Integrating civil unmanned aircraft operating autonomously in non-segregated airspace: towards a dronoethics?

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Abstract. In the context of integrating Unmanned Aircraft Systems (UAS) in non-segregated airspace, autonomous operations raise legal and ethical questions. What is the expected behaviour of a civil unmanned aircraft operating autonomously in an airspace shared with other airspace users? And how could we implement this behaviour? We present in this paper a preliminary study that allowed us, through the analysis of aviation reference documents, to identify some ethical criteria necessary to develop a first set of logical rules formalizing this expected behaviour.

1 TERMINOLOGY AND SCOPE

UAS and UAOA

The term UAS designates the global system of an aircraft (UA) and its associated elements operated with no pilot on board. Regulators currently distinguish two types of Unmanned Aircraft (UA): the Remotely-piloted aircraft (RPA) which are remotely and fully controlled from another place by a licensed remote pilot, and autonomous unmanned aircraft, that do not allow pilot intervention in the management of the flight. As the purpose of our study is not to clarify the terminology linked to autonomous aircraft or operations, we will use in this paper the unofficial acronym UAOA (Unmanned Aircraft Operating Autonomously) to designate an UA that must at time t manage its flight and make decisions without any human intervention. This definition does not exclude communication links with pilot or any other authorized personnel such as Air Traffic Service (ATS), and potential orders or requests sent by these actors.

Dronoethics

In reference to the term roboethics, the name dronoethics is introduced to refer to an Applied Ethics dedicated to UAS.

Civil vs military

Our study is focussed on civil autonomous operations and does not encompass specific military ethical issues, such as the acceptable loss of human life.

2 INTRODUCTION

In the last decades, the use of Unmanned Aircraft Systems (UAS) has significantly increased in the military domain but despite the large variety of civil applications identified, the civil market has not yet developed significantly, due to the inability for UAS to access to non-segregated airspace. The need to operate military, commercial, and privately-owned unmanned aircraft in the same airspace as manned aircraft, especially outside segregated areas is now considered by all regulators as a high priority [1].

Nowadays, UAS are generally operated in segregated areas or with operations limited to specific airspace (e.g. temporary restricted, low-density/unpopulated areas) and specific procedures (e.g. low-range, visual observers on ground) [2]. If these alternatives allow managing current operations on a case-by-case basis, they are not sufficient to deal with the forecast growth of UAS operations and the whole ATM/UAS community is now developing simultaneously the operational, procedural and technological framework required for the UAS integration in non-segregated airspace [25].

According to ICAO, only Remotely-piloted aircraft (RPA) will be able to integrate into the international civil aviation system in the foreseeable future [3]. Nevertheless our study is focussed on Unmanned Aircraft Operating Autonomously (UAOA) operations in non-segregated airspace that may represent the biggest challenge of the UAS integration in the future.

If we consider the new Air Traffic Management (ATM) Concepts of operations (CONOPS) defined within current international programmes such as SESAR [4], the first idea is that UAS, as new airspace users, should mirror the procedures applicable to manned aircraft, without any special requirement for the Air Traffic Controllers (ATC), and without increasing the risk for other airspace users. Thus if we intent to integrate UAS into non-segregated airspace, within this ATM framework, they should behave like manned aircraft, whatever their mode of operations (human-in-the-loop or acting autonomously): an UAOA is then supposed to reproduce manned aircraft behaviour i.e. to make the same choices as a pilot onboard would make.

If many technical and operational studies have dealt with problematic like the Detect and Avoid concept to replace the See and Avoid procedure, the legal framework linked to the responsibility of an UAOA in case of accident is insufficient [5] and ethical issues have not been enough addressed [6]. In parallel, the importance of robot ethics (or roboethics) has been raised recently by working groups such as [7]. Following roboethics recommendations e.g. from the ethical committee of the French Scientific Research Centre CNRS [8], could we also consider endowing UAOA with moral sense or ethics that could allow them to act ethically when they must make decisions?

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To the heart of these considerations, our study aims at exploring three questions:

- What could be the ethical behaviour expected from an UAS in non-segregated airspace? Which criteria express this behaviour? Is this behaviour a mirror of the manned aviation behaviour?
- Could we formalize this behaviour as a set of logical rules?
- How do we imagine applying these rules to UAOA?

As a first answer, this paper presents a preliminary analysis leading to the elaboration of a first set of ethical principles that could serve as a basis for the definition of UAOA logical rules.

3 TOWARDS AN ETHICAL BEHAVIOUR: IDENTIFICATION OF CRITERIA

3.1 Rules of the Air

Whatever the region of the world overflown, pilots are supposed to know and apply Rules of the Air that provide rules to properly fly and manoeuvre aircraft. Defined at regional [9], sub-regional [10] or national level [11], they guarantee the rational behaviour of each aircraft. Within all these documents, we have identified five major topics that could be applicable to unmanned aircraft.

Safety - An aircraft must not endanger persons and property

During all the flight phases, the aircraft should not have behaviour potentially dangerous to persons or property. For instance, if the aircraft flies over a congested area, it should be at such height as will permit, in case of emergency, to safely land without hurting people on the ground. The main rule is that aircraft shall not be operated in such proximity to other aircraft as to create a collision hazard. Nevertheless according to the Rules of the Air, a pilot may depart from these rules in the interest of safety.

If we consider an UAOA, these simple rules are already challenging: a prerequisite is that the aircraft must know its position and be able to detect and analyze its environment before modifying its path.

Priority and status - An aircraft must interact with other Airspace Users (AU) according to priority rules

When two aircraft are converging, each of them must act according to right-of-way rules: one must yield the way and the other that has the right-of-way must maintain its heading and speed. Rules have been refined according to several scenarios e.g. approaching head-on, overtaking or converging but these rules have exceptions linked to the type of aircraft. Typically aircraft with less manoeuvrability has the right-of-way but this rule is superseded when an aircraft is in distress and therefore has the priority to all other traffic.

From an UAOA point of view, several conditions seem to be necessary. Firstly the aircraft must have self-awareness about its type of aircraft and its current status (Unmanned aircraft with no passengers onboard? Flight leader of a squadron of aircraft flying in formation? In a final approach? In an emergency mode?). Then knowing its type and status, the aircraft must be able to communicate this information to all other airspace users via signals or anti-collision and navigation lights. It must also identify the status of the surrounding traffic. For instance even if it is supposed to have the right-of-way, it must detect whether the convergent aircraft is landing or is in distress and in that case yield the way.

Communication - An aircraft must continuously communicate with Air Traffic Services (ATS)

Each aircraft should comply with any instruction given by the appropriate ATS unit. Even if its flight is in line with the flight plan and the ATC orders, it should report its position when passing reporting points or periodically. And as soon as there is a deviation from the requirements, it should be communicated to air traffic services unit. To ensure this permanent interaction, the aircraft should always maintain a continuous air-ground communication, if possible with a dual channel (radio and data link). In case of failure of this communication, the aircraft must attempt to restore a communication with the appropriate ATC unit using all other available means.

In case of UAS, this could imply to maintain or try to establish the communication, to answer to potential ATS requests and to take into account these clearances in its decision-making process.

Predictability - An aircraft must have a predictable flight

Before departure, for each aircraft flying in controlled airspace, a flight plan should have been submitted to air traffic services containing as information as possible, including the forecast route but also alternative procedures. If any potential modification can be anticipated, it must be indicated in the flight plan. During the flight, the aircraft is supposed to adhere as much as possible to the flight plan but if it fails to stick to this plan, its behaviour should still be predictable. For instance the aircraft could maintain its heading and speed when it encounters some problems and then rejoin its current flight plan route no later than the next significant point. In the same way, it could land at the nearest suitable aerodrome, easily identifiable by air traffic services.

This requirement of predictability is one of the most challenging when considering an UAOA that could make decisions based on different choices, including ATC instructions. This implies specifically that alternatives should be identified and emergent behaviours anticipated.

Emergency - An aircraft must handle emergency procedures

A predictable behaviour includes non-nominal use cases when the aircraft operates in an emergency mode. In case of a loss of communication, it could for instance maintain its speed and heading during a few minutes and try to reconnect to its ground station, before entering a new emergency phase with the choice of continuing its flight or landing at a close aerodrome. Aircraft should also be able to comply with interception rules that specify the procedures to manage the instructions given by the intercepting aircraft. Therefore an UAOA should firstly know when it is operating in emergency mode, then have a catalogue of contingency plans, communicate all its choices and finally if intercepted act accordingly with interception rules, superior to any previous order.

3.2 Limitations of the Rules of the Air

Rules of the Air allow identifying high level requirements defining the rational behaviour expected from an aircraft in a shared airspace. Nevertheless a major question in the current development of UAS regulation is whether it can be based on these regulations or whether UAS have substantially different characteristics that require new regulation. According to [12], only 30% of current manned aviation regulation applies as it to UAS, with 54% that may apply or require revision and 16% that does not apply.

Some initiatives [2][13] recommend consequently considering alternative approaches with a new way of thinking. Following UAS specificities could lead for instance to new operational procedures and modifications to existing regulations:

- Priority: in some cases, small unmanned aircraft could yield the right-of-way to manned aircraft
- "Sacrificability": in order to minimize risk to persons and property, an UAS crash could be considered in a controlled manner
- Severity of loss: although for manned aviation loss of an aircraft would mean a high probability of multiple fatalities, in the case of UAS this is not necessarily true
- Security of communications: with a pilot on ground, the importance of communications link and availability of bandwidth is now fundamental

3.3 Key ATM expectations

If Rules of the Air are a set of rules guaranteeing a safe manned aviation, they do not explain the fundamental values that support these rules. And with a new airspace user that could imply the need for a revision of these rules, the whole coherence of the system may not be ensured. Like many industry business, the ATM world has defined its own performance indicators to assess the performance of the current system and to guide the development of future ATM systems. ICAO has thus defined eleven Key Performance Areas (KPAs) [14] [15] to categorize performance subjects related to high-level ATM ambitions and expectations. The figure hereafter presents these expectations that have been clustered during the SESAR definition phase [4] into three major groups, according to the degree of visibility of the KPA outcome and impact.

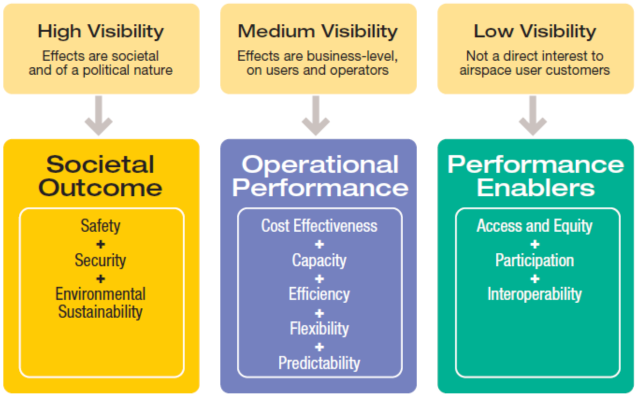

Figure 1. ATM performance targets applied to the European ATM system

As stated by ICAO [14], the ATM system should involve the participation of the entire aviation community: UAS, as new airspace users should therefore operate with a behaviour compatible with these ATM values, which means behaviour based on these values or that respects other airspace users in accordance with these values.

If we consider these ATM criteria from the UAS perspective, i.e. a new airspace user point of view, we can split these criteria in 3 groups according to the rules that can be inferred:

- ATM services: as any airspace user, UAS should have right to operate in a way compatible with [access and equity, participation to the ATM community, interoperability]
- ATM rules: as any airspace user, UAS operations should take into account [safety, security, environment, efficiency, flexibility and predictability]
- ATM global common good: UAS should not be operated in a way that could decrease the global performance of the ATM system according to [ATM rules], cost-effectiveness (cost of ATM services, e.g. the number of the Air Traffic Controller to face a raising workload, or the integration of new tools and systems to be developed and maintained) and capacity (decrease of the global capacity linked to UAS operations e.g. the insertion in a high density approach or the activation of a reserved airspace).

3.4 Limitations of ATM expectations

ICAO expectations are not fixed moral rules: they have been defined to answer to the 2025 expected scenario (without UAS specificities taken into account) and may be moving in the future [16]. Besides, like in many other domains it has always been difficult to quantify ethics in ATM and to transcribe an ethical behaviour into indicators.

3.5 UAS behaviour versus manned aviation behaviour

We noted in the introduction that one of the main concepts proposed for the integration of UAS in ATM environment was that UAS, as new airspace users, should mirror the procedures applicable to manned aircraft. After this analysis of current regulations and ATM expectations, we decided to transcend this first statement and envisage an UAS behaviour different from the manned aviation behaviour and in the same time acceptable for the manned aviation community.

Considering some criteria previously defined, we could imagine some UAS able to integrate as a parameter the global interest of the ATM community. Advanced algorithms could simulate and analyze the global impact of a modification of the UAS flight on the overall traffic based on criteria such as the capacity or the efficiency. Besides, data of interest (weather data, surrounding non-cooperative traffic detected by a Detect and Avoid system) could be shared with the ATM community according to the current needs, e.g. a volcanic ash particles analysis after a volcanic eruption. Finally we could imagine for some type of UAS mission a "Good Samaritan Law" that would bind an UAOA to assist other airspace users (or more generally humans) in need like basic international laws that require ships to assist other naval vessels in distress.

Such behaviour could also be beneficial to the manned aviation community that could adapt its own behaviour according to these new principles: a part of the role of the Network manager, in charge of the common good of the ATM (notably via the traffic flow and capacity management processes) could be delegated to airspace users, currently focused on personal mission/business needs.

4 TOWARDS A FIRST SET OF RULES FOR UAOA

As we considered roboethics studies and roadmaps as a reference for our study, we firstly explored sets of rules defined for autonomous robots to analyse their form (granularity of rules, logical assertions) but also their content (ethical requirements for autonomous agents, conflicts among laws).

4.1 Back to sci-fi robot rules

The most famous robot rules have been defined in 1942 by the science fiction author Isaac Asimov. In his novel [17], he introduced the following three laws of robotics:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm
2. A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

He also added a fourth law in a following novel to precede the others:

4. A robot may not harm humanity, or, by inaction, allow humanity to come to harm.

Within our UAOA problematic, the first law could refer to the first principle (safety) identified in the Rules of the Air: UAS should not be operated in such proximity to other aircraft as to create a collision hazard that could lead to human injury. Besides the injury through inaction could evoke the Good Samaritan law described at the end of first part. The second law could be interpreted as a rule specifying that an UAOA must always obey the orders of authorized personnel such as operators, ATS, and possibly in the future the Network Manager. The third law could be adapted to UAS operations that should avoid any danger threatening the existence of the aircraft (safety of goods). Nevertheless it should be linked with the principle of "sacrificability" described in first part. Finally, in the last law, humanity could recall the global common good described previously in the ATM expectations paragraph.

In our UAS context, it appears that sci-fi robot rules could help defining the expected behaviour of an UAOA integrated in air traffic. Some examples are listed hereafter:

- A robot must establish its identity as a robot in all cases (communication) [18]
- A robot must know it is a robot (identity) [19]
- A robot will obey the orders of authorized personnel (communication/orders) [20]
- Robots must refrain from damaging human homes or tools, including other robots (safety) [21]

4.2 Working groups and national initiatives

In April 2007, the government of Japan published recommendations to “secure the safe performance of next-generation robots”. The same month, the European Robotics Research Network (EURON) updated its “Roboethics Roadmap” [7]. But the most relevant initiative comes from South Korea that provided a “Robot Ethics Charter” that describes the rights and responsibilities for Robots on the basis of Asimov's laws but also with rights and responsibilities of manufacturers and users/owners.

According to [22], E.U will also establish a Roboethics Interest Group (RSI). Some standards should be particularly taken into account in the implementation of all robot types:

- Safety**:** Design of all robots must include provisions for control of the robot’s autonomy. Operators should be able to limit robots autonomy in scenarios in which the robots behaviour cannot be guaranteed
- Security**:** Design of all robots must include as a minimum standard the hardware and software keys to avoid illegal use of the robot.
- Traceability**:** Design of all robots must include provisions for the complete traceability of the robots’ actions, as in an aircraft’s ‘black-box’ system.
- "Identifiability"**:** All robots must be designed with protected serial and identification numbers.
- Privacy**:** Design of all robots potentially dealing with sensitive personal information must be equipped with hardware and software systems to encrypt and securely store this private data.

4.3 First set of rules

Starting from criteria identified via manned aviation reference documents or roboethics studies, we developed a first set of rules and rights that should be applicable to UAOA during the execution phase of its flight:

1) An UAOA must not operate in such a way it could injure a human being or let a human being injured without activating controls or functions identified as means to avoid or attenuate this type of incident.

2) An UAOA should always maintain a continuous communication with predefined interfaces to obey orders of authorized personnel (UAS operator, ATS, Network Manager…) except if such actions conflict with first law.

3) An UAOA must operate in such a way it could protect its own existence and any other human property, on ground or in the air, including other UAS, except if such operations conflict with first or second law.

4) An UAOA must always have a predictable behaviour, based on its route but also alternative pre-programmed scenarios, except if all forecast options conflict with first, second or third law.

5) An UAOA interacts with surrounding traffic (separation, communication) according to requirements of the operating airspace, general priority rules and emergency and interception procedures except if such actions conflict the first, the second or the third law.

6) An UAOA must always know its UAS identity and status and indicate it honestly when requested or when deemed necessary.

7) As any airspace user, an UAOA should not operate in a way that could decrease significantly the global performance of ATM system in terms of safety, security, environment, cost-effectiveness, capacity and quality of service (efficiency, flexibility and predictability), except if such operation is required by first, second or third law.

8) An UAOA must ensure a complete traceability of all its actions.

Other rules should be added but they seem difficult to implement at the UAOA level. They should then be ensured by the UAS community (participation to the ATM community, interoperability) and UAS designers/operators (security, privacy or interoperability). Some recent initiatives such as the UAS Operations Industry "Code of Conduct" [23] aim at providing such guidelines and recommendations for future UAS operations.

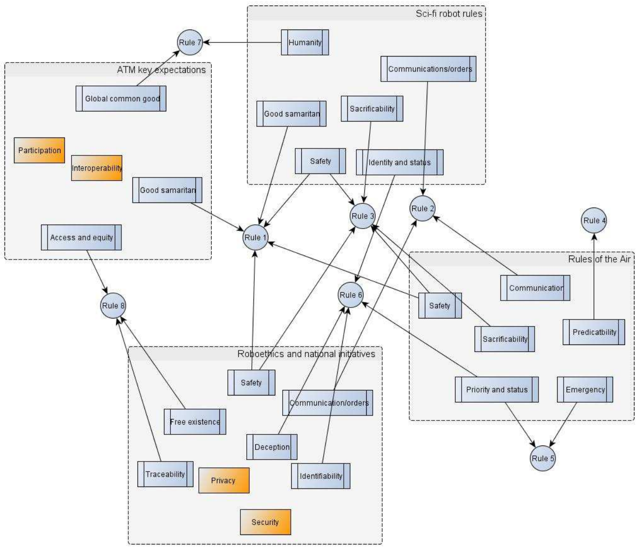

Figure 2. Correlation between UAOA rules and criteria

It should be noted that if these rules seem in line with current ATM regulations and principles, the exceptions and priorities may introduce important changes. For instance, if the fourth law states the need for a predictable behaviour, its exceptions allow unpredictable actions and therefore emergent behaviour in circumstances linked to the three first laws. Besides, the transformation of these ethical principles into logical rules will necessarily rely on the essential UAOA specificity, i.e. the absence of a pilot able to make decisions taking into account its own ethical values.

In the same way, some UAOA rights could be ensured by the establishment of general procedures. Last rule could help to verify the application of such rights, like the real access in equity of UAS to ATM resources without a priority mechanism leading to a systematic abuse limiting its efficiency and cost-effectiveness.

4.4 Conflicts and priorities among laws

Within the rules previously enounced, inherent criteria e.g. capacity or safety are interdependent, which implies improving the performance in one area can come at the price of reduced performance in another area. Some conflicts are unavoidable because ethics is by nature contradictory: they have been analyzed in [15] that presents some trade-offs between ATM criteria such as the access and equity versus the capacity. In the same way, the establishment of this first set of rules and rights applicable to UAOA allows us to identify potential conflicts:

- Human order versus safety: some orders given by the operator could contradict information coming from sensors onboard indicating a potential collision.
- Priority rules versus protection of existence: if the UAOA has the right-of-way, it should maintain its heading and speed. Nevertheless if another aircraft refuses to yield the way, the UAOA could adapt these parameters to protect its existence. In case of systematic violation of priority, such procedures should be considered to respect the right of UAOA to access and equity.
- "Sacrificability" versus safety: in some exceptional circumstances, some low-cost UAOA could be asked to voluntarily crash in order to avoid a potential danger.

According to the variety of aircraft and mission concerned, it seems therefore difficult to introduce clear priorities between logical UAOA rules previously described. However, safety is always the highest priority in aviation and is not subject to trade-offs. Therefore all the laws and even a combination of laws are applicable except if they conflict with first law. We can for instance imagine an UAOA threatened by an aircraft converging very quickly that chooses to violate the right-of-way of another UAS converging (law 5), even if the risk of collision with this UAS threatens its own existence (law 3) because of the risk of endangering human life aboard the first aircraft (law 1). In that kind of worst-case scenario, with a combination of laws conflicting together, we can foresee the danger of the behaviour of other airspace users that could be tempted to divert these rules to ensure personal benefices. Such behaviour should be analyzed in the post-flight phase ensured by the traceability ensured by the eighth law.

4.5 Limitations of UAOA rules

This first list of eight UAOA rules is an example that must be considered as the initial starting point of our study. Some iteration would be needed to review some terms and express clear responsibilities. For instance in the first law, it must be clarified who will "identify" the controls and functions that could allow an UAS to intervene after an accident. In the same way law 6 should specify exactly how an UAOA could answer "honestly" to requests. Then all the laws should be confronted to identify conflicts between laws.

Depending on the result of this analysis, another set of rules could be proposed, with fewer rules and less complexity between conflicting laws, such as the following set:

- Law 1: An UAOA should always maintain a continuous communication with predefined interfaces to obey orders of authorized personnel (UAS operator, ATS, Network Manager…).
- Law 2: An UAOA must not operate in such a way it could endanger persons and property except if such operation conflicts with first law.
- Law 3: An UAOA must always have a predictable behaviour, based on its route but also alternative pre-programmed scenarios, except if all forecast options conflict with first or second law.

This simplified set of rules could also ease the societal acceptability of autonomous operations. It could be then considered as a first step towards the application of the final set. That's why we inverted two first laws, considering that in a near future autonomous operations could be better accepted if it is acted that any human order can overcome any other decision.

5 CONCLUSION AND PERSPECTIVES

In this first phase of our study, we defined a first set of rules and rights via the analysis of criteria identified in ATM reference documents and in roboethics studies. As many other documents could be also relevant, we could reiterate this process in order to identify new criteria and refine this set.

Nevertheless we wish to explore alternative means to consolidate this first set of laws for instance via the definition of scenarios of UAOA integration such as UAS scenarios defined in [24] [25]. We will notably describe procedures for special cases such as loss of communication or critical system failures and apply them considering an UAOA complying with ethical rules. In parallel, we will analyse the potential correlation between various levels of automation in ATM and the integration of UAOA.

These analyses should allow us to identify rules to be added, removed or corrected and potential conflicts between combinations of laws, but also whether several sets need to be defined, according to the type of UAS, its type of mission and its degree of autonomy.

After this consolidation, we intend to formalize this ethical set a rules using non-monotonic logics [27], probably with the Answer Set Programming (ASP) formalism. This formalization will finalize the "logical" consolidation of our set and probably raise the question of how these rules could be applied to the development and execution of an UAOA: in the process of validation of control algorithms? Or directly injected as software overlay within an AI onboard able to integrate ethical criteria in its decision-making process?

Finally, in the same way as the development of intelligent robots raise the question of our fundamental ethical values, this study on UAOA could allow to consider new approaches for the "manned" aviation, with the introduction of new concepts of operation, the refinement of current rules and the application of UAS algorithms or systems to all airspace users.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to Jean Hermetz, Assistant Director of the System Design and Performances Evaluation Department and my colleagues Luis Basora and Dr. Charles Lesire for their valuable and constructive suggestions during the reviewing of this paper. I hope this final version will contribute to convincing them to start many studies on this topic.

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