A NEW AIRCRAFT CONCEPT: THE COMBAT MALE

Dario Manzato*, Franco Persiani*, Alberto Beccaro**
***University of Bologna, **Alenia Aeronautica S.p.A**

Keywords: *Unmanned, New, Design, Concept, Configuration*

Abstract

The aim of the present article is to show a research activity, carried out jointly by University and Industry, about a new unmanned aircraft concept. The novel idea is to make a feasibility research in order to achieve an innovative configuration, performing typically Usav loiter capability with Ucav raid and survivability ones.

This hybrid aircraft represents a new system concept so, because of non existence of comparable projects, requirements have been defined on the basis of operational needs and, consequently, aerodynamic and propulsion configurations analyses have been performed in order to evaluate the maximum available endurance by means of simple (and rapid) calculation techniques, differentiating design parameters like wing's aspect ratio or engines' bypass ratio.

Technical results have been used to evaluate the feasibility of joining long endurance, high flight performances and medium payload capability without reaching typical bombers dimensions and costs, besides conceiving the better configuration with a higher level of detail and confidence.

1 Introduction

Since 1989 the military scene has substantially changed; in fact, there are many nimble and dynamic threats as opposed to the former confrontation of big armed forces. Continuous control of large areas, associated with rapid action capability, is needed; currently this demand is usually performed by fighters or surveillance aircraft.

Fighters increase the mission costs, because they have a poor flight endurance consequently many aircrafts must be used to get continuous coverage; on the other hand, surveillance aircraft usually have no attack capability, so there is a dead time between the detection of a threat and the action, with a tactical inefficiency.

Nowadays, dirty, dull and dangerous missions are increasingly fulfilled by unmanned aerial vehicles; in particular, surveillance ones can perform till more than 30 hours missions and their design is only optimized for the best endurance. Unfortunately, they have to operate far from their targets and from the battlefield, not having high performance and survivability.

The question we asked ourselves is: is it possible to trade off these requirements, obtaining a medium-sized aircraft with long endurance and high performances and survivability? High performance in this case means speed and SEP capabilities similar to a manned attack aircraft.

To match these requests, a new unmanned system concept, which can do both the operation of surveillance and attack, has been carried on by University of Bologna and Alenia Aeronautica in order to significantly reduce time and costs of missions.

The new aircraft doesn't belong to a specific class, so statistical data are not available for preliminary design evaluations. During the first phase of the activity, to face this lack , some configurations have been analyzed starting from an UCAV preliminary design, changing aerodynamics and propulsive parameters to see what aircraft dimensions would have been necessary to satisfy enhanced endurance requirements. Such survey has been carried out to avoid the risk that considering only one requirements would lead up to an heavy and expensive aircraft, like a bomber, that cannot be affordable.

The analysis shows that is possible to match long endurance and high flight performance requirements at the same time, even with a reasonable aircraft dimensions.

2 Configurations analysis

What are the necessary aerodynamic and propulsion configurations to get an endurance higher than 20h, with a maximum design weight limit around 10000 kg?

The analysis purpose is to estimate an endurance performance trend, changing parameters like aspect ratio (lift-to-drag ratio) and bypass ratio (thrust specific fuel consumption) which have more influence on it.

Aspect Ratio AR={3,5,7,9,11,13,15,17,19,21}

Bypass Ratio BPR={1,2,3,4,5,6}

Flight endurance has been appreciated inverting the "Breguet formula": a Matlab function has been created once defined a specific mission profile, entering inputs like flight performances, maximum design weight, empty weight, payload, thrust specific fuel consumption (TSFC), range and aerodynamic efficiency.

Mission profile is made up by an high altitude cruise and loiter segments, other than a raid in order to identify and eventually attack threats.

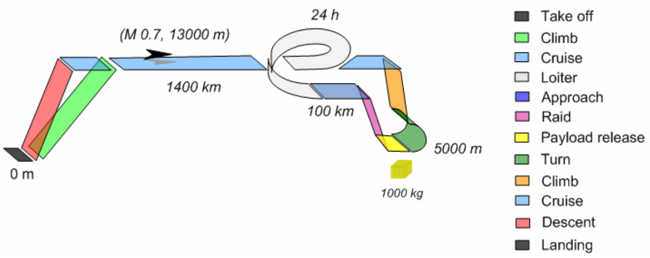

Fig. 1. Mission profile

Turbofan cruise TSFC has been esteemed by means of literature statistical data [3], while a particular database has been created for the empty-maximum weight ratio and for the aerodynamics efficiency, because of lack of comparable aircraft class.

Function outputs (Fig.2) reveal the concrete possibility to conceive the hypothetic system: using this results, some general design guidelines could be also drawn out in order to satisfy the over 20h of endurance requirement.

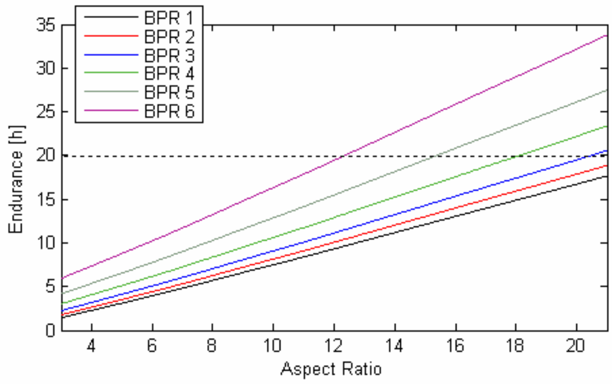

Fig. 2. *Endurance* $= f\,(AR,BPR)$

For example, it is possible to define a region of plane where extracting the variables' better values.

- $12 < AR < 18$
- $BPR > 4$

Achieving 20h endurance could be possible using engines with BPR>6 or wings with AR>18 but these selections would be inefficient due to an excessive thrust loss at high Mach number and a considerable aircraft structure weight improvement because of the likely high load factor which is requested to maneuver performances.

2.1 The best configuration

A particular aerodynamic and propulsive choice affects not only the aircraft endurance performance but also other design features which must be taken into account since from the project beginning.

The hybrid aircraft have to fly over dangerous zones, thus survivability is a fundamental project aspect which must be considered; although such a specific requirement doesn't exist yet, the aircraft has been thought to have a very low radar and infrared signature.

Stealth geometry is achieved optimizing the external shape of the aircraft, adopting appropriate geometries that also allows the minimum use of RAM, and reducing the exhaust engine gas temperature. So, an high by-pass-ratio engine (6) and a medium-high aspect ratio wing configuration (15) have been preferred to optimize the trade-off among the different design requirements.

3 The combat MALE

Once obtained a positive feasibility result, better AR and BPR parameters have led up to a more detailed conceptual layout, through four consecutive steps: (1) sizing (Tab.1.), (2) thrust-to- weight ratio and wing-loading estimations, (3) aerodynamic shape definition and main subsystems (tanks, landing gear, engines, payload bays and avionics) locations, (4) layout and performance check.

3.1 Sizing

The empty, fuel and maximum design weights estimations have been carried out by means of "direct" Breguet formula, specifying a 24h loiter segment and using the same aerodynamics and propulsive parameters of the previous feasibility analysis.

$W_{Payload}$ $[kg]$	W_{Fuel} $[kg]$	W_{Empty} $[kg]$	W_{Design} $[kg]$
1000	3900	4400	9300

Tab. 1. Weights: *AR* 15 e *BPR* 6

Endurance and range performances can be arbitrary managed depending on airbase or target locations, improving the aircraft operational flexibility.

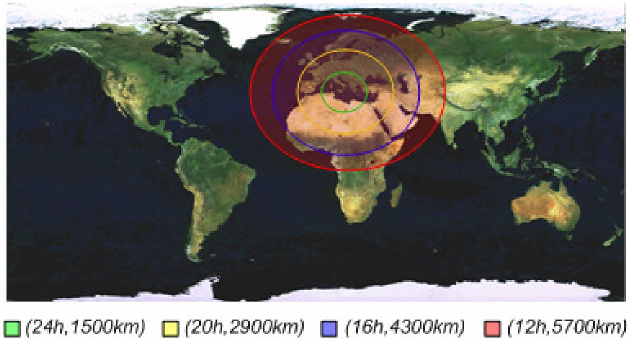

Fig. 3. Possible MALE missions (Loiter, Radius)

3.2 Wing loading and thrust-to-weight ratio

Thrust-to-weight ratio and wing-loading parameters are needed to draw a new aircraft configuration layout from a "blank paper": statistically, engine diameter, length and weight can be estimated from the thrust required value.

Thrust and wing surface area will have to be esteemed as functions of hypothetic flight performances to satisfy: such performance constraints, by means of namesake diagram, are summarized in the only two parameters of thrust-to-weight ratio (T/W) and wing loading (W/S).

$SEP_{[M\ 0.5,5000m]}$ $[m/s]$	$STR_{[M\ 0.7,5000m]}$ $[g]$	$ITR_{[M\ 0.7,5000m]}$ $[g]$
30	4	≥ 4

Tab. 2. Flight performances: specific excess power (SEP), sustained turn rate (STR) and instantaneous turn rate (ITR).

In fact, flight performances can be explained as functions T/W=f(W/S) which are represented by curves on the plane (T/W,W/S) and each line divides the plane into acceptable/unacceptable value zones; the region of plane where the couples (T/W,W/S) satisfy all flight performance requirements is shown by functions intersection.

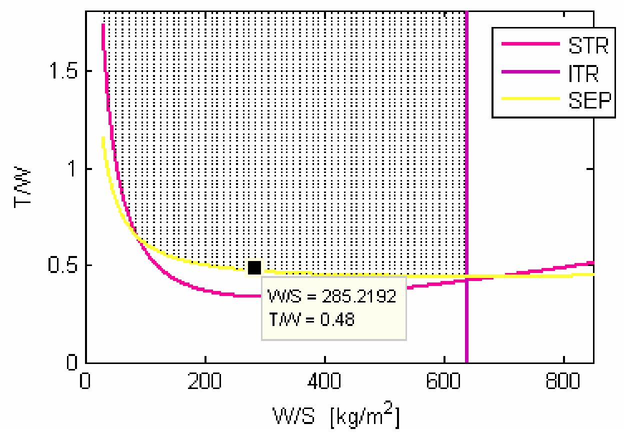

Fig. 4. Constraints diagram; *AR* 15, *BPR* 6

Thrust-to-weight ratio value must be the lowest possible in order to reduce engine weight and cost: SEP function is a rectilinear line for a wing loading higher than 250kg/m^2, so the value has to be selected only taking a 4% confidence margin into account.

Wing loading considerations are quite different: an important constraints is represented by the available wing volume where stowing fuel so, for this type of aircraft, a medium-low value is a good sense choice. Now, the design sequence is evident: thrust and surface wing area can be calculated by means of T/W,W/S and aircraft weight valuations.

T/W	$W/S\ [kg/m^2]$	$W_{Design}\ [kg]$	$T\ [kN]$	$S\ [m^2]$
0.485	285	9300	44.2	32.6

Tab. 3. Design parameters

3.3 Configuration layout

The combat MALE has been conceived as a tailless configuration for its advantages in terms of drag (less wet wing surface), weight reduction (span-load distribution) and radar signature (no tail planes and blended surface), while complex longitudinal and lateral controls represent the main disadvantages.

After thrust and wing surface estimations, drawing an aircraft configuration layout needs to other design information about wing (sweep angle and taper ratio), engine (number and position), main internal subsystems (landing gear, fuel tanks, bays,..) and structure.

In a tailless configuration, subsystems cannot be placed inside fuselage, so their sizes have to be carefully estimated in order to compare them with the available wing volume; if such volume is not enough, wing surface has to be increased by means of an iterative design process.

Aerodynamics

Sweep angle (Λ) must be selected trading off the stealth design constraint, and pitch up longitudinal instability: for a wing with AR=15, sweep angle should be lower than 15° to avoid it. The choice has been made also using ($\Lambda_{l.e.}$,M) statistical data of all aircraft built before 1999 [5]: $\Lambda_{l.e.}=30°$

A correct taper ratio assessment, for backward swept wings, can be extracted by NACA wind tunnel data; they link ideally elliptical lift distribution on a wing with its sweep angle and taper ratio values. Even tough the taper ratio looks down to zero for increasing sweep angle, a value smaller than 0.2 is not recommendable to prevent wing tip separation and, consequently, ailerons control loss [5].

The combat MALE leading edge sweep angle has been set to 30°, so taper ratio (λ) should be 0.2; nevertheless, a confident higher value has been chosen to improve tailless aircraft stability and control features. $\lambda = 0.35$.

Propulsion

The 44,2kN of required thrust can be provided by one or two turbofans, with a bypass ratio value equal to six. One-engine configuration allows an empty weight and costs reduction; nevertheless, aircraft survival probability is equal to zero in case of flight engine failure. Moreover, stealth air intake must be downsized; diffuser diameter is strongly dependent on bypass ratio which have to be very high to achieve low fuel consumption.

Looking at statistical data, 44,2kN of thrust can be performed with a single engine of 1,150m diameter, or twin engine of 0,7m one.

A twin engine configuration has been chosen to satisfy the low radar signature requirement; each engine design parameters are presented in the table below.

Thrust [kN]	Diameter [m]	Length [m]	Weight [kg]
22,1	0,7	1,5	450

Tab. 4. Engine parameters

Turbofans have to be installed nearest aircraft longitudinal axis: in fact, a tailless aircraft couldn't balance the high yaw moment due to one engine failure.

Longitudinal engines installation needs to a trade off between longitudinal aircraft stability, intake radar signature and diffuser aerodynamic efficiency: for example, placing turbofans forward will improve the aircraft pitch stability but the air intake will become more visible by a radar ground station, also making worse the air compression inside a shorter diffuser.

Landing gear

Landing gear location is one of the most critical design phase during configuration layout fulfillment due to its reliance on aircraft centre of gravity; an iterative drawing process is needed to achieve a "correct" position.

Among the many landing gear configurations a tricycle one has been chosen to enhance aircraft ground stability. Extended leg length and tires diameter and width have to be esteemed to correctly draw both nose and main landing gear: typically shock absorber length values are numbered among 25cm and 30cm range while tyres are sized by means of statistical method, assuming $W_{l.g.}=0.04 \cdot W_{Design}$. The maximum design weight has been shared out as 14%-86% over the nose and the main landing gear respectively: fighter class statistical coefficients have been selected to sized tyres [5].

Landing gear	Nose	Main
Leg [cm]	40	50
$Weight_{Wheel}$ [kg]	1302	3999
$Wheel_D$ [cm]	40	60
$Wheel_L$ [cm]	10	20

Tab. 5. Landing gear: design parameters

Fuel

The aircraft burns 3900*kg* of fuel to perform the assumed mission profile: 4,785m^3 is the required wing volume because, at standard temperature, fuel density is about 0,815kg/dm^3. Fuel capacity check is critical, because it's another wing loading constraint: obviously, this aspect becomes much more binding for a tailless configurations. The 3m^3 available wing volume has been valuated by means of semi-empirical formula [5].

Even tough the wing has been considered without subsystem, the free volume is insufficient to stow all the fuel; as the matter of fact, wing surface has been decided to be increased.

Bays

The payload have to be sited inside two rectangular bays whom length, height and width are, respectively, equal to 3000mm x 500mm x 700mm. These parameters are requirement specifications.

Bays will be set nearest longitudinal axis according to the following considerations:

1. More distant the bays are from centerline, more backwards they should be located due to 30° wing sweep angle, increasing the wing area and reducing the longitudinal stability.
2. Aircraft payload is expendable so it should be located nearest centre of gravity avoiding its excessive excursion.
3. Fuel is stowed directly inside the wing structure so engines, landing gear and bays must be contained into sealed housings; if the bays are close to engines, only one engine bay could be designed in order to achieve an easier wing construction
   Moreover, a correct leading edge shape isn't achievable placing the bays too forward; a compromise design solution is needed again.

Structures

The correct subsystem locations couldn't be achieved without considering spars, bulkheads and ribs design because of strictly structural constraints to comply with.

Besides, aircraft internal volume needs to the most rational segmentation because fuel is directly in contact to the wing structures.

1. One main bulkhead or rib should be located in correspondence to both nose and main landing gear.
2. Turbofan is connected up to structures by means of two hinges, placed at 20% and 80% of the total engine lengths: first positions is referred to the force transmitting pivot, the second one to a pendulum which balances engine oscillations during aircraft maneuvers. Each stick need to one main bulkhead.
3. Two main bulkheads should be foretold in correspondence to the forward and backward bays walls.
4. Spars have to be bound to the strong ordinates, also delimiting the watertight housing at the same time.

Once aerodynamics parameters have been valued and all subsystems have been sized, the summary of all these aspects is represented by the conceptual aircraft layout.

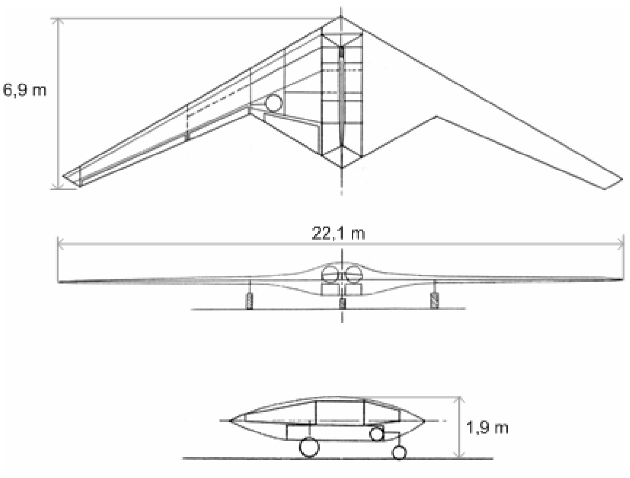

Fig. 5. Conceptual layout (three views)

The theoretical wing area has been increased of about 12m^2 by means of a diamond shape; this solution numbers the aircraft Cl among 0,2 and 0,6 during mission development.

As a result of this range, the NACA 65_2415 reference airfoil has been selected because its laminar bucket ranges to Cl±0,2 from the design point (Cl=0,4). Moreover, increasing wing area allows to locate landing gear, engines, bays and fuel following all the drivers set out previously.

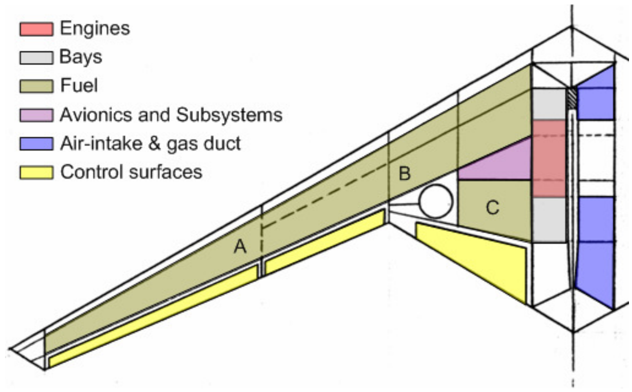

Fig. 6. Internal subsystems arrangement

Fuel is stowed inside two watertight unlinked housings; inverting the position of the avionic bays with the backward "tank" would have simplified fuel system and sealed structure realizations but, in this way, the spar connected to the forward engine pivot would have to be sloped in order to satisfy the different wing volume arrangement.

Moreover, this hypothetical design solution would have carried out a longitudinal stability reduction because avionic and system loads are not time-variable as fuel, so they would have weighted on the forward part of the aircraft during all mission time progress.

Fig.6. shows only two "tanks" apparently; as the matter of fact, the forward tank is divided in two subparts in correspondence to the span-wing discontinuity in order to control the excursion of the centre of gravity better.

Fuel weight has been managed in this way:

- 1000kg stowed inside wing tip tank (A)
- 1700kg stowed inside forward tank (B)
- 1200kg stowed inside backward tank (C)

The third spar, shown with a cross-hatched line in the figure, is not part of the baseline and will be introduced only if required by the bending stress; this will be decided after FEM analysis and checks; the two main bulkheads, referred to engines pivots, are represented in the same way.

3.4 Layout and performances check

Carrying out the aircraft layout means having more confidence about the dimension and location of main aircraft structural parts, leading up to a new weight estimation besides centre of gravity position calculation.

The previous weights estimation, and also the correct position of nose and main landing gear, can be checked by means of the achievable results. Moreover, the aircraft centre of gravity excursion can be shown graphically, due to the progressive fuel consumption, immediate payload release and landing gear extraction during takeoff or approach mission segments.

Each structural part weight has been estimated by means of relevant tables which report statistical ratio between weight of frame elements with regard to wing wet area they take up. Wet area can be valued multiplying the theoretical one by coefficients related to the wing thickness-to-chord ratio within structural elements are located.

New aircraft empty weight estimation (4358kg) was coherent with the previous one (4400kg), so the analysis has gone on estimating the centre of gravity position. Six positions have been valued with reference to takeoff mission segment, fuel exhaustion stowed inside A and C tanks, 1000*kg* of fuel consumption stowed inside B tank, payload release and landing; progressive tanks emptying sequence (A,C,B) has been manage to assure maximum aircraft longitudinal stability.

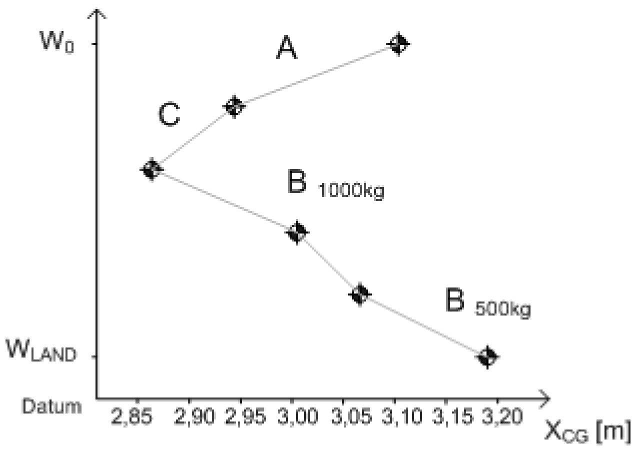

Fig. 7. Longitudinal *CG* excursion: graphic

Nose and main landing gear have been drawn and positioned following specific design assumptions, like the aircraft weight sharing out on wheels (14%-86%); such hypothesis has been checked after esteeming the centre of gravity position during takeoff phase, that is the heaviest condition for the landing gear.

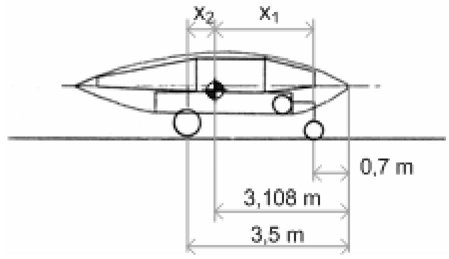

Fig. 8. Landing gear: longitudianal location check

Moreover, following other landing gear design drivers [6], in-depth checks have been made about runway, seat and wing tip angles.

Assumed flight performances check represents the final project phase: during layout carrying out, the wing surface has been increased of about 12m^2 so the requirements couldn't be satisfied. In this case, layout has be changed. SEP, STR and ITR performances have been checked by means of an Alenia Aeronautica tool which works out the classical flight mechanics formula once inserting geometric, aerodynamic and propulsive features of the aircraft. Since SEP and STR are highly dependent by engines performances, a 5% of available thrust loss has been simulated, assuming a turbulent flux inside turbofans air-intake.

SEP [*m/s*]	*ALFA* [*deg*]	*CL*	*CD*	*T* [*kg*]	*D* [*kg*]
30.88	−0.387	0.1732	0.0084	1932.2	390.7

Tab. 6. *SEP* (*M*=0.5, *h*=5000*m*)

STR [*deg/s*]	*ALFA* [*deg*]	*CL*	*CD*	*T* [*kg*]	*D* [*kg*]
13.38	5.464	0.4775	0.0202	1842.8	1834.8

Tab. 7. *STR* (*M*=0.7, *h*=5000*m*)

ITR [*deg/s*]	*ALFA* [*deg*]	*CL*	*CD*	*T* [*kg*]	*D* [*kg*]
9.69	3.914	0.3510	0.0141	1842.9	1282.5

Tab. 8. *ITR* (*M*=0.7, *h*=5000*m*)

Finally, a maximum structural load factor has been assumed equal to 4.
The tool calculates an ITR real value (4), that is considering the structural load limit, and STR theoretical one (5,44); the same ITR value, referring to the requested altitude and velocity, would be 13,52.

Maneuvering performances have resulted exuberant because limited by structural strength, while SEP has been satisfied with a very narrow margin, therefore it represents the engine sizing performance. Anyway, all the requested flight performances have been satisfied so the aircraft layout hasn't to be revised.

4 Conclusions

Since 1989 the military scene has substantially changed; in fact, there are many nimble and dynamic threats as opposed to the former confrontation of big armed forces. Continuous control of large areas, associated with rapid action capability, is needed; currently this demand is usually performed by fighters or surveillance aircraft.

The aim of this work was to analyze and develop a new unmanned aircraft concept able to perform long endurance, typical of surveillance aircrafts, and fighters high performances, good payload capability and survivability at the same time, without reaching bombers dimensions and costs.

Today, this novel idea arouses considerable interest inside military aviation field, because it could reduce operative time and costs; even if a specific requirements doesn't exist yet, some Countries are already conceiving new unmanned aircraft configurations which carry out several missions simultaneously. Since reference requirement nor alike systems don't exist yet, the first problem was to define a qualification which takes well-known or predictable operational needs into account leading up to a reasonable costs and dimensions aircraft.

The project's initial idea has been valued by means of a feasibility study: this analysis has ended successfully, so the internal and external layout of a new UAV have been sketched out schematically. Its main design and performance features are listed in the following table.

Range	3000 km
Loiter	24 h
Design Weight	9300 kg
Payload	1000 kg
n_{Max}	4
S	48 m^2
AR	15
T_{St}	$44,2\ kN$
BPR	6
$SEP_{[M=0.5,h=5000m]}$	$30,88\ m/s$
$STR_{[M=0.7,h=5000m]}$	$5,44\ g\ (4)$
$ITR_{[M=0.7,h=5000m]}$	$13,52\ g\ (4)$

Tab. 9. *Main design parameters*

In conclusion, this new aircraft concept, complying with hypothetical dimensions and costs requirements (not explained in this article), is effectively useful, as well as technically and economically viable (currently, a project refinement is in progress by means of a CFD/CAD iterative process in order to create a wind tunnel aircraft model using rapid prototyping approaches).

References

[1] Ira H. Abbott and Albert E. Von Doenhoff. *Theory of wing sections*. Dover Publication, New York, 1959

[2] John D. Anderson. *Aircraft Performance and Design*. McGraw-Hill International Editions, Printed in Singapore, 1999

[3] B.Gunston OBE, FRAeS. *Jane's Aero-Engines*. Hobbs the Printers, Surrey CR5 2YH, UK, 2006

[4] Attilio Lausetti. *Elementi di Meccanica del volo*. Editrice Universitaria Levrotto & Bella, Torino, 1980

[5] Daniel P. Raymer. *Aircraft Design: a conceptual approach*. Third edition, AIAA Education Series, Reston, 1999

[6] Darrol Stinton. *The Design of the Airplane*. BSP Professional Books, Oxford OX2 0EL, Great Britain, 1983

[7] Darrol Stinton. *The Anatomy of the Airplane*. BSP Professional Books, Oxford OX2 0EL, Great Britain, 1985

Copyright Statement