UAV Autonomy –
Which level is desirable? – Which level is acceptable?
Alenia Aeronautica Viewpoint

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ABSTRACT

The implementation of the autonomy is an essential step inside the roadmap for the development of UAV systems.
This capability would allow performing some of mission functionalities with better efficiency and effectiveness. Moreover it allows mitigating some of the problems related to the latency in the operational control of the system, reducing the need for high performance communication infrastructure and increasing the robustness of the system against intentional or unintentional interference.
Some of the key technologies required to support the implementation of the autonomy in the UAV have reached an adequate maturity levels allowing the development of demonstration on ground and in flight, essential before the migration of such solutions to products.
The roadmap for such demonstrations cannot forget the implications of the UAV autonomy from the air traffic control and certification authorities and Customer community.
One of the key questions is which level of autonomy is acceptable by air traffic authority and by type certification requirements.
Also in the military field similar issues are important for the implementation of the appropriate level of autonomy: the trade-off is between the level of autonomy that is desirable for an effective use of the weapon system and the one that is compatible with the legal constraints and need for compliance with the Rule of Engagement.
Alenia Aeronautica is working in addressing these issues from the conceptual and technologies demonstration point of views.
Indeed, Alenia Aeronautica is sustaining both a number of applied researches in UAV autonomy and UAV demonstrator programs, like Sky-X and Neuron.
The intended demonstrations will include: automatic takeoff and landing, initially with landing aids, for evolving to a full autonomous TOL after an autonomous taxi, autonomous mission re-planning, contingency managements and mission automation.
Further demonstration will address the capabilities of performing a full autonomous attack phase that include: autonomous target detection, recognition and classification, autonomous attack plan definition along with re-planning, and ordnance release management in coordination with GCS for human consent when needed.

1.0 INTRODUCTION

The increasing number of UAV in service inside the military fleet of several nations has allowed the users to define the improvements needed in order to increase the operational effectiveness of such systems and to identify the requirements to expand the roles and missions allocated to such systems.

Comprehensive analyses have been carried out to identify the critical technologies that would enable the

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development of autonomy in several nations and to correlate them to the different classes of UAV and missions (see reference [1]).

Moreover the industry analyses of the technical solutions, feasible to expand the market opportunity for UAV systems, have also identified the autonomy as a critical capability.

Alenia Aeronautica has identified the UAV as an important opportunity and has started since early 1990 to work on the technologies and concepts to support the development of system solutions.

During these activities a set of key enabling technologies has been identified and a roadmap for their maturation has been established.

The paper provides the company view through the answers of three basic questions:

- Why we address autonomy in our systems?
- How much autonomy is required for a specific system?
- How to assess the autonomy level of a system?

These analyses have been based on the company experience, including its collaboration with several academic organisations, and on the analysis of the literature addressing the issue of unmanned systems autonomy.

A view of the experience and on-going activity in Alenia Aeronautica has been finally provided.

2.0 WHY WE ADDRESS AUTONOMY IN OUR SYSTEMS?

The UAV have been originally considered as a solution to conduct the dangerous, dull and dirty (D3) missions.

The first generation of these systems has been designed with quite limited capabilities, that affected their flexibility and in some operational situation also their effectiveness.

The physical separation between the human operator, that maintains the authority and responsibility over the mission execution and the air vehicle that executes the tasks over the area of interest introduces some potential weaknesses in the system.

The communication link, that assures the command and control, introduces latency that can prevent the operator to effectively provide feedback, with reaction time compatible with the mission requirements; moreover the datalink bandwidth can limit the extent at which the data and information collected in the area of operations can be available to the operators for analysis, exploitation and dissemination.

The communication link is also susceptible to intentional or unintentional jamming that can limit its availability also during critical phases of the missions.

Moreover the analysis of the records relative to the mishap of in service UAV has shown that a significant number of events are due to operator errors (see reference [2]).

In order to overcome such potential shortfalls, among the possible solutions, the development of the UAV autonomy has been identified as a feasible way.

The autonomy shall compensate the possible break in the command and control link and shall allow the air vehicle implementing a behaviour that can be predicted by the operator, that remains the final authority in the system, but it is defined autonomously by the air vehicle itself.

The autonomy allows reducing the frequency at which the operators has to interact with the air vehicle supporting the implementation of more robust system solutions, where the role of the operators is to manage and supervise, through appropriate human machine interface, the command and control functions without direct interaction.

This approach will impact in reducing the human errors, allowing operators to concentrate on the key tasks and events that characterise the mission.

The capability for the air vehicle to execute some tasks of the missions with limited interaction with the operator reduces also the susceptibility of the UAV system to temporary loss of the communications link, assuring a predictable behaviour of the air vehicle and supporting the overall system safety.

Example of typical applications will include the autonomous implementation of the following functionalities:

- fly by sensor, allowing the air vehicle to implement trajectory optimised to support sensor employment;
- fly by signature, allowing the air vehicle to implement trajectory optimised to limit its exposure to hostile sensors;
- communication system management, allowing the air vehicle to optimise the use of the communication resources;
- air vehicle health management, allowing the air vehicle to check and react autonomously to failures;
- air vehicle contingency plan definition and management, allowing the air vehicle to define and implement solution in case of failures;
- overall mission management, allowing the air vehicle to re-plan the mission in case of event based on available situation awareness, defined on the basis of self defined information or data provided externally.

Besides the air vehicle, there are the sensor management and data processing that can be greatly benefit by the availability of autonomous functionalities that can reduce the communication bandwidth requirements and the operator workload allowing him to concentrate on the analysis and on the exploitation of a subset of pre-filtered data.

All these benefits assume more relevance during the execution of the complex missions carried out in hostile environments where the operators should concentrate on the primary mission objectives.

The evolution of UAV in executing combat missions increases the need to implement higher degree of autonomy. Combat missions are characterised by larger complexity with usually more than one system acting in the scenario. In this situation the role of operators is likely to be the monitoring and the supervision of the mission execution by a group of UAV systems, up to a swarm in the future.

These UCAV need to have the capability not only to manage themselves but also to coordinate each other to assure a safe and efficient conduct of the mission and to manage their interaction with the operator in the Control Station and with the other systems, acting them as part of a System of Systems.

3.0 HOW MUCH AUTONOMY IS REQUIRED FOR A SPECIFIC SYSTEM?

The answer to this question implies to address two issues:

- Which functionalities of the UAV need to be autonomous, taking into account the specific roles to be executed by the system?
- Which level of autonomy is required for these functionalities?
- Which is the balance between the human supervised and the autonomous behaviour?

The implementation of the autonomy in the different functionalities performed by the UAV system is steered by the identification of the key areas whose autonomous execution would improve the system safety, the system reliability and the mission effectiveness.

A general rule of thumbs correlates the level of autonomy to the complexity of the tasks to be performed by the UAV systems: simple surveillance missions conducted by a single air vehicle in friendly area would require less autonomy than complex combat missions executed by a swarm of UAV inside a hostile scenario.

The regulations could affect the implementation of the autonomy.

- They can require the definition of some automatic behaviour for the system in case of loss of the communications or can require the capability of the system to perform self diagnosis to be able to manage on-board failures.
- They can prevent the implementation of high level of autonomy that can prevent a completely predictable behaviour of the air vehicle

In any case it is essential that the implementation of the autonomy in the UAV keeps into account the level of the situation awareness of the system and specifically that the air vehicle can base its autonomous decision on a reliable set of information about the evolution of the situation including its status.

Moreover in specific mission phases the impact of unpredictable changes of behaviour could have catastrophic effects and any system autonomous decisions, implying re-planning of the mission, needs to be validated by the operator when feasible (datalink loss).

Beside these issues, the effectiveness of the UAV, in performing specific mission tasks, could be increased through the implementation of further autonomy.

The development of autonomous capability to develop on-board situation awareness and take decisions about the implementation of the next mission phases is important in order to compress the timeline in reacting to the evolution of the scenario conditions. It is an important factor during long surveillance missions in order to reduce the operator workload and the datalink bandwidth requirements. It is also a critical factor to support a timely reaction of the air vehicle to unplanned events.

Finally there are tasks that can be only managed through their automation, such as the control of several air vehicles acting co-operatively in the same mission.

On the other hand there are a number of factor that would limit the implementation of autonomy on the system. Among the other is significant to refer to the superior capability of human to understand even for simple problems and to the availability of appropriate technologies.

In any case the integration of autonomy on the air vehicle is not the full story. The capability of the air vehicle to implement its mission planning with limited interaction with the operators should not reduce the

situation awareness in the Control Station about the evolution of the situation, including the status of the air vehicle. In order to allow the operators to maintain a complete control of the air vehicle a synthetic representation of the mission status needs to be implemented, with an accuracy and reliability sufficient to provide to the operators the awareness of the evolution of the mission execution.
It is in fact essential to provide the operators with a robust knowledge about the behaviour of the air vehicle in order to allow him to monitor the evolution, with the possibility to react in case unexpected events would happen.

4.0 HOW TO ASSESS THE AUTONOMY LEVEL OF A SYSTEM?

Once the level of autonomy, required to implement properly the required functionalities, is defined, the issue that immediately arises is relative to the process to be used in order to verify that the adequate level of autonomy is reached.

The task is not straightforward because, as all novel technological areas, the maturation of the autonomy is almost parallel to the development of the process to assess it.

Efforts are on-going in the Customer, academic and industrial community to define an approach that can be jointly agreed. Specific programs are on going in US (see reference [2] and [3]).

There have been attempts (see references [4] and [5]) to compare the execution of the surveillance mission by human directed systems and by autonomous systems.

Studies have been conducted to address specific issues that are key in supporting the proper implementation of the autonomy in the UAV (see references [6] and [7])

One of the most comprehensive approach is the US Air Force Research Laboratory (see reference [8]) that defined the Autonomous Control Level (ACL): it maps 11 levels of autonomy over the 4 descriptors represented by the steps of the Observe-Orient-Decide-Act (OODA) loop.

This approach covers also the multi UAV operations that, as said before, are absolutely dependent on the implementation of appropriate autonomy levels.

The National Institute of Standards and Technology (NIST) has set-up an ad-hoc group to address the autonomy issue. The group proposed a framework to manage the Autonomy Levels for Unmanned Systems (ALFUS) (see references [9], [10] and [11]).

Level	Level Descriptor	Observe	Orient	Decide	Act
		Perception/Situational Awareness	Analysis/Coordination	Decision Making	Capability
10	Fully Autonomous	Cognizant of all within Battlespace	Coordinates as necessary	Capable of total independance	Requires little guidance to do job
		Battlespace inference - Intent of self and others	Strategic group goals assigned	Distributed tactical group planning	Group accomplishment of strategic goal with
9	Battlespace	(allies and foes).		Individual determination of tactical goal	no supervisory assistance
	Swarm	Complex/intense environment - on-board tracking	Enemy strategy inferred	Individual task planning/execution	
	Cognizance			Choose tactical targets	
8		Proximity inference - intent of self and others	Strategic group goals assigned	Coordinated tactical group planning	Group accomplishment of strategic goal with
	Battlespace	(allies and foes)		Individual task planning/execution	minimal supervisory assistance
	Cognizance	Reduced dependance upon off-board data	Enemy tactics inferred	Choose targets of opportunity	(example: go SCUD hunting)
			ATR		
7		Short track awareness - History and predictive battlesp	Tactical group goals assigned	Individual task planning/execution to meet goals	Group accomplishment of tactical goal with
	Battlespace	data in limited range, timeframe, and numbers	Enemy trajectory estimated		minimal supervisory assistance
	Knowledge	Limited inference supplemented by off-board data			
6	Real Time		Tactical group goals assigned	Coordinated trajectory planning and execution to meet	Group accomplishment of tactical goal with
	Multi-Vehicle	Ranged awareness - on-board sensing for long range,	Enemy location sensed/estimated	goals - group optimization	minimal supervisory assistance
	Cooperation	supplemented by off-board data			
					Possible close air space separation (1-100 yds)
5	Real Time	Sensed awareness - Local sensors to detect others,	Tactical group plan assigned	On-board trajectory replanning - optimizes for	Group accomplishment of tactical plan as externally
	Multi-Vehicle	Fused with off-board data	RT Health Diagnosis; Ability to compensate for most	current and predictive conditions	assigned
	Coordination		failures and flight conditions; Ability to predict onset of	Collision avoidance	Air collision avoidance
			failures (e.g. Prognostic Health Mgmt)		Possible close air space separation (1-100 yds) for
			Group diagnosis and resource management		AAR, formation in non-threat conditions
4		Deliberate awareness - allies communicate data	Tactical plan assigned	On-board trajectory replanning - event driven	Self accomplishment of tactical plan as externally
	Fault/Event		Assigned Rules of Engagement	Self resource management	assigned
	Adaptive		RT Health Diagnosis; Ability to compensate for most	Deconfliction	
	Vehicle		failures and flight conditions - inner loop changes		
			reflected in outer loop performance		Medium vehicle airspace separation (100's of yds)
3	Robust Response	Health/status history & models	Tactical plan assigned	Evaluate status vs required mission capabilities	Self accomplishment of tactical plan as externally
	to Real Time		RT Health Diag (What is the extent of the problems?)	Abort/RTB if insufficient	assigned
	Faults/Events		Ability to compensate for most control failures and		
			flight conditions (i.e. adaptive inner-loop control)		
2		Health/status sensors	RT Health diagnosis (Do I have problems?)	Execute preprogrammed or uploaded plans	Self accomplishment of tactical plan as externally
	Changeable		Off-board replan (as required)	in response to mission and health conditions	assigned
	Mission				
1	Execute	Preloaded mission data			
	Preplanned	Flight Control and Navigation Sensing	Pre/Post Flight BIT	Preprogrammed mission and abort plans	Wide airspace separation requirements (miles)
	Mission		Report status		
0	Remotely	Flight Control (attitude, rates) sensing	Telemetered data	N/A	Control by remote pilot
	Piloted	Nose camera	Remote pilot commands		
	Vehicle				

Figure 1: final ACL chart (from ref. [8])

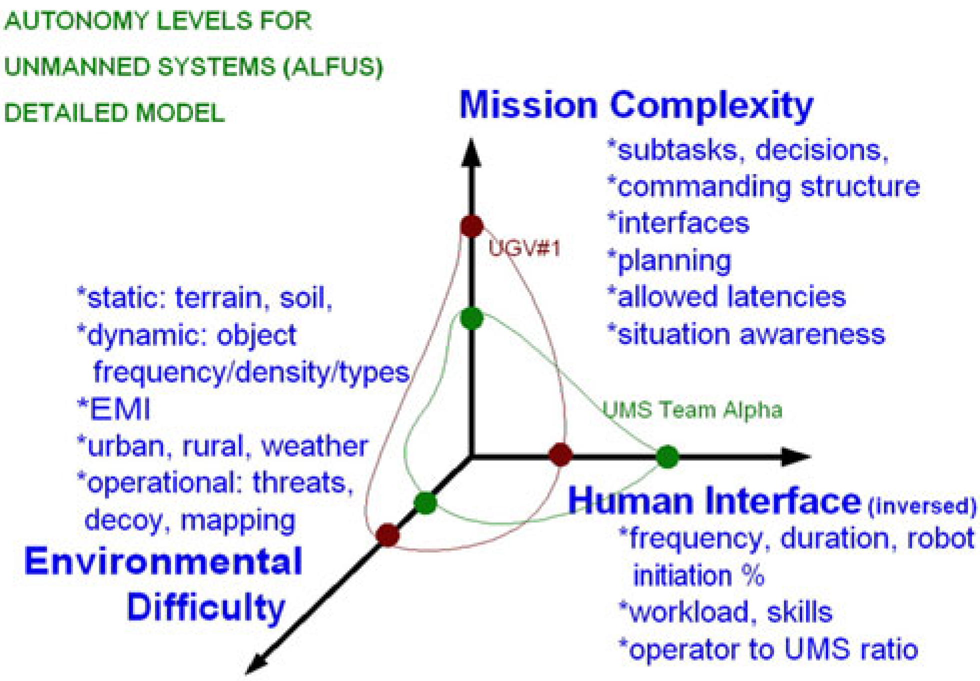

Figure 2: ALFUS model (from http://www.isd.mel.nist.gov/projects/autonomy_levels/)

Within the ALFUS work group, the autonomy of an unmanned system is defined as its own ability to achieve its mission goals. Therefore, the more complex goals imply higher levels of autonomy. A model to assess the achievement of the level of autonomy required has been defined.
Several others studies have been conducted in US, Australia and Europe, generating alternative metrics to assess quantitative and qualitative the autonomy of a system or of a system of systems.

NATO has launched a specific initiative in the recent past that had the aim to create an agreed definition of the autonomy (see reference [12]).

The NATO WG defined four levels to classify the autonomy of a UAV system.

Level 1: Remotely Controlled System - System reactions and behaviour depend on operator input

Level 2: Automated System - Reactions and behaviour depend on fixed built-in functionality (pre-programmed)

Level 3: Autonomous non-learning system - Behaviour depends upon fixed built-in functionality or upon a fixed set of rules that dictate system behaviour (goal-directed reaction and behaviour).

Level 4: Autonomous learning system with the ability to modify rules defining behaviours - Behaviour depends upon a set of rules that can be modified for continuously improving goal directed reactions and behaviours within an overarching set of inviolate rules/behaviours.

The approach is similar to the one applied by AFRL: the NATO metrics to evaluate the autonomy level of a system is related to the OODA loop steps.

The proposed metrics requires the evaluation of the autonomous functionalities, in most cases at qualitative levels, but, as mentioned before, the ALFUS initiative tried to set-up quantitative metrics.

There are other approaches to define quantitative metrics (see reference [13]), at least for some specific mission tasks where it seems possible to develop a structure quantitative approach that correlate the execution of the specific functionalities to the effectiveness of the overall missions.

All the above efforts have been essential steps in developing a robust path to the implementation of the autonomy in the UAV and they are at the basis of the current approach in the assessment of the development activities.

5.0 ALENIA EXPERIENCE

Alenia Aeronautica has developing a set of UAV related activity able to support the definition in the near-medium term of UAV products.

Specific research programmes have been carried out, in Italy or in Europe, in partnership with other companies, to identify technology requirements and develop solutions in the areas of autonomous mission management and advanced control station (see references [14] and [15]).

Alenia has also participated to several NATO initiatives: among the other is worthwhile to cite the NATO Industrial Advisory Group Study Group 75 on "Pre-feasibility Study on UAV Autonomous Operations" and System Concepts and Integration (SCI) Panel Task Group 118 on "Automation Technologies and Application Considerations For Highly Integrated Mission Systems".

These on-going activities include also the development of applied researches in the field of UAV autonomy finalised to develop the enabling technologies that would support the implementation of autonomous behaviour.

The programmes cover the full spread of UAV classes from surveillance systems to UCAV, operating as single air vehicle, with the need to be integrated in civil air traffic or as formation of combat systems with the need to strictly coordinate their behaviour inside hostile environments.

The on-going technology maturation and related full scale flight demonstrations will include: automatic takeoff and landing, initially performed with landing aids, for evolving to a full autonomous TOL after an autonomous taxi, autonomous mission re-planning, contingency managements and mission automation.

Further demonstration will address the capabilities of performing a full autonomous attack phase that include: autonomous target detection, recognition and classification, autonomous attack plan definition along with re-planning, and ordnance release management in coordination with GCS for human consent when needed.

All the demonstration activity is based on the availability of technology demonstration UAV systems:

- Sky-X
- Neuron

While other company UAV demonstrators are presently in full development.

Each of them has its own demonstration activity plan that includes the maturation of the technologies, their integration in the systems and the relevant validation test in flight.

The final goal is to reach a Technology Readiness Level allowing the migration of the technologies in the future UAV products with a minimum technological risk.

The following autonomous technologies will be demonstrated in the Sky-X:

- Autonomous Take-off and Landing (ATOL)
- Autonomous Mission execution (synthetic vision)
- Autonomous mission re-planning
- Automatic Air Refuelling

Figure 3: Sky-X UAV demonstrator during flight test in the Vidsel test range (Sweden)

The following technologies will be demonstrated in the Neuron:

- Autonomous Ordnance Management
- Autonomous Target Identification

The first item includes the capability to implement an intelligent management of the ordnance integrated in the weapon bay, including the definition of the optimum release point and the management of the contingency.

The second item includes the capability to implement ad-hoc trajectory suitable to the collection of the information in the area of interest and the capability to process the data in order to autonomously detect and recognise the targets.

The above technologies will be demonstrated through the Smart Integrated Weapon Bay (SIWB) concept.

Figure 4: Neuron UCAV demonstrator

The first UAV system that will benefit of the autonomous technologies will be the Molynx. It is an Alenia Aeronautica initiative aimed at providing an advanced MALE UAV product for a large spectrum of applications, such as:

- Border Patrol and Smuggling Prevention
- Fire Fighting: Detection/Monitoring/Rescue operation
- Disaster relief
- Traffic Control
- Emergency Communication Relay
- Environmental Monitoring
- Fishing control

This product will implement several autonomous capabilities including

- Automatic take-off and landing
- Automatic taxi on ground
- Automatic contingency management
- Automatic mission re-planning
- Automatic avoidance of dangerous areas
- Automatic execution of mission planning

Potential evolution of the system to carry out commercial activities is envisaged, even if a maturity of the market, including the proper evolution of the regulations related to the use of the UAV in non segregated areas is required.

Figure 5: Molynx Male UAV

6.0 CONCLUSION

The development of the autonomy of the UAV is a key factor in evolution of such system.

There are several initiatives on-going in order to set-up a properly framework that supports the definition of the autonomous needs and controls the implementation of the autonomous capabilities.

It is clear that the allocation of more and more complex tasks to the UAV would require the increase of the autonomy of the air vehicle in order to allow it to conduct the associated functionalities with performance compatible with the tasks.

A proper balance between the benefits coming from more autonomous systems and the cost and complexity derived from the integration of high level of autonomy need to be pursued.

Moreover any technical solution needs to guarantee the levels of safety and controllability of the system by the human being, in compliance with regulations defined the authorities that certify the system and that supervise the air traffic.

Alenia Aeronautica, as part of the efforts to mature the UAV enabling technologies, has developing and testing a set of autonomous capabilities on its UAV technologies demonstrators.

These technologies maturation is a step for the development of the autonomous functionalities of its UAV product.

Significant results in this area have been achieved, also through a continuous collaboration with the academic community.
New challenging objectives have been set in the company UAV roadmap to mature a set of enabling technologies that are considered essential for the development of effective systems.

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