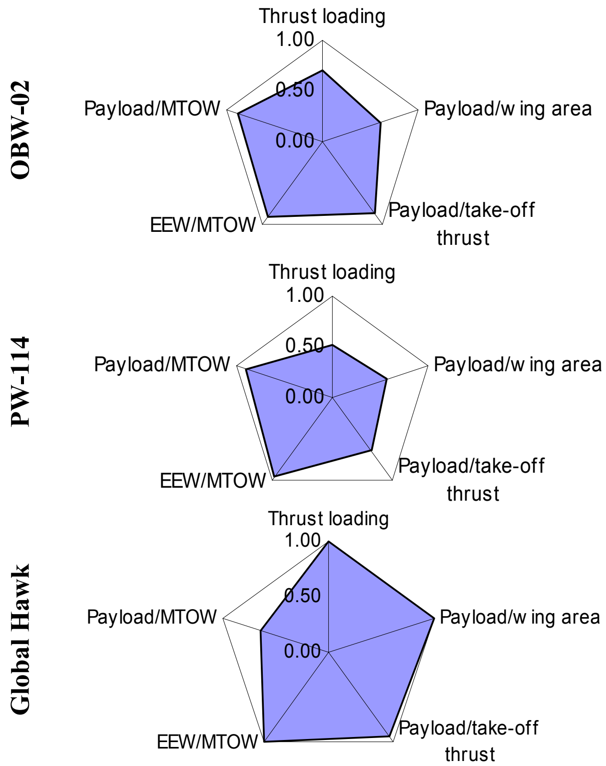

Fig. 24 – Design criteria (referenced to the best mark for each criteria)

Considering the comparison features listed above, a critical review of the two concepts, keeping in mind this rather close distance between them, has been done in order to identify their main advantages and drawbacks. It concludes that the definition of a joint configuration could be envisaged.
Based on the planform of the OBW-02 concept, the main features of this new merged vehicle should be the use of buried engines in the central section, as proposed on the PW-114, in order to free the field of view of sensors of the two nacelles masking. In addition, that should improve the lateral control in critical conditions and potentially the aerodynamic efficiency. Moreover, the accurate analysis of the control surfaces, done in the field of the PW-11x design, leads to promote their use on the joint configuration, with a possible light increase of the outer wing sweep in order to improve the pitch control.
Obviously, the joining of the two concepts on a unique one remains a proposal of the joint WUT-ONERA team and requires a deeper analysis which was not done within the CAPECON project.

5. Conclusion

This common work concluded on the definition of two concepts for which the two cycle analysis done gives confidence in their ability to fulfill civilian mission requirements (500 kg during 24 h at 60 kft and 1000 km egress). The level of design of the two concepts is consistent with the required level of details to provide information needed for a precise cost evaluation and also for a complete multicriteria comparison with other concepts, which will be performed at the end of the CAPECON Project.
Beyond the main aims of the CAPECON project, these two concepts have been designed in parallel with different methods and tools and based each of one kind of "flying wing vehicle" which logical should lead to two very different and also unusual UAV systems.
Although the two proposed concepts differed apparently in their architecture, they are very close in term of performance and overall merits (maintainability, reliability, safety) required to fulfill civilian operational needs. This similarity led the team to point out what should be a joint vehicle merging the advantages of the two concepts and minimizing their drawbacks.
Nevertheless, the design analysis also points out the high sensibility of Blended Wing UAVs to several aspects, mainly:

- flutter risks which require a deeper analysis
- the rather poor stability of such a vehicle that could lead to the use of robust flight control laws

- the rather poor exchange capacity between fuel and payload, due to the short centre of gravity range.

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