

## **nEUROn UCAV: Development and Operational Assessment Campaign**

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### ***ABSTRACT***

*The paper is focused on the combat capability flight test logic adopted within the nEUROn project for the demonstration of a European Low Observable UCAV capability. The article is to present the path according to which the UCAV, which includes newly conceived technologies specifically developed for the program and newly developed equipment and software, has reached the maturity level required for demonstration in flight in a relatively small numbers of flight tests. In order to reach this result, the flight tests dedicated to combat capability have been properly distributed along the French and Italian flight test campaigns, with successful adjustments and refinements in between, designed to contain the time required for results maturation. The challenging part of the flight test campaign dedicated to the combat capability is the one demonstrating the core technologies of the Smart Integrated Weapon Bay (SIWB) system. Focus has been put on the autonomous attack mission management with automatic ground targets detection and recognition, and, once it will be applied in an operational scenario, on the effective ability to ingress, autonomously detect, recognize and attack (after human approval) the planned target and safely egress.*

## 1.0 nEUROn PROGRAM

nEUROn is the first UCAV (Unmanned Combat Aerial Vehicle) European Technology Demonstrator Program and has been launched as a French initiative with six European Partners. French DGA (Direction Generale de l'Armement) is the Executive Agency and Dassault-Aviation is the Industrial Prime. Italy, the main partner after France, has participated with the leadership, on the Governmental side, of the DAAA (Direzione Armamenti Aeronautici e per l'Aeronavigabilità) and, on the Industrial side, of AleniaAermacchi. Other Partners are Sweden, Spain, Greece and Switzerland.

Main scope of the Program has been to maintain and reinforce an advanced level of European know-how and, more specifically, to mature key technologies for future European Combat Air System (manned and unmanned) mastering at the same time the programmatic aspects of the cooperation such as costs and schedule.

Technically, the main demonstrator goals have been:

- very low radar and IR signature;
- autonomous flight consistent with airworthiness regulations;
- Air-to-Ground weapon delivery from internal bay;
- automatic detection and recognition of relocatable ground targets.

The first flight of the nEUROn took place in December 2012 and, since then, the LO measurements carried out on the real aircraft (March 2013) as well as the envelope expansion and demonstration flight campaign, have been a sequence of successes which deserved the attribution, in September 2014, of the prestigious ICAS (International Council of the Aeronautical Sciences) Von Karman Award which acknowledges an exceptional achievement for the international cooperation in the aeronautics field.

## 2.0 nEUROn DEMONSTRATOR

The aircraft main characteristics are the following:

- fuselage length  $\approx 9.3$  m;
- wing span  $\approx 12.5$  m;
- MTOW (Maximum Take-Off Weight)  $\approx 7000$  kg;
- engine: RRTM Adour Mk951 hybrid;
- main performance: total mission duration  $\approx 3$  hours;
- max mach  $\approx 0.80+$ ;
- VLO (Very Low Observability) radar and IR.

The aircraft shapes and real picture are reported Fig. 1.

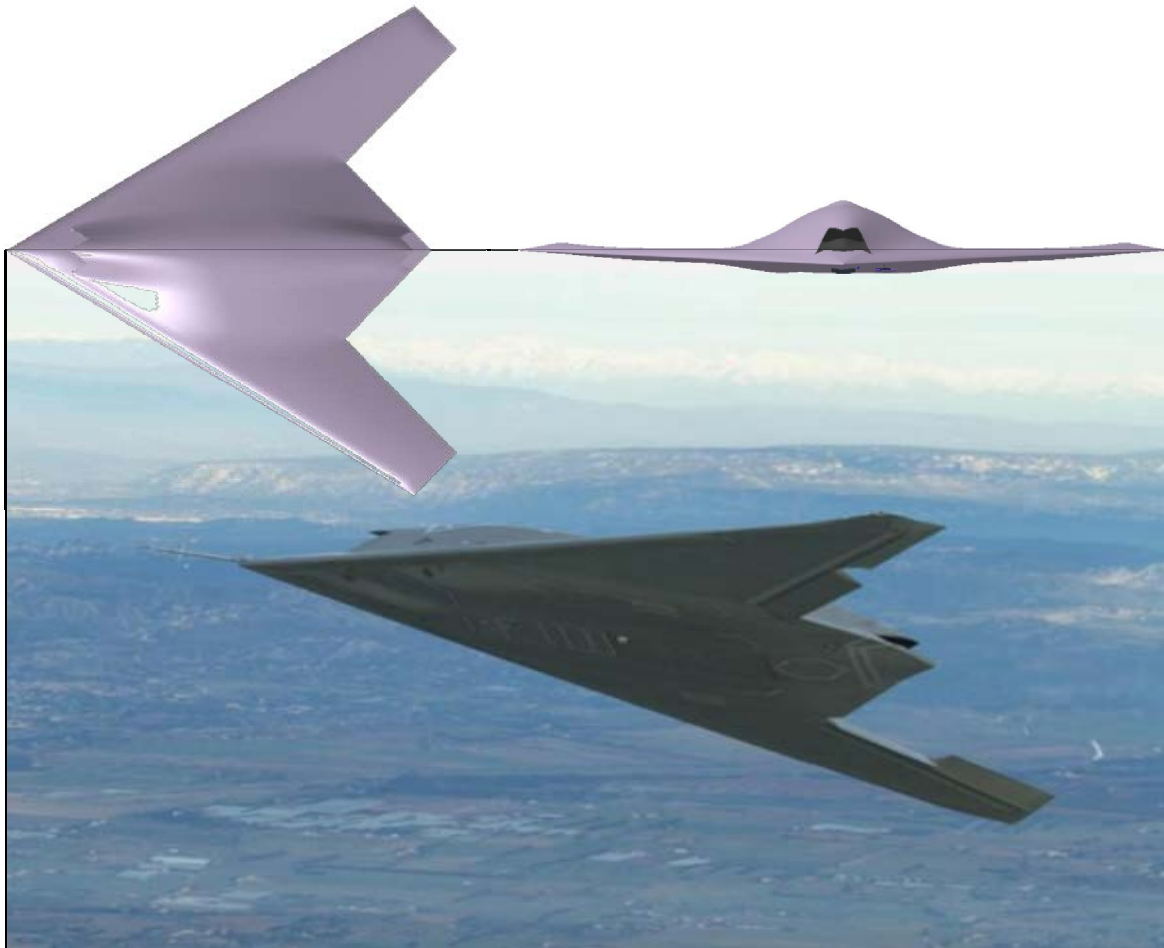


Fig. 1: aircraft shapes and real picture

### 3.0 SIWB SYSTEM DESCRIPTION

Italy has participated in the program contributing to overall design and airworthiness aspects and with full responsibility for a range of subsystems and structural parts. Key technologies have been matured in particular for the subsystems participating in the combat capability (of which Italy has first level responsibility within the program) and the LO Air Data System (ADS). The Smart Integrated Weapon bay (SIWB) is the subsystem responsible for the management of the nEUROn attack functionality and therefore of the main goal of automatic detection and recognition of relocatable ground targets.

The overall SIWB system is composed of an on-ground segment, the SIWB Control Box, and the air segment. The SIWB control box is part of the nEUROn GCS (Ground Control Station) and is devoted to attack missions planning and monitoring. The air segment of the SIWB is composed of the following equipments:

- Mission Controller (MC);
- Electro Optical Processor (EOP);
- Integrated Optronic Head (IOH);
- Environmental Control System (ECS);
- weapon bay doors and mechanisms.

The Mission Controller ensures the following high-level functionalities:

- interface with avionics;
- managing of SIWB health status;
- driving and controlling of the weapon bay doors and weapon release mechanisms;
- managing of the mission and replanning;
- release sequence computation;
- maintenance activities.

The EOP is a real time processing unit for IR digital signal: it performs the search, detection, tracking and recognition of possible targets present in the scenario by means of processing techniques based on target and background IR signatures. In addition, the EOP receives and manages the navigation/positioning data from the avionics and the incoming IR data flow from IOH. It provides data concerning the tracked and recognized objects, information about internal status and commands for the IOH steering. To fulfil such duties, the EOP is slaved to the Mission Controller from which it receives the high level commands and all the necessary information to define the operational behavior, and communicate with IOH controlling the motion platform.

The IOH equipment is composed of a stabilized platform housing a sensor payload: it can provide both high quality images in medium wave infrared spectral band and target ranging by means of a dedicated laser range finder. It can be slaved to point the LOS (Line Of Sight) to any directions inside the field of regard in order to perform the scanning of the pre-planned Target Search Zone (TSZ) through a dedicated LO flush mounted sensor window.. All the processes performed by IOH are activated upon the reception of a dedicated command issued by the EOP. The IOH internal processes are the following:

- pointing process;
- video tracking process;
- electro-optical video process;
- laser ranging process;
- mode & maintenance process.

The ECS (Environmental Control System) has been designed and developed in order to ensure the proper environment conditions in the IOH bay where the optonics is installed.

Fig. 2 and 3 show a picture of the SIWB architecture together with its interface.

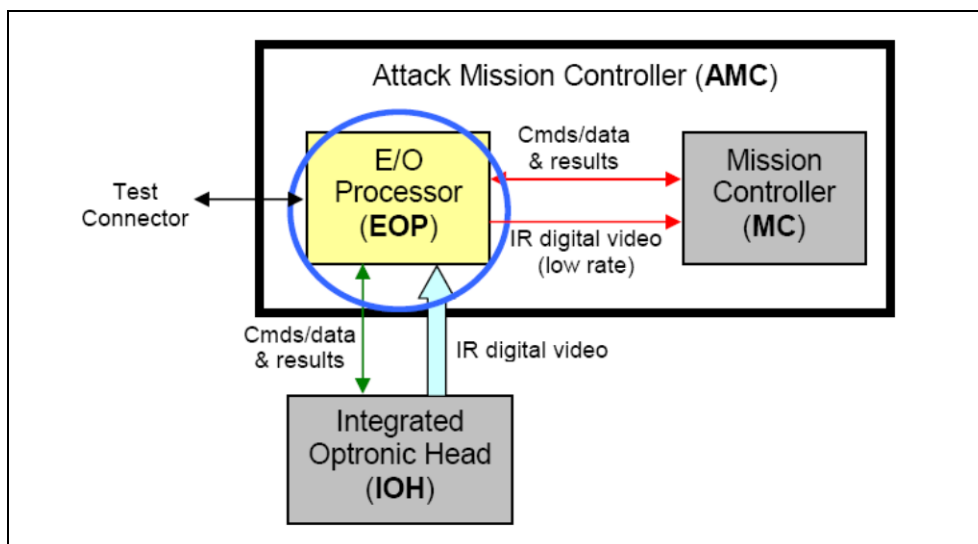


Figure 2. SIWB General Architecture

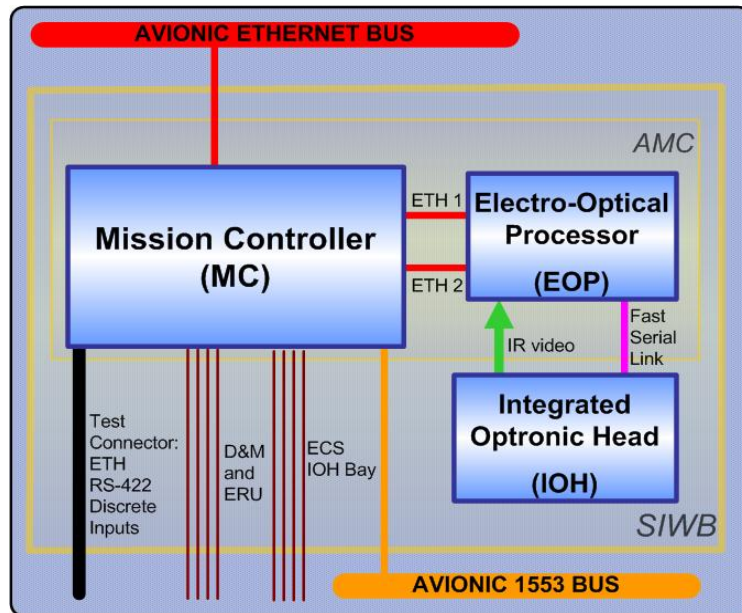


Figure 3. SIWB Interfaces

#### 4.0 GENERIC MISSION PLAN

During an attack mission, the SIWB sub-system carries out:

- Search, Detection and Tracking phases: the system searches and tracks possible targets located in the pre-planned area called TSZ;
- Recognition phase: when the previous phase is completed, the detected tracks undergo recognition algorithm to check if they belong to any of the target classes present in EOP database. After that each image is sent on ground to SIWB control box via DL together with its class declaration.

The automatic recognition phase relies on an internal target models database used for comparison with real IR images incoming from the IOH. Fig. 4a and 4b show schematic pictures of the Search/Detection/Recognition process.

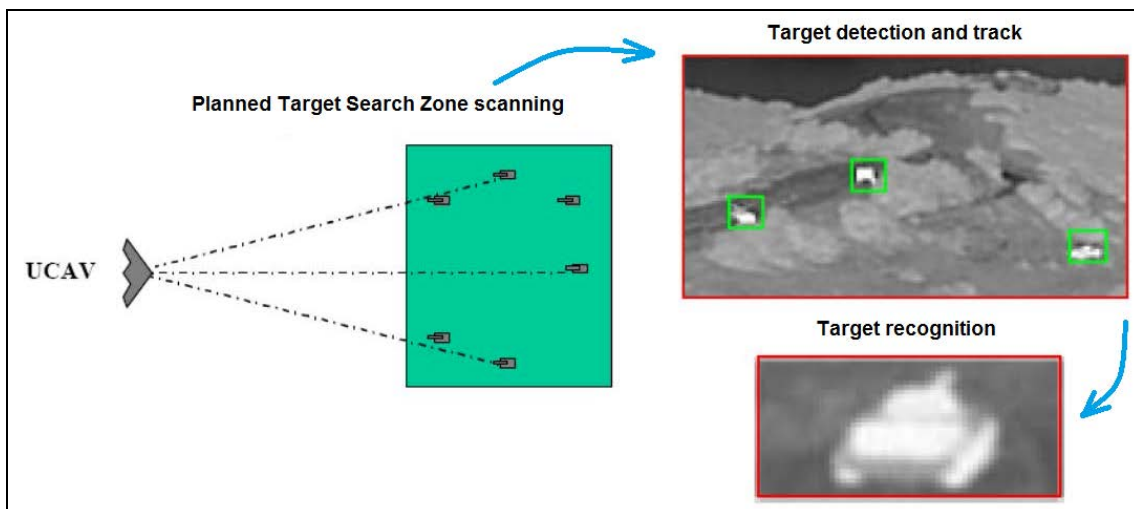


Fig. 4a: steps in the Search/Detection/Recognition process

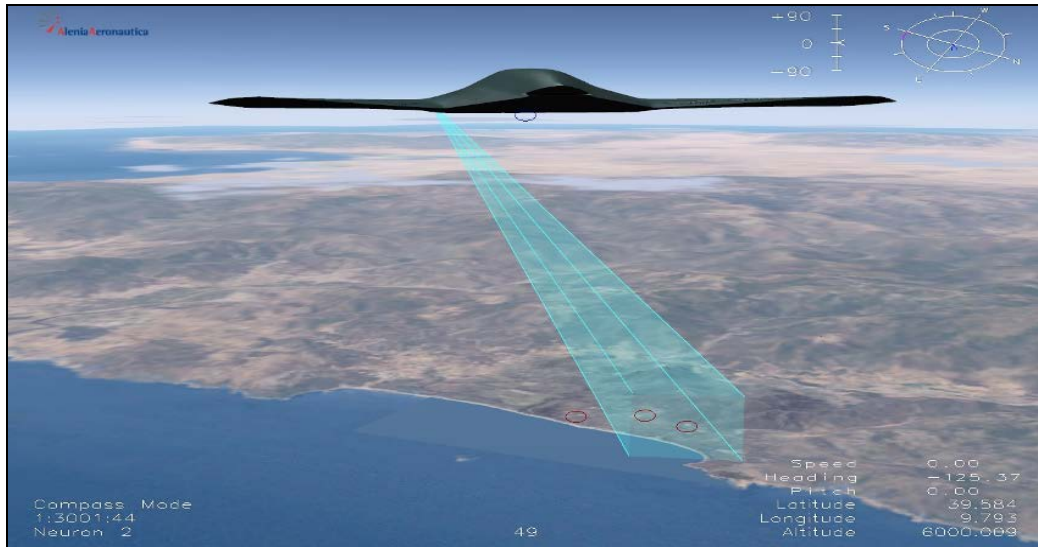


Fig. 4b: SIWB sensor scanning the TSZ

## 5.0 DEVELOPMENT FLIGHTS TEST

An incremental approach to the flight test program has been essential to gradually check all aspects which contributed in determining the performances of the SIWB system. As the number of factors contributing to the attack mission performance is so high, testing the attack mission from the start would have left the AleniaArmacchi and Dassault Aviation team with inadequate results impossible to decode or interpret. To mention just a few of the factors which contribute to the overall results:

- adequate environment of the IR sensor bay (temperature, cleanliness, vibrations, ... );
- adequate environment for the optical window (humidity level, mechanical stress inducing bending, ... );
- LO window material, coating optimization;
- adequate FoR of the items combined;
- adequate stability of flight;
- atmospheric transparency;
- targets  $\Delta T$  (Temperature);
- targets orientation;
- background characteristics;
- Detection algorithms performances;
- Recognition algorithms performances;
- navigation system accuracy.

In addition to abovementioned variables, common checks to the mission software, distributed in several computers such as SIWB, avionics, Flight Control System (FCS) and GCS, have to be done to ensure correct interfacing and proper latencies among the processors.

As one could expect, some of the mentioned contributors were not performing adequately in the first place and had to be tuned or corrected. This is where an incremental approach to flight test has been key to success. In the following we list these incremental test phases, keeping in mind that the phases have been planned leaving adequate and flexible time between them in order to design, implement and lab-test the modifications/corrections:



- 1) IR sensor bay and Optical Window environment characterization (vibration, temperature, ... );
- 2) pointing accuracy test;
- 3) IR image quality evaluation;
- 4) detection performance evaluation;
- 5) Detection tests with different backgrounds and targets  $\Delta T$  and gradual understanding of how factors such as direction of approach to targets, targets orientation, targets manufacturing (materials, colours, ... ), time of day play together in determining detection performance including false alarm rate issues. In order to have precise references, the  $\Delta T$  of the targets had to be measured with adequate means and from the actual direction of aircraft approach to the targets. Improvements in the automatics detection algorithms has been introduced between the steps and the system has been re-evaluated accordingly;
- 6) once detection was successful, so that NFOV (Narrow Field Of View) images of targets could be obtained, test of automatic recognition capability in flight could begin. This included several optimization and recheck steps, also in laboratory, done by testing modified algorithms on the real images acquired in flight.

Peculiar results, which could turn into lessons learned and steer future developments, have been the following:

- the optical performance of the system (sensor and optical window) has been satisfactory since the start, inducing some less refinement activity then expected;
- on the other hand, tuning the Detection and Recognition algorithms has been demanding due to the clash between a desired robust and systematic process and a dynamically changing not-controllable conditions scenario (starting from the  $\Delta T$  of the targets and its distribution): this created a very difficult problem to solve within the limited available time.

The SIWB flight activity has been carried by AleniaAermacchi and Dassault Aviation with the precious participation and support of the Italian and French Ministries of Defence, who have provided means, materials and analytical capabilities to allow for a complex and successful flight test campaign. nEUROn Flight 99 (the 10<sup>th</sup> and last SIWB development flight carried out in France) closed the SIWB development flight test phase with good results: the 2 targets deployed by the customer were automatically detected and recognized during all passes, at different distances and matching the requirement, with a probability higher than 90% (as the system communicated to the GCS operator). In the following, Fig. 5 shows a NFOV picture of a tank.



Fig. 5: NFoV IR tank image captured by the sensor during flight 99

The demonstration of the autonomous detection and recognition capability of relocatable ground targets has been therefore reached in France along the development flight campaign, before shipping the aircraft to Italy, Decimomannu Airforce Base, to carry out the set of Italian operational assessment flights. The SIWB development flight campaign has represented about 10% of the overall nEUROn flight campaign, which has successfully opened the flight envelope of the aircraft and demonstrated all key technologies incorporated in the UCAV demonstrator.

## 6.0 OPERATIONAL ASSESSMENT: OPTIMAL TRAJECTORY DESIGN AND FLIGHT TEST

As part of the program, following the success of development testing, an operational assessment has been performed, letting the nEUROn fly a representative mission in a realistic scenario. Specific studies regarding the design of minimum RCS profiles and related flight testing were performed. A brief overview is given in this section. The problem of designing an RCS optimal trajectory is graphically reported in Figure 6, where, for the ease of discussion, a 2D case has been represented.

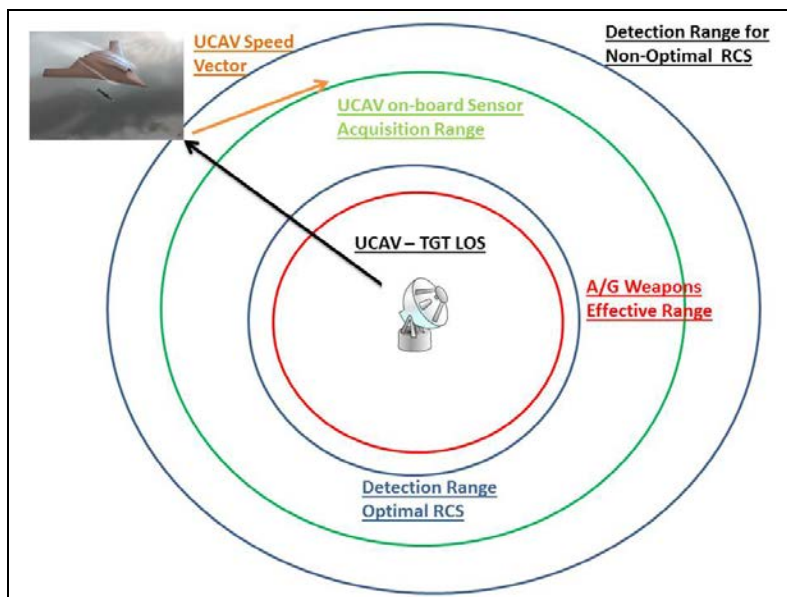


Fig. 6: optimal RCS design problem



UCAV tasks are:

1. positively acquire and identify the target;
2. perform the attack run by coming close enough to the target to effectively use onboard weapons;
3. being effectively covert while executing the previous tasks: this may include that the UCAV may not stay covert in some transients, provided that the time would be so short that Anti-Aircraft defenses cannot initialize a useful track.

Thanks to its LO characteristics, the UCAV can exploit the reduced RCS features to increase mission success. Nevertheless, as well known from theory, optimal RCS cannot be guaranteed under all aspect angles, i.e. there are solid angles where RCS is optimal and where it is not, therefore the reduction of detection range from ground threats is possible only when the threat is placed under such optimal solid angles. Moreover, due to design trade-offs, on board sensors effectiveness is limited to a number of solid angles and, obviously, to specific ranges. The profile design should be divided in the following phases:

- acquisition/identification, during which the UCAV places the threat in the solid angle resulting from the intersection of sensors field of regard and optimal RCS solid angles;
- attack run, during which the UCAV flies towards the target at the effective weapon range, minimizing the RCS exposed to the threat.

This exercise should take into account:

- on-board sensors field of regard limitations and asymmetries with respect to the UCAV centre-line;
- UCAV acquisition/identification time;
- conservative assumption that effective weapon range might be below the optimal RCS detection range;
- ground threat detection/acquisition time.

Moving to 3D modelling, and taking into account all the related constraints, the RCS trajectory design can be formalized in terms of a complex non-linear constrained optimization problem. Provided that the problem is feasible and some solutions can be found, one or more possible trajectories can be designed.

Some simple results, based on pure geometrical analysis, can be discussed:

- if the optimal RCS angle is around boresight, the UCAV would be covert during attack run but this will reduce the available time for the target acquisition/identification phase;
- if the optimal RCS is at an off-head angle from around 80° onwards, the UCAV would enjoy the possibility of loitering around the target for longer time, easing the target acquisition/identification phase, whilst losing covertness during the attack run;
- if the optimal RCS is at an off-head angle around 45°, the trajectory would take the form of a spiral: at each 360° heading change, the UCAV will get closer to the threat. In this case a trade-off is possible between the available time to staying covert during the acquisition/identification phase, and the minimization of the time to perform the attack run.

Once the mathematical problem of designing a trajectory is solved, the following one is to verify that this trajectory can be translated in a flyable flight plan to be precisely flown, not only in terms of 3D deviations, but also with planned attitude maneuvers. The resulting flight path must not unacceptably deviate from the ideal one. This consideration is the starting point of the flight test campaign, that is, basically, a specific verification of the suitability of:

- the mission planning station;
- the guidance law of the UCAV FCS;
- proper flying qualities.

The goal of the operational flight test activity was therefore to:

- verify the suitability of the navigation system/logic in order to allow the precise navigation of the optimal trajectory, both in terms of localization and aspect angle to the threat;
- verify that the transitions among different parts of the navigation plan do not expose non-optimal RCS angles to the threat for sufficient time to initialize a track;
- verify that UCAV flying qualities do not alter the planned aspect angles exposed to the threats.

Part of the flight test campaign would therefore be devoted to verify if possible shortfalls of the navigation system can be identified and solved in next system developments and if suitable workaround can be identified to ensure mission effectiveness

## **7.0 CONCLUSIONS AND FUTURE DEVELOPMENTS**

The nEUROn UCAV demonstrator represents a success story of European cooperation at its best. Reaching sufficient maturation within the program time frame and demonstrating in flight a full new set of technologies was the main challenge, which has been well managed thanks to partners' cooperation and customers' support, so that expectations have been met.

The paper, focused on the Italian workshare contribution, has shown how this result has been reached regarding the combat capability technologies and LO operational assessment. In order for these technologies to be operational in a UCAV in a real combat scenario, some maturation still needs to be performed, in particular in terms of adaptability to different scenarios. It is our wish to complete this step in a possible future program which would see Europe developing a joint operational UCAV.