European Commission

JRC SCIENCE AND POLICY REPORTS

Identification of current limitations for the use of unmanned aerial systems for border surveillance

Part A: Analysis of possible use for surveillance/monitoring, communications, signal detection

Limited Distribution

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2015

Report JRC96423

Joint Research Centre

European Commission
Joint Research Centre
Institute for the Protection and Security of the Citizen

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JRC96423

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Abstract

This report has been drafted upon the request of DG HOME in line with the Administrative Arrangement between JRC and DG HOME. The report provides an analysis of the possible use of Remotely Piloted Aircraft Systems (RPAS) for surveillance/monitoring, communications and signal detection, making a distinction between different types of RPAS (large, small or even immobile aerostats) as well as green and blue border surveillance. The analysis is used to define Criteria for supporting the design and procurement of RPAS or RPAS services for border surveillance missions. The fourteen Criteria address operational aspects for the establishment of surveillance networks using RPAS as well as aspects linked to the management and sustainability of the surveillance networks.

Contents_Toc421283319

Section 1 Introduction........ 4
1.1 Description of general approach........ 4
1.2 Breakdown of Missions of interest........ 5
Section 2 Analysis of Establishment (deployment capability) of surveillance systems........ 6
2.1 Analysis of deployment based on the location of the Specific Area of Interest........ 6
2.2 Analysis of deployment based on a RPAS systems approach........ 12
2.2.1 "Where" considerations........ 12
2.2.2 "When" considerations........ 14
2.3 Assessing the operational use and limitations of deployed RPAS........ 15
Section 3 Analysis of Management of RPAS Sensor Network: Sustain, Protect and Command & Control capabilities........ 29
3.1 Sustainability........ 29
3.1.1 Whole-life cycle: Conceptualisation........ 29
3.1.2 Whole-life cycle: Design........ 31
3.1.3 Whole-life cycle: Production/Procurement........ 31
3.1.4 Whole-life cycle: Operational sustainability........ 35
3.1.5 Whole-life cycle: Decommissioning........ 38
3.1.6 Whole-life cycle: Lessons Learned........ 39
3.2 Protection and Safety........ 40
3.2.1 Safety........ 40
3.2.2 Protection/survivability........ 42
3.3 Command and Control in RPAS missions........ 47
Section 4 Analysis of Information collection from RPAS Sensor Network: Communication capabilities........ 50
Section 5 Conclusions........ 54
Annex 1: Detection of mobile phone communications using RPAS........ 57
Annex 2: Test Case Request from MS........ 67
Annex 3 Derivation of equations........ 69
Annex 4: RPAS types and parameters........ 71
Annex 5 List of acronyms........ 72
Bibliography........ 74

Section 1 Introduction

This document has been drafted upon the request of DG HOME, linked to Task 6 of the Technical Annex I.b addendum of the 1st Amendment of the ADMINISTRATIVE ARRANGEMENT HOME/2013/EBF/AA/0001-C1 JRC EUROSUR (JRC Contract nr.333008-2013 NFP). The aim of this Task is to provide an indication of "if and where" unmanned aerial systems can contribute to meeting EUROSUR requirements. For this purpose, JRC has been tasked to:

a) Analyse possible use for surveillance/monitoring, communications, signal detection;
b) Provide a concise and clear identification of legal, technical and operational obstacles for the use;
c) Identify, based on comparison with existing RPAS roadmaps – if and when it is realistic to use unmanned aerial systems on a regular basis.

In its analysis, the JRC has been asked to make a distinction between mini-UAVs (flying under 150m), MALE, HALE and distinction between land/sea/air border surveillance.

This report deals with the first task requested by DG HOME, which is to analyse the possible use of RPAS for surveillance/monitoring, communications and signal detection. This request is linked to the broader possible use of RPAS for contribution to the EUROSUR system. RPAS could in particular support functions linked to the Common Application of Surveillance (CAST) tools and the building of National or European Situational Pictures (NSP/ESP). This includes surveillance/monitoring but also other types of sensing such as Signature Intelligence (SIGINT). Furthermore, the communication elements requested in the tasking by DG HOME are linked not to the EUROSUR communication network (i.e. for communication amongst the NCC and FRONTEX) but to the network connecting sensors to processing bases. Hence any communication aspect is considered as part of the CAST/NSP/ESP.

1.1 Description of general approach

Following discussions with DG HOME, the aim of this task is to produce an assessment methodology which is relatively independent of the exact RPAS mission. The methodology could then be used by DG HOME as a tool for assessing the utility of RPAS in various border surveillance scenarios in the future. This approach is deemed essential, due to the current interest from MS in procuring RPAS for border surveillance missions, which could include surveillance/monitoring, SIGINT and communication-relay functions but could also expand to other relevant missions including the neutralisation of fast boats or the rescue of people at sea through the delivery of appropriate payloads (e.g. life-boats). The methodology proposed will make use of several Criteria established based on operational but also technical aspects linked to RPAS border surveillance mission. These Criteria would enable DG HOME to assess the level of maturity of MS proposals for RPAS use but could also be used for the identification/design of the most appropriate RPAS for surveillance missions of interest.

To accomplish our task, we will first break down the surveillance mission into operational requirements. These operational requirements will be analysed in more detail and technical requirements will be extracted. Assessment Criteria will then be produced based on critical requirements.

1.2 Breakdown of Missions of interest

In this chapter we will analyse more closely the operational aspects linked to the missions of interest (surveillance/monitoring, SIGINT and communications). For all cases, we will adopt six capability domains that would need to be addressed for each mission: Command, Inform, Protect, Engage, Deploy and Sustain (see Fig.1). It is also worth noting that surveillance/monitoring and SIGINT missions do not largely differ from each other, though to support the request from DG HOME we include a specific analysis of mobile phone signal detection using RPAS in Annex 1. Furthermore, communication aspects, including the establishment of communication channels using RPAS, can complement both surveillance/monitoring and SIGINT missions. Therefore, the three missions can be described through a single surveillance mission requirement which is to:

Establish and manage surveillance systems (including sensors and platforms) and collect sensor information, including meteorological and environmental information. This requirement can be broken down to the following two components:

- General information collection Sensors (Systems, Platforms, Components) and
- Communication networks for collection of data from sensors.

Taking into consideration the six capability domains, the above mission requirement can be split into the following operational requirements which will be analysed in the following sections:

- Establish: Deploy capability
- Manage: Sustain, Protect and Command capabilities
- Collect info: Inform/Communicate capability

- Engagement: No Engagement capability requirements are identified and hence this domain will not be analysed further.

Fig.1 The six capability domains used for fully defining the operational mission. These domains are Command, Inform/communicate, Engage, Protect, Sustain and Deploy.

Section 2 Analysis of Establishment (deployment capability) of surveillance systems

2.1 Analysis of deployment based on the location of the Specific Area of Interest

Based on the above division we will proceed with the generic analysis of the operational requirement out of which technical requirements will also emerge. Starting with the Establishment or Deployment of the sensor network, the operational user requirement would be to "Deploy an appropriate surveillance capacity where and when required at an acceptable cost".

To analyse further this first part of the surveillance mission, a generic scenario is created that would include the following deployment parts:

A) From EU base to a point in the General Area of Interest (GAoI) and back;
B) From the GAoI to a Specific Area of Interest (SAoI) and back;
C) Stationing/hovering/operating at the SAoI.

These elements are shown in Fig.2 and each element is addressed below as its inclusion in the mission would have an impact on the RPAS technical requirements.

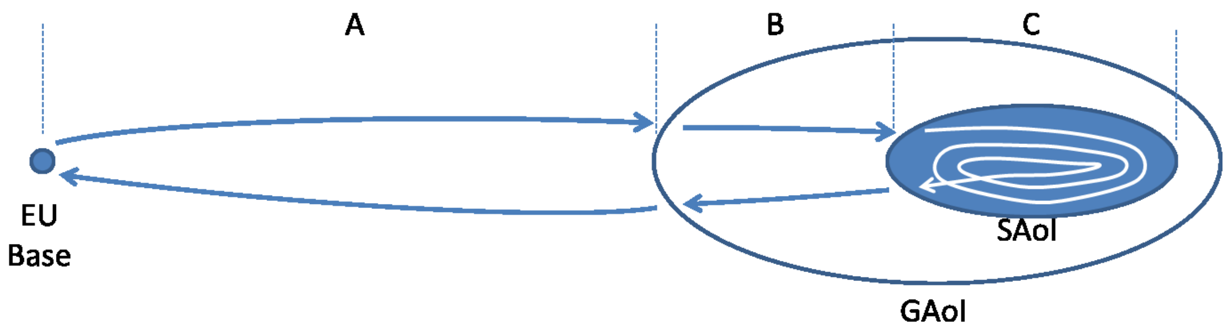

Fig. 2 The three deployment parts of a generic surveillance mission.

A. **From EU base to a point in the general area of interest (and/or return).** Operationally, this is not part of the actual RPAS surveillance mission and hence a significant number of on-board mission equipment, including surveillance sensors, could remain switched-off during this part, in order to preserve energy. Depending on the length of the "EU-base to the GAoI" distance, two possibilities exist:

   1. <u>This distance is non-negligible.</u> In this particular case the RPAS would need to transit from an EU base (port, airport or land base) to the general area of interest. The transit could be achieved using two technical sub-options:
      i. *The RPAS is able to achieve the transit at its own means*. This implies significant technical requirements with regards to Deployment (L&R, transit speed); Sustainability (enough endurance to enable the additional operation within the specific area of interest including sufficient power for activating power hungry sensors); Command (enough capacity to enable navigation, if needed autonomously (e.g. using Instrument Flying Rules(IFR)), to the GAoI); Inform/Communication (enough capacity to enable Beyond Visual Line of Sight (BVLOS) communications used for transfer of sensor-data and the Command & Control (C2) data of the RPAS).

ii. *The RPAS is not able to achieve the transit at its own means*. In such a case the RPAS would first need to be taxied from the EU base to the GAoI via a separate vessel/vehicle/asset. This sub-option reduces the technical requirements on all the above aspects Deployment, Sustainability, Command and Inform/Communication as the transit vessel/vehicle/asset can act as an intermediate between the RPAS and the EU base.

2. The distance from the EU base to the GAoI is negligible. This implies that there is no need for transit and hence again reduced RPAS requirements with regards to Deployment, Sustainability, Command and Inform/ Communication in comparison to Option A.1.i above.

B. **From GAoI to SAoI (and/or return).** Again different possibilities exist depending on the length of this distance:

1. The distance from GAoI to SAoI is non-negligible. In this case the RPAS should have the technical capacity to transit from the GAoI to the SAoI. Operationally, given that the distance is significant, the SAoI should be well defined and focused within the GAoI and hence would make sense to utlise a fast RPAS to access the SAoI as fast as possible. Such a mission could be the re-detection/ classification/ identification and tracking of a target of interest already detected via other means. In such a case, additional endurance and power for high-transit speeds would be required for covering the transit distance from the launch area to the specific area of interest. On the other hand the mission sensors/payload should remain switched-off until the RPAS reaches its SAoI thus saving energy.

2. The distance from GAoI to SAoI is negligible. In this case the RPAS would not require significant technical capacity to transit from the general area of interest to the specific area of interest. This implies reduced endurance capacities but also reduced power capacities as there is low need for high-transit speed. Operationally, given that the distance should be relatively small, the RPAS could be fully functional immediately after deployment, depending on its mission profile. More specifically, such a mission profile could be an RPAS mission to detect a possible target of interest. This means that the actual SAoI could be very large and possibly equal to the GAoI. The RPAS would then be required to activate from the start all mission sensors/payloads and operate under relevant conditions (e.g. speed and

altitude) to maximise the effectiveness of the sensors to perform general surveillance.

C. **Stationing/hovering/operating at SAoI.** For this part of the operation, the technical requirements of the RPAS would vary in accordance to the type of mission:

1. Short endurance mission: If the mission of the RPAS would be to re-detect/ classify/identify a target of interest already detected via other means, this would imply low endurance requirements since the RPAS would be deployed and directed in a very focused SAoI to perform its operation and then return to its base. No, or very limited, hovering or stationing would be required thus reducing significantly the required endurance capacity.

2. Long endurance/persistent mission: If on the other hand the operational mission of the RPAS would be to detect a target of interest or to also track a target of interest, then longer endurance is required in order to be able to scan the whole SAoI or track the target. The larger the SAoI, the higher are the technical requirements for the RPAS in terms of endurance and mobility but not transit speed. On the other hand a large SAoI could also be addressed using a less-mobile, higher altitude RPAS with higher resolution sensors; while a small specific area of interest could be addressed using an almost immobile RPAS requiring almost no endurance for mobility but mainly for sensors (e.g. an aerostat could be sufficient).

Fig. 3 provides a graphical representation of the elements described above. In Fig.3.a the RPAS is performing the whole transit from the EU base to the GAoI and SAoI. The distance from the EU base to the SAoI is covered by the RPA at a transit speed V_T. When at the SAoI the RPAS adopts its speed to the one optimised for its mission (V_m). In Fig.3.b the RPA is taxied by another vessel/vehicle/asset from the EU base to the GAoI at a speed (V_v). It is then launched from the vessel/vehicle/asset and transits the distance from GAoI to SAoI at its transit speed V_T. Once at the SAoI the RPA adopts again its mission speed to V_m. Fig.3.c shows the final case where the RPA is taxied all the way from the EU base to the SAoI by another vessel/vehicle/asset. Once at the SAoI the RPA is then launched and adopts its speed in accordance to its mission. It is important to note that the different distances and speeds indicated are variables (hence could vary from 0 to very high numbers). For example, if the distance from the EU Base to GAoI is 0km then this is described by case A.2 above. In a more complex example, if V_T is reduced to zero, then this implies the RPA needs to be taxied at the SAoI or that the distance from the EU base to the SAoI is also zero. The more mathematical approach shown in Fig.3 will be the basis for the further analysis.

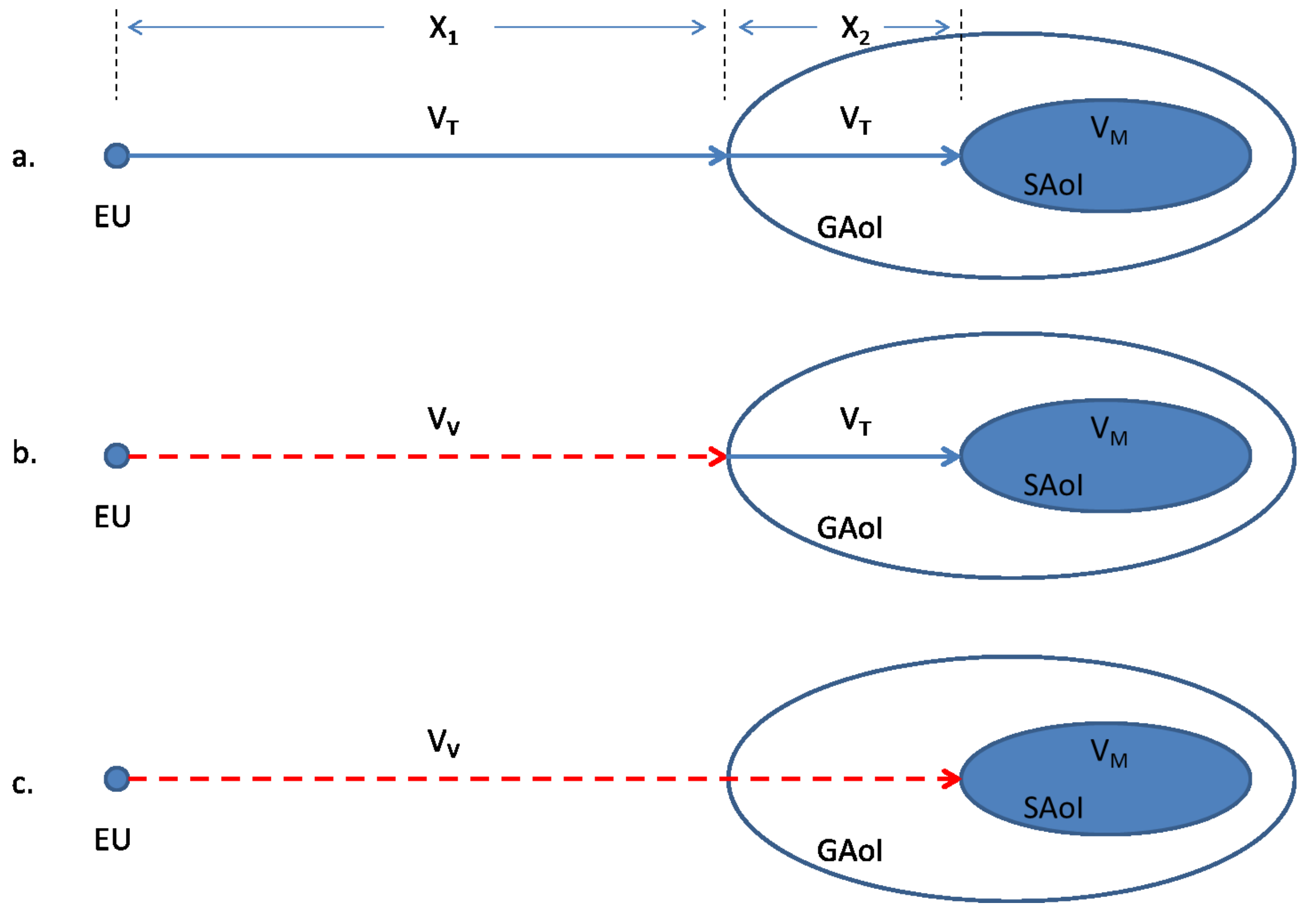

Fig.3 Graphical representation of the different deployment distances, areas and speeds. (a) The RPAS is transiting from the EU base to the GAoI and SAoI at transit speed V_T and then adopting its speed to the one optimised for its mission (V_m). (b) The RPA is taxied by another vessel/vehicle/asset from the EU base to the GAoI at a speed (V_v). It is then launched from the vessel/vehicle/asset and transits the distance from GAoI to SAoI at its transit speed V_T. Once at the SAoI the RPA adopts again its mission speed to V_m. (c) The RPA is taxied all the way from the EU base to the SAoI by another vessel/vehicle/asset and once at the SAoI the RPA is then launched and adopts its speed in accordance to its mission.

Table 1 below attempts to link the different operational and technical aspects mentioned above with regards to deployment. A higher number of stars in the table indicates a stronger linkage between the technical elements and the specific part of operational deployment. It is also noted that the table only indicates a general trend and that some missions may have different technical requirements. It is also important to note that some missions may make use of different parts of the elements described above. As an extreme example, one mission could involve the RPA being launched by a vessel/vehicle/asset outside the SAoI and having the RPA crash-landing at sea or on land without a return to the vessel/vehicle/asset that launched it. In such a mission the vessel/vehicle/asset may proceed with transiting towards the landed/surfaced RPA in order to recover it or the cost of the loss of the RPA may be deemed acceptable and hence no effort would be made to recover it.

	L&R	Endurance	Power	Max speed	Comms	Autonomy	Sensors
Launch	***		***		*	***	*
Long Transit		***		***	***	***	*
Medium Transit		**		**	**	**	*
Short Transit		*		*	*	*	*
Operation		***	***	*	***	***	***
Recovery	***				*	***	*

Table.1 Linking Surveillance operational and technical aspects. A higher number of stars in the table indicates a stronger linkage between the technical elements and the specific part of operational deployment.

The above table is in effect declaring the obvious, namely that “where” your area of operation is, plays a significant role in defining the RPAS requirements. The longer the transit from the area of RPAS deployment, the more stringent the requirements will be in terms of energy, speed, communications and autonomous navigation/obstacle avoidance. However, one not so obvious conclusion from the above discussion, is that the RPAS should be considered as a system (RPAS = RPA, supporting system and control station) and not simply as the RPA itself. This is because a number of support system/control station characteristics, and especially the relative position of the different RPAS elements, will affect the RPA characteristics. For example, if the supporting system (including the L&R) can be placed on a mobile platform that can taxi the RPA closer to the area of operations then this would reduce several of RPA requirements (e.g. endurance, autonomy, etc). Looking at it from a different angle, if the SAoI could be specified, minimised and made equal to the GAoI, then the transit and mission speed requirements of the RPA can be reduced to a zero so that even an aerostat could be used assuming that the RPA could be taxied to the GAoI/SAoI (see Fig. 4).

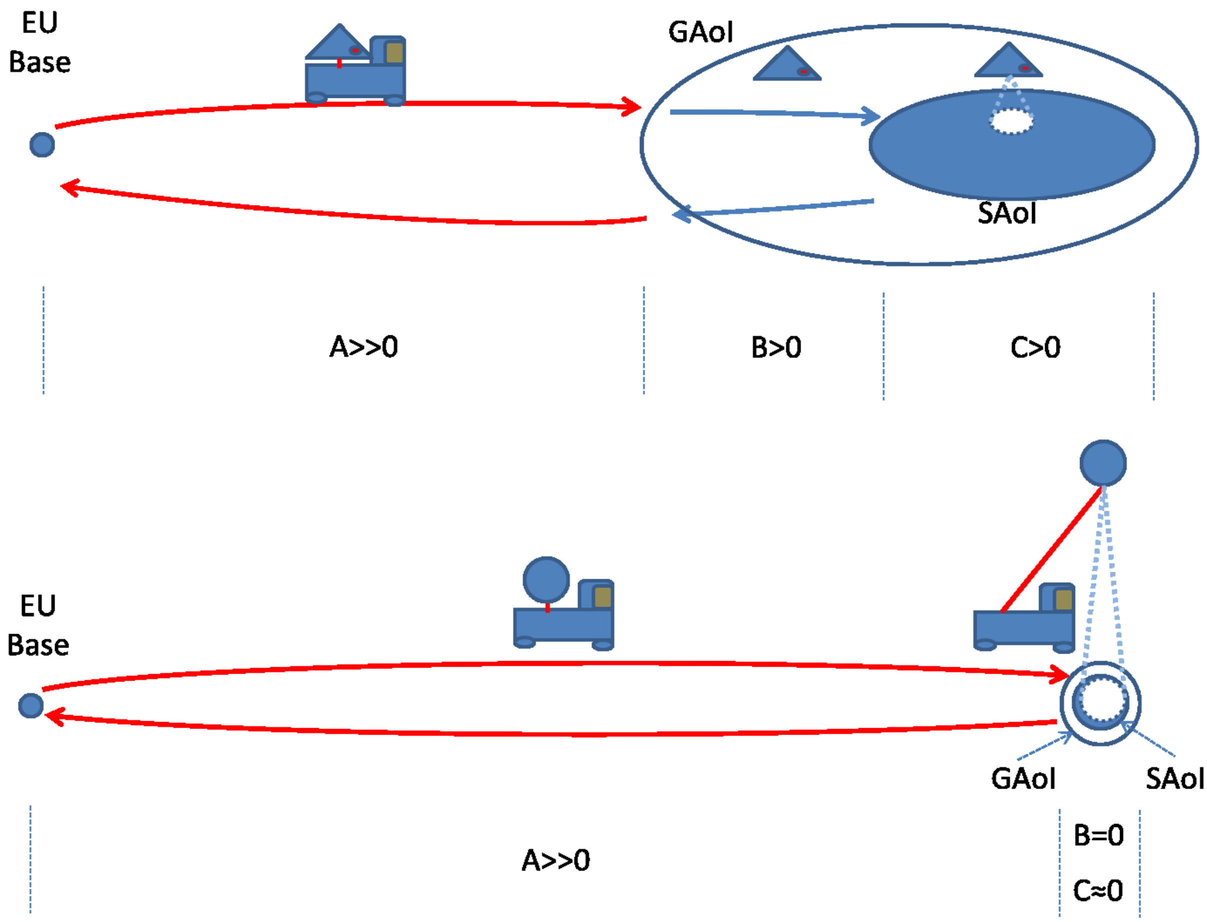

Fig.4 The figure demonstrates the importance of considering the RPAS as a system and not only as the RPA. The relative positioning of RPA and the supporting system or control station will have impact on RPA requirements as shown in the figure. In the upper part, the RPA is taxied by a vehicle and then launched in the GAoI. The RPA has then to transit to the SAoI and perform its surveillance mission. In the lower part of Fig.4 the GAoI and SAoI are considerably smaller and hence the RPA remains in proximity to the taxing vehicle / support station. If the SAoI is sufficiently small and equal to the GAoI then the RPA requires no mobility and hence a tethered aerostat could be used.

2.2 Analysis of deployment based on a RPAS systems approach

2.2.1 "Where" considerations

As mentioned above, it is important to consider the RPA as part of a system. This systems oriented approach with regards to deployment, leads to the following technical solutions that could be envisaged depending on "where" the area of operations lies and the mobility of the supporting system/base:

I.1 Immobile supporting system/base and long RPA transit to GAoI: This translates to case A.1.i described above (i.e. the GAoI is far from the EU Base) and implies highly enduring RPA, which translates to a larger RPA size capable of carrying an energy supply/fuel, but also a more performing propulsion system to minimise the transit time; and a more capable communication system to enable long distance communications to the control station. The RPA size requirements would then increase further depending on the mission at the SAoI (i.e. C.1 or C.2 described above).

I.2 Immobile supporting system/base and medium/small RPA transit to GAoI: This translates to case A.2 described above (implying that the distance of the area of interest from the EU is medium/small, e.g. littoral EU areas) and implies a less enduring RPA, which translates to a smaller RPA size than the one described in point (I.1) above. Again the RPA size requirements would also depend on the mission at the SAoI (i.e. C.1 or C.2 described above).

I.3 Immobile supporting system/base and no RPA transit to GAoI: This case could fall again under case A.2 described above. This is the situation where the actual area of interest is in or next to the EU. This could be the case for Green Border surveillance or confined waters such as those created via EU islands near non-EU territory or a critical land passage. In this particular case, the RPA requirements would depend solely on the mission type (C.1 or C.2 described above). C.1 could make use of a very small and relatively simple RPA while C.2 would make use of a relatively large and more enduring RPA. As the area of interest decreases, so do the overall mobility requirements for the RPA, giving rise to other possibilities such as the use of aerostats mentioned earlier.

M.1 Mobile supporting system/base and relatively long RPA transit to SAoI: This case could fall under A.1.ii and subsequently B.1 described above. The RPA would be taxied from the EU base to the GAoI via a vessel/vehicle/asset along with its mobile supporting system/base and then launched towards the SAoI. This situation could arise in both Maritime Surveillance (where the RPA is taxied by a vessel/ship) or in Green Border Surveillance, where the RPA is taxied by a vehicle. The long RPA transit to the SAoI would imply that the own vessel/ship/vehicle/(or even larger unmanned system) that performed the taxing of the RPA wishes to stand-off the SAoI for any reason (e.g. reducing its visibility, protection by maintaining a long distance from possible danger/threat, reduced mobility capacities, etc). Technically, the RPA would have much less endurance than the case I.1 described above but would still require sufficient endurance for the transit to the SAoI and the performance of its mission at the SAoI. The RPA size requirements would increase depending on the mission at the SAoI (C.1 or C.2).

M.2 Mobile supporting system/base and medium/short/no RPA transit to SAoI: This case could fall under A.1.ii and subsequently B.2 described above. The RPA would again be taxied from the EU base to the GAoI via a vessel/vehicle/asset along with its mobile supporting system/base and then launched towards the near-by SAoI or within the SAoI. This situation could arise in both Maritime Surveillance (where the RPA is taxied by a vessel/ship) or in Green Border Surveillance, where the RPA is taxied by a vehicle or even a person. The technical requirements would depend largely on the mission profile (C.1 or C.2) with RPA capacities and size increasing for the C.2 case of long endurance mission profile unless the SAoI is significantly decreased or the supporting system/base can be physically connected to the RPA even during its mission within the SAoI (e.g. tethered RPA or aerostat option).

2.2.2 "When" considerations

As mentioned earlier, the operational requirement, is to deploy the capability "where and when" needed. Above we have analysed in detail the "where". Considering the "when" aspect of deployment, this implies that the RPA is able to perform its mission when required and as long as required in different types of conditions. Obviously, the availability in time is dependant not only on the availability of the capability to be deployed but also on the location of the SAoI (i.e. the "where") vis-à-vis the launch and/or recovery area of the RPA. From an operational point of view, the usefulness of the RPAS increases in most missions, proportionally to its mission endurance within the SAoI. Hence, the transits from the EU base to the AoI and from the AoI to the SAoI need to be minimised if possible distance-wise or time-wise. A distance-wise reduction would imply that the EU base is in proximity to the SAoI (a combination of case A.2 and B.2 described above) such as in the case of Green Border or confined waters. It could also imply that the taxing vessel/vehicle/person is situated permanently near the SAoI (in the maritime situation this would be a sea-basing concept).

If the distance to the SAoI cannot be reduced then operational usefulness would increase if the transit time to the SAoI is reduced. This implies that the transit speed (V_T) of the RPA and/or the taxing speed (V_V) of the taxing vessel/vehicle/person are as high as possible (see Fig.2). Increasing the V_T of the RPA or using a different taxing RPA/UxV would be the most cost-effective solution as the absence of the man on-board would allow the RPA/UxV to reach the maximum V_T possible based solely on its propulsion and structural capacities and not the human factors of the pilot. It is for this reason that some RPAS end-users (in particular military) are experimenting with high RPA speeds, in some cases multi-mach speeds, enabling an extremely fast approach to the area of interest but at high energy-cost and overall RPAS price.

Once at the SAoI, the operational usefulness of the RPAS would increase if the RPA could perform its mission faster or more effective or for longer period of time (i.e. with high endurance). This requirement may need reconciling with the transit strategy as an increased V_T may lead to extremely low mission endurance. Hence a compromise between transit speed and mission endurance would need to be reached depending mostly on the priority of the mission. High priority missions would most probably require a minimisation of transit time while for low priority (or regular mission) a maximisation of the mission endurance would be the most optimum solution.

2.3 Assessing the operational use and limitations of deployed RPAS

Using all the above considerations, we now enter into a more detailed analysis of the Border Surveillance missions in order to extract criteria based on which an assessment of the use of RPAS for surveillance missions could be made. During a surveillance mission the operational usefulness would increase if the RPAS could detect, classify, identify or track all targets of interest independently of their size, as fast as possible and for as long as possible (persistent surveillance). The RPAS technical requirements would again depend on the subset of missions to be performed:

1) **Detection**: Detection implies that the RPAS is able to sense the presence of a target of interest (cooperative or non-cooperative[1]), but not necessarily able to classify and identify or track it. We note here that by "target" we mean the "minimum element of interest" even if this element is embedded in a bigger vessel. For example, in the case of a fishing vessel currying a high number of immigrants, the main element of interest is not the fishing vessel but the fact that a great number of people are on-board a tiny vessel (indicating an anomaly that could be detected). This is because there may be several fishing vessels operating legally in the area, which are not of real interest. Another example of detection "target" could be the detection of a mobile phone signal emanating from a vessel or vehicle or a person within the SAoI. Taking this into account, the operational usefulness of the RPAS would increase if the detection would take place as fast as possible once a target or the RPAS enter the SAoI. This leads to the following considerations:

    a. The fastest possible detection would take place if the RPAS is able to cover the whole SAoI with its sensors without requiring even to displace itself within the SAoI. This implies that either the SAoI is extremely small (e.g. a

[1] Cooperative implies that the target is emitting information (AIS, VMS, etc) about itself in accordance to the regulations.

specific confined water area or a land passage) or that the RPAS is technically capable of reaching a high enough altitude and possesses highly capable sensors (high sensitivity, big field of view and spatial resolution) to be able to detect targets of appropriate size or signals emanating from the targets at that altitude. In such a case the RPAS would have much less requirement for propulsive power. These extreme cases are depicted in Fig.5, where fast detection can be achieved using assets placed at higher and higher altitudes as the SAoI increases. Such assets could range from an immobile, tethered aerostat, to a high altitude RPA or even a geostationary satellite.

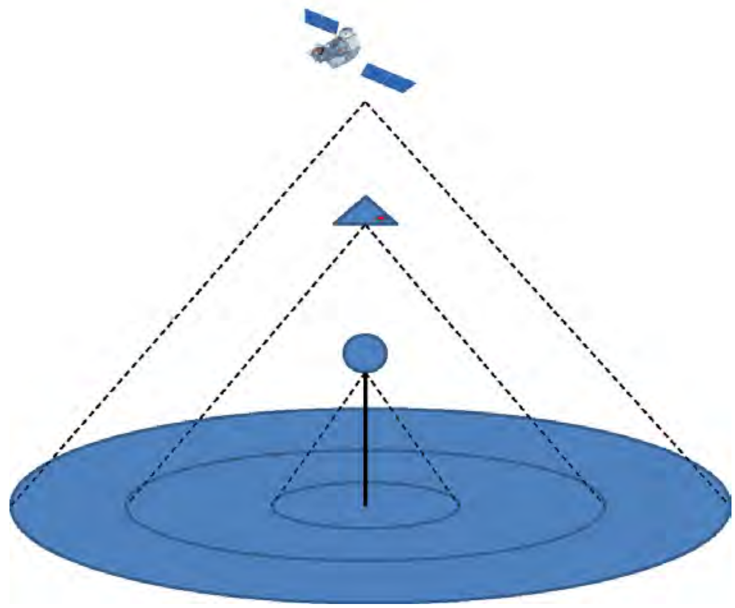

Fig.5 The fastest possible detection would depend on the SAoI size and the altitude of the surveillance asset assuming the same sensor field-of-view and that spatial resolution on the ground is not compromised as the area of sensor coverage is increased.

b. Less fast detection would take place in all other situations as they would require that the RPA executes a mission path to cover/scan the whole of the SAoI. In such a case the altitude and sensor capacity of the RPA would need to be adjusted based on the size of the SAoI (A) but also the mission speed and endurance of the RPAS. Mathematically, this is described via Eq.1 which implies that the time required for the RPAS to execute the mission path is proportional to the difference between the SAoI size and the area of sensor coverage, and inversely proportional to the diameter of the area of sensor coverage and the speed of the RPA. Hence the minimisation of time required for covering the mission path can take place by increasing the area of sensor coverage (without compromising spatial resolution on the ground) or increasing the RPA speed during the mission. In the special case where the area of sensor coverage is increased to be equal the SAoI then the time for covering the mission path is minimised independently of the mission speed (this is in fact the 1.a detection case above, where an aerostat or satellite at high enough altitude with a high sensitivity, high resolution, wide field of view sensor, covers the whole SAoI).

$$T_m \approx \frac{A-d^2}{d \cdot V_m} \quad \text{Eq.1}$$

c. A third situation could occur in the case where the RPA mission speed and sensor coverage area, cannot guarantee detection. To further clarify, the detection cases 1.a and 1.b described above assume that the target is immobile or its speed (V_{TAR}) does not exceed V_m*d/w where V_m is the mission speed of the RPA, d is the diameter of RPA sensor coverage and w is the width of the SAoI assumed to be a straight line (a more complex situation will be described later), as shown in Fig.6. Hence, an increase of the RPA mission speed will be essential in case the target of interest is highly mobile. Even so, as the coverage of the RPA sensor increases (i.e. by increasing altitude and maintaining resolution) the time available for the target to avoid the scanning of the RPA decreases and hence the target would need to increase its speed towards infinite values to avoid detection. This best-case detection scenario would occur again if the SAoI is fully covered by the RPA sensor in which case the RPA does not need to be mobile and could be replaced by a tethered aerostat or a satellite (see again detection case 1.a). In the case of a highly mobile target, large SAoI and low RPA altitude and speed, the only solution for full detection capacity is to increase the number of assets (RPAS or other types) thus covering in parallel different parts of the SAoI. If this is not possible then the detection of the target would depend on chance and hence a probabilistic approach is used to define the probability of detection (see for example [1]).

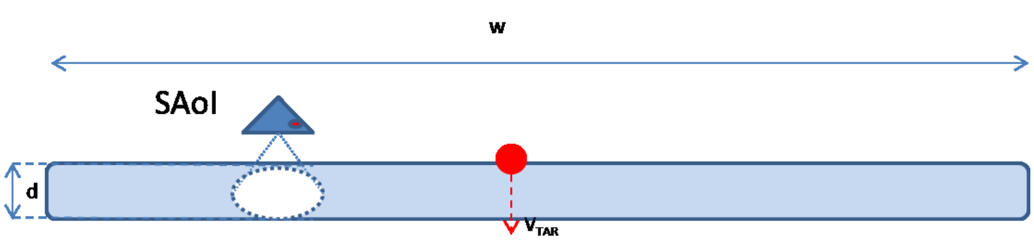

Fig.6 A simplified case having 100% detection probability where the SAoI is confined in a straight line with dimensions w and d (equal also to the diameter of sensor coverage of the RPA). A target will be detected if stationed within the SAoI or if travelling at a speed which does not allow it to travel the distance d of the SAoI faster than the RPA can scan the whole SAoI ($V_{TAR} \leq V_m$*d/w).

2) **Classification**: The classification mission takes place once detection of a target of interest has been achieved. Classification implies that the RPAS has been able to obtain a good enough image of the target of interest, or some of its effects (e.g. vessel wake) or its signals (e.g. acoustic or electromagnetic signatures) to be able to classify the target in accordance to a predetermined categorisation. This means that the same equations as for detection apply however in this case the resolution of the sensor would need to be sufficiently high in order to obtain an image of the target structure or its effects or receive classifiable signals. This implies that the planned mission altitude of the RPA would most probably need to be reduced in comparison to the detection mission, unless the RPA possesses a very high spatial resolution sensor (either the same as the detection sensor or an additional one). A reduction of the altitude would automatically imply a reduction in the sensor coverage area and hence an increase in the time required to perform the full detection mission unless the RPA has the capacity to modify its altitude during the mission. In that particular case, following detection of a target of interest by the RPA, the same RPA would reduce its altitude from the optimum detection-level in order to increase the resolution of the image and enable classification. This requires additional time and energy as the RPA would need to divert from its originally planned mission but once the classification is completed, the RPA could return back to its original optimum detection mission altitude.

3) **Identification**: Identification implies that the RPAS has been able to obtain an even better image of the target of interest than that required for classification, including specific features which would support the exact identification of the name/ID of the target; or has received specific "credible" identification signals from the target (e.g. identifiable mobile phone signals, AIS, VMS, etc). In the case of image identification, the image of the target would need to be precisely correlated with other previously taken images of the same target or the actual identification (name, license plate, etc) of the target would need to be seen through the RPA image sensor. This again implies that the RPA would need to divert from its original detection mission, unless its sensors have sufficient spatial resolution to capture this improved image or the identification signals. As in the case of classification, the diversion from the original course will result in additional time and power requirements to complete the full detection mission.

4) **Tracking**: Tracking of a target of interest would imply that the target has been at minimum detected or even classified and identified before being tracked continuously by the RPAS. For continuous/persistent tracking the RPAS would need to be able to follow the target within the SAoI. Similar to detection, the most effective approach would be to have an RPA with a very high spatial-resolution

sensor, flying at an altitude which is high enough to cover the whole of the SAoI. If this altitude and sensor spatial-resolution cannot be achieved then once a target is detected, the RPA would need to modify is trajectory (thus modifying its mission plan). The level of tracking that could be achieved would then depend on the RPA endurance capacity. If the target of interest is confined in a rather small SAoI then a relatively small size RPA would be sufficient. However, if the target of interest would need to be tracked through a large SAoI then the endurance; and subsequently size; of the RPA would need to increase unless a more coordinated/multi-asset approach is used. In such a case the RPA would detect, track and inform the control station about a target of interest operating within a defined SAoI. The information would then be used by the decision makers in order to plan for other assets to take over the target tracking once it has left the SAoI defined for the RPA. When this is done the RPA would be able to return back to its previous mission (e.g. detection).

Fig.7 shows a possible simple operational concept for a mission requiring detection, classification, identification and tracking of targets of interest. In this operational concept the first step sets the RPA into a specific mission path for scanning the SAoI for possible targets. Once a target of interest is detected (step 2), the RPAS is able to classify and identify it as a target of interest requiring tracking. In this concept of operation (CONOPS) the RPAS needs to deviate from its detection mission plan and track the target of interest until it exits the SAoI (step 3). As a fourth step, the RPA then returns to the point of the scanning path where it detected the target of interest, and continues its scanning of the SAoI for more targets of interest.

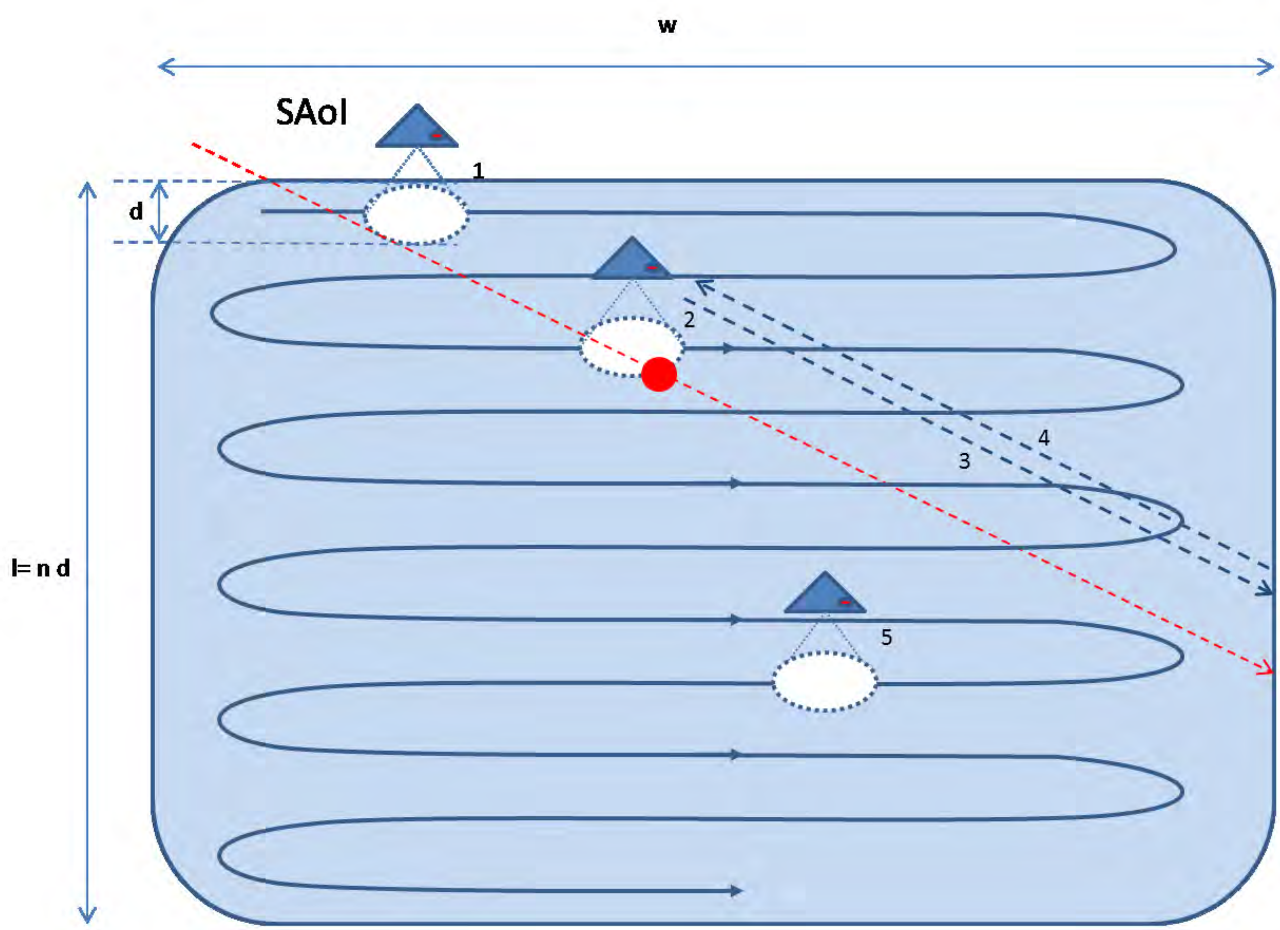

Fig.7 A diagrammatic representation of a possible operational concept of a mission including detection, classification, identification and tracking of targets of interest within a SAoI.

Based on the above considerations we can define a relationship between the RPA parameters, sensor parameters, target parameters and SAoI which can provide a first indication of the selection criteria required for the RPAS. The first two Criteria are:

- **Criterion 1**: Define the target you wish to detect in terms of type and size (S_{TAR}) and speed (V_{TAR}). The size as mentioned above would need to be the size of the smallest element of interest, even if embedded in a larger vessel/vehicle (i.e. human beings in a fishing vessel).
- **Criterion 2**: Define the dimensions and shape of the SAoI (e.g. for a rectangular area = A = width w * length l).

The responses to the above criteria will assist in making a first estimation of the required RPAS capacities. In more detail, using the size of the target (S_{TAR}), the minimum spatial resolution R_{min} of the RPA detection-sensor would be identified. This will enable a first identification of required sensors. For some detection-sensors, the R_{min} can be achieved at a certain max distance or height (h) from the target and hence a first indication of the max altitude that the RPA should operate. Depending on the sensor, the coverage area diameter d can be derived either directly from the detection-sensor data or using the detection-sensor field of view θ (see simplified linear case Eq.2 and Fig.8 for vertical case). The sensor coverage area diameter d of the detection-sensor in combination with the target speed (V_{TAR}) and the size of the SAoI will enable the approximate calculation of the minimum mission speed (V_m) for the RPA using Eq.3 based on which detection of a target or any target with the size and max speed selected will be detected with probability of 100%, assuming no system failure. A similar calculation could be made for the side scanning case. As mentioned above, any reduction of the RPA mission speed (V_m) or sensor spatial resolution R_{min} or increase of the SAoI or speed of the target (V_{TAR}) would result in a reduction of the probability of detection[2]. The estimated RPA mission speed (V_m) and the dimensions of the SAoI would then provide an estimation of the time (T_{D-m}) required for the RPA to complete its detection mission. The required mission time (T_{D-m}) combined with the RPA mission speed (V_m) would then enable an estimation of RPA endurance for completing the detection mission (E_{D-m}) once (this could be done using manufacturers data).

$$h = \frac{d/2}{\tan(\frac{\theta}{2})} \qquad \text{Eq.2}$$

$$V_m \geq V_{TAR} \cdot \frac{A}{d^2} \qquad \text{Eq.3}$$

The third criterion relates to the operational concept envisaged for the border surveillance mission:

- **Criterion 3**: Define the operational concept (CONOPS). More specifically, will the RPA be used for detection; and if yes:
    - Would the RPA be required to proceed with classification, identification or tracking of detected targets or
    - Would other means/assets be used for the classification, identification or tracking of detected targets while the RPA continues its detection mission.

[2] For military applications a reduction of the probability of detection may result in enemy penetration and loss of high value units / life of personnel. In the civil, border surveillance applications, a reduction of detection probability could be acceptable for certain missions, e.g. the detection of illegal trafficking of objects with no immediate impact (e.g. cigarettes). However, for the missions related to trafficking of human beings, especially in difficult environmental conditions (high sea states) and poor transport mechanism (small ill-equipped or poorly-fueled vessels), a reduction in the probability of detection would most probably lead to loss of life which is considered unacceptable. Hence, in this case the civil and military applications have similar probability of detection requirements giving rise to possible dual-use synergies.

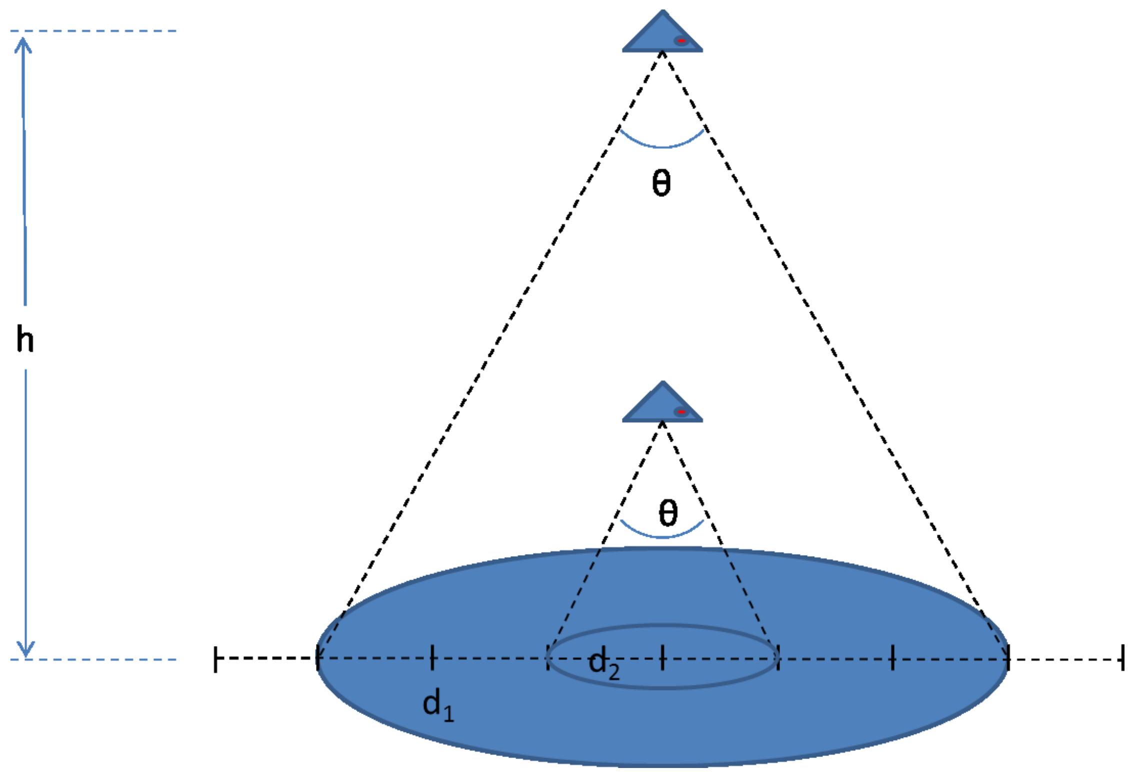

Fig.8 The figure shows that if the RPAS altitude (h) is increased while the field of the view and spatial resolution of the sensor at the ground remain the same (or adequate) then the diameter of the area of sensor coverage d increases thus reducing mobility requirements for the RPAS (vertical view case).

The response to the above criterion would provide an indication of additional sensors or endurance required by the RPA. In the simple case that the RPA should continue only with its detection mission, then no additional RPA sensors or RPA endurance are required if the mission is to be completed only once (we do not take yet into account any transit requirements to the SAoI). However, if the RPA would need to also classify, identify or track (CIT) the target of interest then the RPA endurance would need to increase by the endurance required for the additional CIT mission (E_{CIT-m}). Two different options could be conceived with different effects on the total RPA endurance:

a) Sensors: One option is to use additional higher capacity sensors that would be switched on only when required for CIT of targets. Such sensors would add additional endurance requirements (E_{CIT-m}) due to an increase in the required MTOW of the RPA but also cost requirements for the RPA. The additional CIT-sensors could zoom into the target for classification and identification purposes or zoom out / rotate to enable continuous or semi-continuous tracking of the detected target.

b) Modification of mission plan: The second option is to modify the mission flight plan so that:
   a. For classification/identification, the RPA flies closer to the target detected in order to perform the classification and identification (see for example Fig. 12.9 from [1]) and returns back to its original mission flight plan or;
   b. For tracking, the RPA tracks the target of interest throughout the SAoI (see Fig.7) and then returns back to its initial mission flight plan (or restarts its mission plan).

   The modification of the flight path would add additional endurance requirements (E_{CIT-m}) for the RPA but would avoid requirements for additional sensors on-board. The exact increase in the endurance requirements would need to be calculated according to the modified mission plan and would depend on the RPA. Hence, manufacturer's data would need to be accessed to assess the additional endurance requirements.

The fourth criterion is linked to the density of targets of interest.

- **Criterion 4**: What is the density in time and space in the SAoI of the possible targets of interest?

Criterion 4, relates to the requirement for the RPA to continue its mission plan even after a first detection has taken place. It also relates to the approach to be taken in Criterion 3. For example, if a specific target needs to be detected[3] within a SAoI then, once detection takes place the RPA can stop its detection mission and concentrate on the CIT mission. In that case a change in the RPA trajectory would be the best solution for Criterion 3. On the other hand, if the number of potential targets of interest within the SAoI is high then modifying the RPA trajectory from its detection to the CIT part would imply an increase in the probability of having targets going undetected. This is because, while the RPA is focussing on CIT for one detected target of interest, other targets may cross or perish within the SAoI. In such a case, it would be advisable to maintain the RPA at its detection mission path and use the option of additional CIT sensors or even assets as mentioned above. Furthermore, the density of targets in time within the SAoI would provide an indication of the persistence required by the RPAS. This would increase significantly the endurance requirements unless the SAoI could be reduced or multiple assets used (e.g. a replacement

[3] We note again that detection relates to the detection of the smallest element of interest, e.g. detecting large number of human beings on a small vessel and not just detecting a small vessel (which could be embedded in other legitimate traffic).

RPA sent to replace the first one once the endurance of the first RPA reaches a critical level).

The above, criteria and considerations enable a first design of the RPAS that could be used to perform the required surveillance mission and are considered to be the most critical for accomplishing the surveillance mission envisaged. However, these first four criteria take into account ideal/optimised operational conditions. The following two criteria address non ideal conditions.

- **Criterion 5**: In what visibility/detection conditions do you wish to be able to operate in?
- **Criterion 6**: In how challenging environmental conditions to you wish to be able to operate in?

Criterion 5 would provide additional information on the capacity of the detection and CIT sensors. If operations during the night or low visibility conditions are also required then additional capacities would be needed for the RPA sensors. This may translate to additional sensors (switched on only when needed) or the use of an improved sensor capable for all weather conditions. The modification of the sensor would have an effect on the Maximum Take-Off Weight (MTOW) of the RPA and hence on its endurance and cost, but also on its supporting system. On the other hand, Criterion 6 relates to the actual RPA in terms of structural, navigational and control aspects. If the detection and CIT is meant to take place even in harsh environmental conditions (strong winds, rain, snow, low/high temperatures, high-sea states, etc) then this would add additional structural, navigational and control requirements on the RPAS. This would most likely increase the MTOW (and hence endurance requirements) and definitely increase cost requirements. Again, it is difficult to provide figures about the required level of increase, but data should be available from manufacturers and hence once the basic RPA design requirements are defined through Criteria 1-4, the additional RPA design requirements could be addressed based on Criteria 5-6.

The above 6 Criteria relate primarily to the mission within the SAoI. However, an important parameter of design for the RPAS would be the transit part of the mission discussed earlier in the document. As discussed earlier, the main design aim would be to reduce the transit time and loss of RPA endurance during transit. With regards to a high-priority mission transit time, as discussed above, information on the time available for performing the mission would provide an indication of the optimal transit speed (V_T) of the RPA. Even so, such an optimal transit speed may result in high fuel consumption and hence endurance requirements. Therefore, a compromise must be reached depending on whether the priority of the mission is high and urgent or not. Data should again be available from manufacturers in terms of maximum speed (to reduce transit time) and optimal cruise speed (to reach the maximum endurance of the RPA). Furthermore, an additional and very significant element to take into account is whether the RPA will be taxied for part of the transit or not. This will depend on the distance of the SAoI from the EU base but also the availability of other assets capable of taxing the RPA to the SAoI. The above aspects are addressed through the criterion provided below.

- **Criterion 7**: Where is the SAoI and from where and how are you planning to send the RPA to the SAoI?

Criterion 7 will have an effect on the transit speed and endurance described above but also several other non-mission specific elements including the Communication links and the Launch & Recover (L&R) system of the RPA. With regards to communications, the distance from the supporting base/control station (whether in the EU or the taxing vessels/vehicle or in a different geographical location) will have a significant impact on the communications requirements because currently (and this is not expected to change significantly in the near to medium term) most drones do not have enough autonomy and require the continuous presence/control of an operator. This is even more so for RPAS which are specifically meant to be remotely piloted and hence require a link with the base at all times. Furthermore, for surveillance missions, real or near-real time reception of data (e.g. signals, images or videos) would be essential unless the RPA has enough internal processing capacity to process the received data and send a reduced amount of relevant data to its supporting base.

Looking again at Criterion 7, if the distance between the base/control station system and the mission area goes beyond the Visual Line of Sight of the pilot (e.g. not more than 500m in the UK) then Beyond Visual Line of Sight operation is assumed. If the RPA is meant to stay within Visual Line of Sight from the operator then simple control communication schemes could be used based on UHF/VHF radio tele-control. This is the case for some of the missions falling under the I.2, I.3 and M.2 cases described above. For BVLOS (e.g. definitely for cases I.1 and M.1 but also possibly I.2 and M.2), special antennas, special communication relays (i.e. intermediary RPAs) but also mobile phone networks and satellite-based communications could be used to connect the RPA to its base. It is worth noting that for the Command and Control (C2) the required bandwidth is low (56kbit/sec is sufficient) but for the payload sensor, larger bandwidths are needed, e.g. up to 8 Mbit/sec for a high quality video link. Any additional communication devices would reduce the transit and mission endurance of the RPA due to both the extra weight but also the power requirements for operating the communication equipment. In addition, BVLOS will have significant impact on the cost of the system not only for the main mission RPA but also for the base/control station supporting system, any additional network elements (i.e. RPA relays) and services (e.g. satellite comms). The transition from VLOS to BVLOS will also have an impact on the rules applicable for the RPAS as we will examine in the second part of the report. The aspects of communication for both the C2 and surveillance-sensor data will be addressed later in this document.

As mentioned above, the Criterion 7 will also have an impact on the L&R system of the RPAS. If the support system is immobile and the RPA has a long transit distance to cover (case I.1 described earlier) then long RPA endurance would be required. This would increase the weight and cost of both the RPA structure but also its internal equipment (sensors, communications). In such a case, the unscathed launch and recovery of the RPA would be extremely important and hence the RPA would require a stable and sophisticated L&R system (e.g. similar to manned aircraft). As the transit distances to the AoI and then the SAoI are reduced (e.g. I.2 case), so is the endurance of the RPA and thus its MTOW. This gives rise to the possibility to use other L&R systems including catapults or even direct hand-throws for launching and nets, crash landings or hand catches for recovery. If no transit is required (e.g. case I.3) then even more simple schemes could be used such inflating and deflating a balloon. The same considerations apply for the cases where the base supporting system is mobile. The L&R system sophistication would then increase depending on the type and size of the platform hosting the support system on which the RPA would need to launch from and/or be recovered from. For example, if the support system is hosted on a maritime platform, then the L&R system would need to be able to take into account the movement of the maritime platform. For low endurance and cost RPAs (e.g. primarily those in case M.2) crash landing at sea or within a net could be a possibility. However, for more enduring and costly RPAs the L&R system would need to be more sophisticated. Such L&R system could include techniques similar to those used for manned aircraft (i.e. VTOL or wheels) as well as modifications on board the vessel to support autonomous or pilot assisted L&R.

Given all the above considerations, we can reach to a more detailed RPA design specification methodology which would include the required sensors and their capacities, the required RPA speeds during transit and mission, the required RPA operating altitude, the required endurance (summing the endurances required for the detection and CIT missions but also the transit time), as well as structural, MTOW, command, control, communications & computers (C4) and L&R aspects. The full, step by step approach in defining the RPAS technical requirements based on the mission operational requirements is shown graphically in Fig.9. Fig.9 shows each design/criteria step with a different colour and makes a distinction between Mission and Transit elements. Furthermore, the technical requirements are divided between the sensor and the RPA. It is interesting to observe in the diagram but also through the sequence of criteria described above that while the aspect of C4 is currently the most important topic of discussion in Europe with regards to drones/RPAS and their possible use (primarily due to regulations), it is actually one of the last concerns for the RPAS operational usefulness with regards to a border surveillance mission.

As an example, of the design methodology, Annex 1 includes an analysis of a Case Request from a MS, based on the operational-use criteria mentioned above. The information provided by the MS is used to answer the seven criteria described above. For this particular case, it is clear that the information from the MS is insufficient to provide an assessment and hence more information should be requested from the MS.

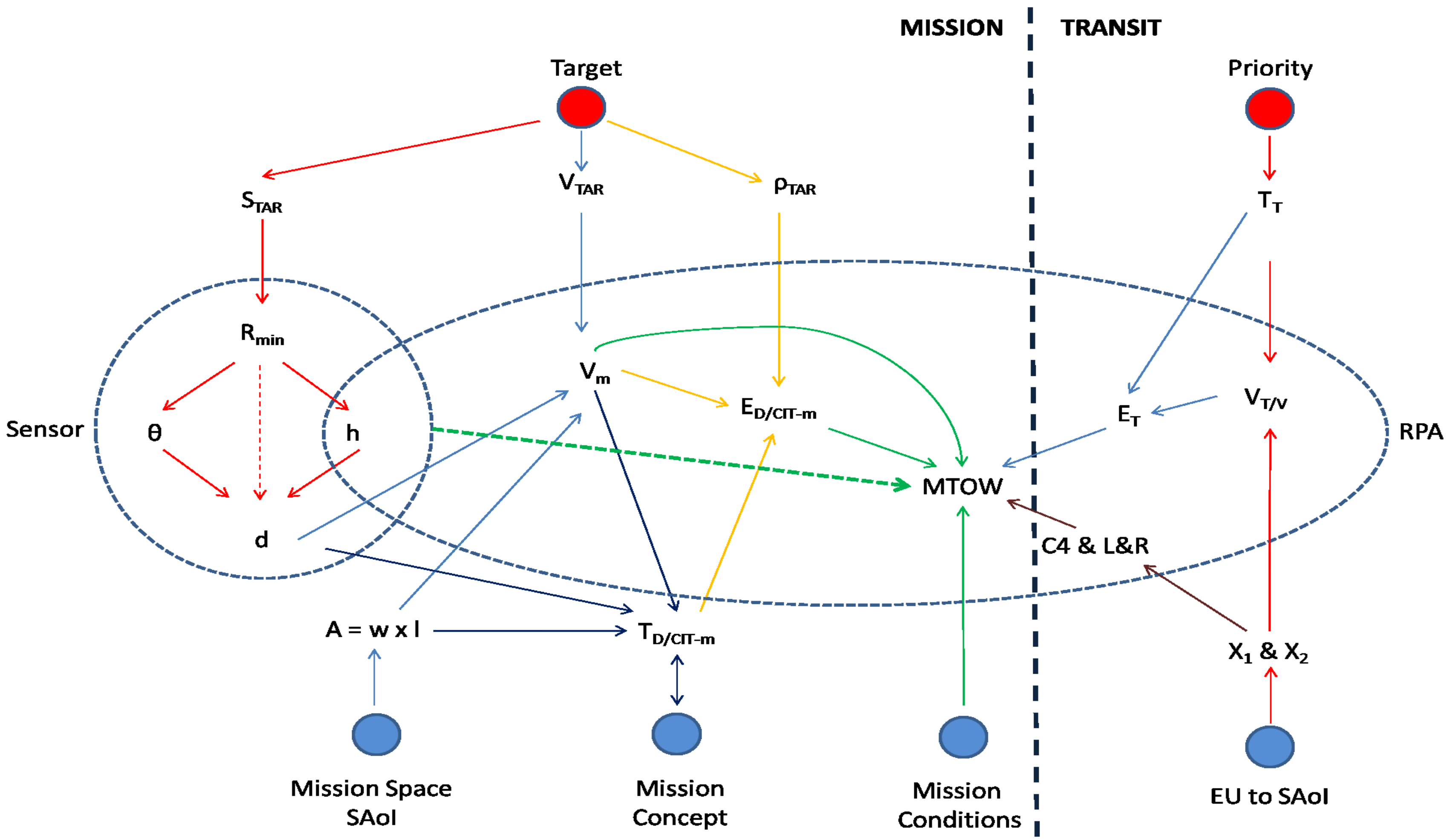

Fig.9 Step-by-step design approach for RPAS in surveillance mission, making a distinction between mission and transit elements. The design start with the Mission part and the target size (red line) which provides information on the sensor and RPA optimum altitude for surveillance. Then the expected target speed combined with SAoI provide an indication of the RPA mission speed (blue line). The CONOPS, RPA mission speed, sensor coverage, SAoI size and density of targets will provide an indication of the required endurance of the RPA. On the transit part, the distance of the SAoI from the EU Base and the approach used to perform the transit will provide information on the C4 and L&R of the RPA. In addition, the priority of the mission envisaged will define the available trnsit time and hence the optimum RPA transit speed. All the design information combined will provide an indication of the MTOW of RPA capable of meeting the requirements.

Section 3 Analysis of Management of RPAS Sensor Network: Sustain, Protect and Command & Control capabilities

The above analysis has provided information on how to identify the appropriate RPAS parameters for operational use. Once the RPAS and relevant network have been established, the next step is to enable their efficient and effective management. This would include the enabling of the Sustainability, Protection and Command management (Command, Control and Computers) capacities of the Surveillance network using one or more RPAS. Below we will analyse all these aspects trying to derive impact on mission and RPAS requirements.

3.1 Sustainability

The sustainability of a sensor-network using RPAS goes beyond the sustainability of a single mission. In other words, the RPAS sustainability does not refer to mission/transit endurance alone but expands to the capacity of the RPAS to remain functional or to be repeatedly functional, mission after mission and in different types of missions. From this point of view, it is thus important to make use of a whole-life-cycle approach where the operational cycle is only part of the picture. The conceptualisation, design, production or procurement, operation, maintenance and upgradability, and eventual decommission all play a role in providing lessons learned that will then re-fuel the conceptual and design phase of an improved RPAS asset. Fig.10 shows the whole life-cycle aspect of a generic asset (not necessarily an RPAS). We will analyse each aspect and its impact on the operational use of the RPAS for surveillance missions below.

3.1.1 Whole-life cycle: Conceptualisation

The conceptualisation of a certain asset/equipment/service would in our case come either from the end-user or the technology/service supplier. RPAS are a new technology and therefore, what is currently the main trend is the promotion of asset / equipment / services from technology/service providers (i.e. industry) towards end-users (e.g. MS and FRONTEX). As end-users become more knowledgeable in the technological and operational aspects of RPAS, they are able to set requirements for the design and production of RPAS or related services. These requirements should relate primarily to the operational Criteria already described in the previous section but other elements should come into play in order to enable sustainability of operations. These sustainability criteria should include a comparison of different RPAS aspects with those of existing solutions. Such aspects would include:

- cost of procurement of services or RPAS or cost of RPAS production but also operation, maintenance and decommission;

- operational life-cycle expectation, which should include delivery, maintenance, upgradability and modularity;
- logistics for both the RPAS and spare parts including
    - support infrastructure for storage, testing, transfer, launch and recovery;
    - security of supply of required material, spare parts and RPAS services;
- organisational and personnel aspects including management and training for personnel;
- impact on the overall system including standardisation and interoperability;
- impact on other elements including environmental and social (also including regulations).

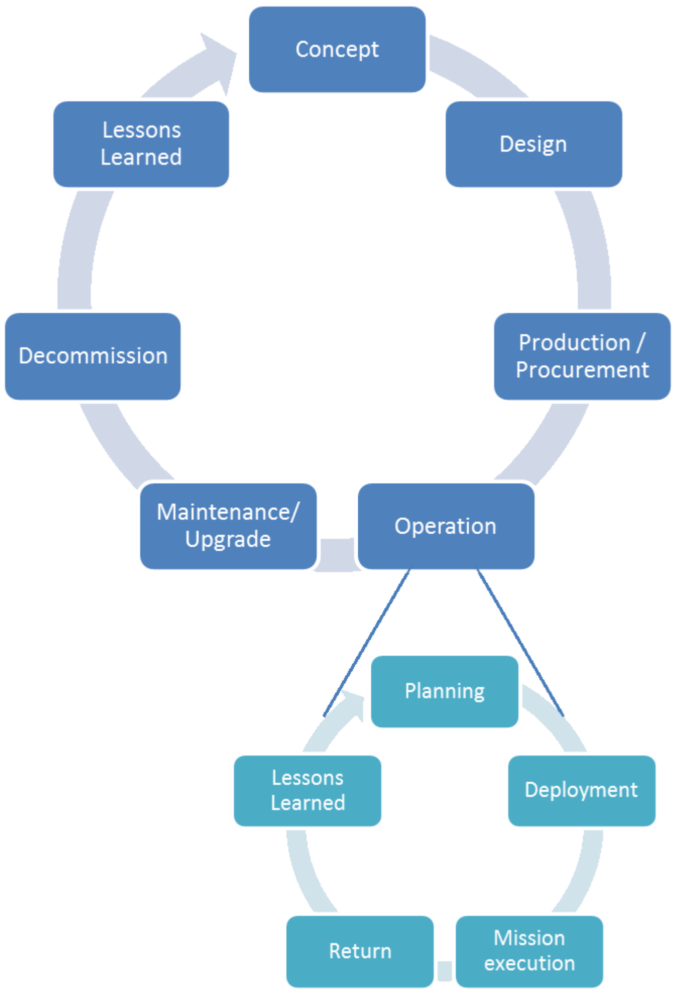

Fig.10 The whole life cycle of a generic asset is shown in the upper part of the figure. It includes the Conceptualisation, Design, Production or Procurement, Operation, Maintenance and Upgrade, Decommission and Lessons Learned that then refuel the Conceptualisation part of the cycle. The Operational part also includes its own Operational Cycle which includes the Planning of Operations, Deployment, Mission Execution, Return to base and Lessons Learned which then refuel the Planning part of the Operational cycle.

If information related to any of the above elements is not clear then a feasibility study would need to be performed in order to clarify all operational and technical aspects. The above considerations give rise to the following Criterion:

- **Criterion 8**: Have you performed a detailed requirements analysis and relevant feasibility study, taking into account not only the first seven Criteria but also cost, life-cycle, logistics, organisational and personnel aspects, impact on overall system; and other impact due to the operation of the RPAS for Border Surveillance? If yes, did this include relevant RPAS tests and were they satisfactory? If not, do you plan to contact further R&T&D on the above aspects?

3.1.2 Whole-life cycle: Design

The design phase covers the translation of the conceptual work to system solutions. A positive answer to the first two answers in Criterion 8 would increase the possibility that the eventual RPAS or RPAS-service would meet the initial end-user requirements. If on the other hand the responses in Criterion 8 are negative then this will increase the possibility that the RPAS or services may not offer operational use either directly (i.e. it do not meet the operational needs) or sustainably as they may become obsolete or too costly to upgrade. Such upgrades may be necessary due to changes in other systems (interoperability), changes in operations (requirements), or on the system itself (e.g. unforeseen damages). If the Criteria 8 is fulfilled, then the next step is to ensure that the requirements have been translated to the design phase of the RPAS or services. This aspect would also depend on the decision between producing or procuring RPAS or procuring RPAS-services.

3.1.3 Whole-life cycle: Production/Procurement

Based on the conceptual and design phases of the whole-life-cycle, the end-user may identify the following options:

- **Produce the RPAS**: This option would provide full flexibility and control over all aspects of the RPAS system and its capacities. It would ensure that the RPAS fully meets the operational requirements set in the conceptual phase and translated into the design of the system. However, it also increases the responsibility and the risk for the end-user, as the end-user would be responsible for the whole-life cycle of the RPAS, from production to decommission. Hence, firstly, the end-user would need to have the capacity to produce either directly or through industrial partners the RPAS meeting his requirements. Unless the concept and design phase are matched by additional end-users (thus enabling wider cooperation on the development and procurement; and thus reduction of cost) then the RPAS system would be bespoke for the end-user thus increasing the cost. On the other hand, industrial and cooperative aspects may increase the cost-benefit of this solution; and the capacity to produce the RPAS also increases the sustainability of the system as the end-user would have full access to spare parts and, in some cases, capacity to upgrade the system. This would facilitate logistical aspects and minimise the impact of the RPAS on the overall system-of-systems of the end-user. Furthermore, training/personnel aspects could be more easily dealt with as the end-user should have full knowledge of the operational and technical aspects of the RPAS.

- **Procuring an RPAS**: A second option would be to procure an off-the-shelf (or semi-customised) RPAS. It is unusual that an off-the-shelf RPAS would be able to match exactly the end-user requirements and hence some compromises would need to be made between what is available in the market and what is required by the end-user. Furthermore, even if the procurement of RPAS gives operational flexibility it also increases the responsibility and risk of loss of sustainability of operations as any technical issue would result in grounding of the RPAS unless appropriate agreements for logistics (especially maintenance and spares supply) are made with the RPAS supplier. In addition, RPAS upgradability and modifications would be expected to be difficult and costly, while agreements regarding training would need to take place. Another possible issue is interoperability as an off-the-shelf RPAS may not be interoperable with the existing end-user system-of-systems thus reducing the effectiveness of the operation. Despite all the possible drawbacks, the off-the-shelf procurement of RPAS would reduce the initial cost and risk of a possible development/production phase failure. This is a significant factor towards selecting this option, as the end-user is certain that the RPAS is usable (assuming appropriate guarantees from the manufacturer), despite any operational compromises. The level of compromises versus cost-benefit would depend on how “intelligent” the end-user is, and hence a significant amount of research, testing and evaluation would be required (as mentioned in Criterion 8) in order to obtain the relevant knowledge for de-risk the procurement but also the remaining life-cycle of the RPAS (i.e. up to decommissioning).
- **Procuring services**: Another option is to procure services from RPAS operators. This approach provides long term sustainability of missions assuming that a market for such services is available and sustainable. However several operational and technical issues may arise. Firstly, the type of services required by the end-user may not exactly fit those supplied by the service provider thus reducing the operational usefulness. Furthermore, as the service provider is expected to be a commercial operator issues of priority for the end-user and availability of RPAS for a certain operation may arise especially as the number of end-users (not necessarily governmental) increases. Such an increase of end-users may also increase the cost for such services. In addition, as the end-user has no technical control over the RPAS system, issues of trust may arise about the RPAS adequacy to perform a certain mission in compliance with certain conditions (including data protection). Such issues could become even more critical in operations where the risk is relatively high leading to liability/risk issues and thus even higher costs for certain high risk operations. It would be

expected that the service provider would be inclined to take part in less risky operations thus meaning those where the RPAS remains off the danger zone or performs simple tasks (e.g. maintains altitude in stable environmental conditions) and hence this implies that service providers would be more oriented towards large RPAS operating at high altitude or small relatively inexpensive RPAS that could be easily repaired or replaced in case of damage. The above operational and technical issues are countered by the reduction of responsibility and risk for the end-user with regards to the non-operational part of the RPAS life-cycle. All aspects of development, maintenance, storage and decommissioning but also logistics and training would be the responsibility of the RPAS service provider. The end-user would thus be able to treat the services as a "black-box" i.e. the end-user would not need to have knowledge about how the service is provided but would only need to be able to define and assess the intelligence inputs, parameters and the outputs of the services. It is worth noting that even in the case of RPAS services, the eventual cost may be reduced if multiple end-users with similar operational requirements could cooperatively procure such services.

Fig.11 provides a qualitative view of the three options mentioned above through a spider-web diagram. The closer the indication is to the centre of the web, the better the expected performance of the option in terms of cost, availability or impact. The positions of the indications of the options on the web are based on the author's knowledge and could hence vary depending on the RPAS the CONOPS and the end-user scenario. Assuming the diagram is on average correct, what we could note is that Option 1 (Developing/Producing the RPAS – blue line in Fig.11) would be more attractive in the case where the operational requirements are stringent and the market-forces are not expected to be interested in addressing these requirements. On the other hand if the operational requirements are not as stringent then Option 3 (Procuring RPAS services – green line in Fig.11) would be the best option as it minimises both the impact on the rest of the end-user system and the non-operational cost. Two of the main issues with Option 3 (Cost of operations and Operational availability) could be improved if long-term agreements are made with service providers in order to ensure that an RPAS can be made available at very short time after a request. Such long-term agreement could reduce the cost of operation, though this would also depend on the expected frequency of RPAS operations. Option 2 (Procuring an RPAS – red line in Fig.11) could be viewed as a mid-solution but its impact and cost could raise significantly in case of unexpected problems or required modifications, as the end-user would not be expected to poses internal know-how/capacity to perform modifications and would thus be required to refer back to the RPAS manufacturer.

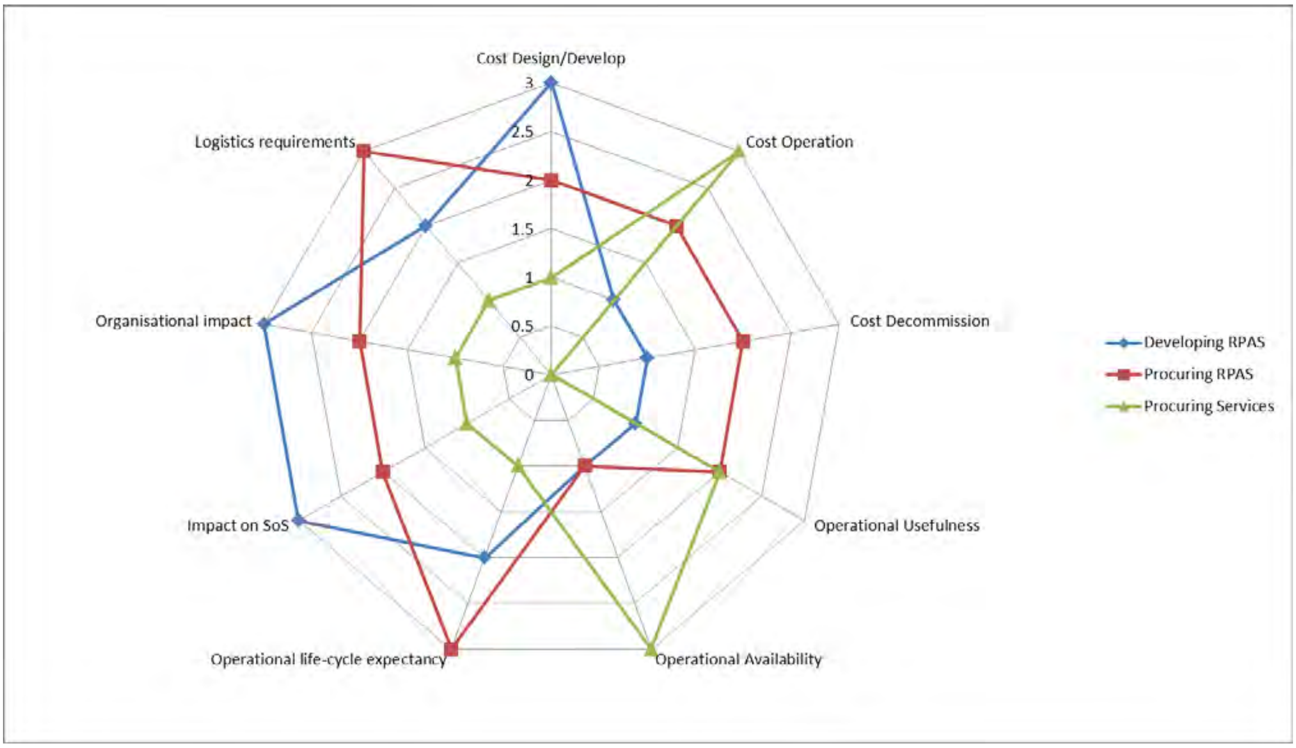

Fig.11 Web-diagram indicating a qualitative comparison of the three options for meeting operational requirements using RPAS. These options are Developing/producing RPAS (blue line), Procuring RPAS (red line) and Procuring RPAS services (green line). Elements of comparison include cost, impact and availability. The closer the line to the centre of the diagram, the better the expected solution is.

All three solutions have advantages and drawbacks as well as risk at different stages of the RPAS life-cycle. Hence, it is not possible to specify a best option but this should be assessed by the end-user based on its specific scenario/requirements, capacities and know-how; affordability but also other national aspects (e.g. industrial aspirations). Independently of the option chosen, cooperation could be used for reducing risk and cost at different stages (development, procurement, operation or decommission). This could include:

- Cooperatively researching and evaluating RPAS solutions for de-risking future procurement.
- Cooperatively developing RPAS solutions based on similar operational requirements but also budgetary and industrial capacities.
- Cooperatively procuring RPAS with different options of system management (especially when the partners are in geographical proximity and operational requirements are similar, e.g. maritime surveillance of neighbouring coastal areas).
- Cooperatively procuring RPAS-services.
- Cooperatively organising logistical, maintenance or other non-operational aspects including decommissioning of RPAS systems.

The above considerations lead to the following Criterion:

- **Criterion 9**: Have you considered and compared different options (development, procurement) for meeting your operational requirements? If yes, have you identified different sub-options in terms of technical solutions or suppliers (of RPAS or services), and if yes how many (if below three then please provide some justification)? Independently of the option chosen, please specify if you have considered the possibility of collaboration (either cross-sectorial, European or international) and what was the outcome of this consideration?

3.1.4 Whole-life cycle: Operational sustainability

Once the system has been produced/procured (either directly or via the service of its operator) then starts its operational life-cycle. The operational usefulness of the RPAS has been analysed through the first seven criteria and hence is not considered further here. However, what needs to be further examined is the sustainability of operations. As mentioned above, if services are being procured then the end-user does not have to deal significantly with sustainability aspects apart from ensuring that enough funding and support to the third party contractor are available. Significantly more sustainability effort is needed in case the RPAS is owned by the end-user. In such a case the end-user would need to ensure operational sustainability by providing personnel, support, and interoperability for the RPAS system both for the operation but also for any subsequent maintenance and upgradability that would need to take place in order to ensure that the RPAS continues to be operational for as long as needed or as possible. The above elements are analysed further below:

- **Support (logistics, maintenance, upgrade, recovery/salvage)**: Support is of particular interest to the case where the end-user is the owner of the RPAS but could also be an issue in the case of procurement of services, especially for sensitive operations (i.e. near borders or coastlines of third nations). Overall, the end-user should ensure that adequate logistical chains have been produced to enable the continuous availability of the RPAS for operation. This would include appropriate operational space but also storage and transfer facilities for the RPAS and relevant systems/components either at the EU Base or on the vessel/vehicle used for transiting the RPAS to its GAoI. It would also include consumable elements (e.g. fuel) but also other components for maintenance purposes (e.g. liquid or solid consumable, spare parts for replacement of damaged components or even a completely new RPAS in case of loss of availability of the original system). In addition, the end-user would need to ensure that the RPAS is appropriately maintained thus ensuring the maximum reliability of the RPAS. This would include both advanced/preventive maintenance but also maintenance due to malfunction or damage to the RPAS. The end-user would thus need to ensure quick and safe access and departure for the RPAS to appropriate maintenance facilities and personnel. Furthermore, the end-user should also enable access and departure of the RPAS to upgrading/retro-fitting facilities in case new improved components/sub-systems are made available or the RPAS needs retrofitting/upgrading to meet requirements (existing or new). Finally, the end-user would need to consider the case when the reliability of the RPAS fails during the mission. In such a case the end-user would need to ensure that adequate capacities for recovery (e.g. from the water) and salvation of the RPAS are available. All of the above would be primarily valid for the case where the end-user owns the RPAS but would also need to be considered even if the end-user is procuring services as cooperation/coordination between the end-user and the service provider may be critical in emergency situations. Please note that liability issues would be addressed in the legal part of this document and hence are not addressed here.

- **Personnel (HF, training)**: The end-user would need to take into account personnel issues, again independently of whether the end-user owns the RPAS or procures services. Such personnel issues would include human-factors linked to the use of RPAS but also appropriate training. The human-factors could include issues such as providing adequate space, infrastructure, equipment, man-machine interfaces and facilities for operators or handlers of RPAS. In addition, issues of acceptance and willingness to use the RPAS may arise even if the personnel are well trained in their use. Training is in fact a crucial element whether the RPAS is owned by the end-user or not. In case the end-user owns the RPAS then the end-user has full responsibility over the RPAS use and hence adequate training is needed both for personnel that directly (RPAS operators, control station personnel, handlers, maintenance, etc) or indirectly (decision makers, commanders, personnel of EU Base or transit vessels/vehicles, etc) are involved in RPAS operations. In the case where RPAS services are procured, the end-user personnel indirectly involved would still need to receive adequate training in order to have a better understanding of technical issues that may affect operations.

- **Interoperability (joint operations, cross-sector, third parties)**:
    - <u>Joint Operations</u>: Another aspect affecting operational sustainability but also impacting operational usefulness is the ability of the RPAS to interoperate seamlessly with the end-user existing or future system-of-systems. The interoperability extends to all possible aspects from storage, transfer, launch & recovery, and maintenance but also operation in terms of exchange of data. The above give rise to standardisation and modularity that would enable the interoperability of the RPAS with other systems. Of particular relevance during operations is the capacity of the RPAS to exchange data with other systems, especially when the RPAS is operating jointly with other assets. In such a case processed or raw

sensor data from the RPAS would need to be transferred as quickly as possible and visualised through the C2 systems of the other assets or the EU base/transit vessels/vehicle. In reverse, commands from the EU base or other assets where the RPAS support system is, would need to be transferred to the RPAS as quickly as possible. The transfer would need to take place via the RPAS control station. Standardisation would be needed for ensuring optimal transfer of the data without or with minimum need for manual intervention. Such standardisation would be easier to obtain if the RPAS is developed by the end-user in which case the end-user would have full control over the whole C4 sub-system of the RPAS. Interoperability is also possible with procured RPAS or services as long as the RPAS or service provider can enable data exchange through the RPAS C4 sub-system using certain standards utilised by the end-user's assets. If the end-user's assets do not use the same standards then further work would be required to enable the exchange of data. Such work could range from producing sophisticated translators enabling the RPAS to directly exchange data with other assets or producing/procuring additional C4 sub-systems that would need to be inserted into the other assets. If additional C4 sub-systems are needed then some level of manual work during the operation may be required for the transfer of data. Along with standardisation, modularity would also play a critical role for interoperability. In the case of data exchange, additional C4 sub-systems may be in the form of modules that could be rapidly installed and uninstalled from other end-user assets. In addition, modularity would facilitate the storage, transfer but also launch and recovery of the RPAS from other end-user assets. In such a case, modularity could imply standardised containerised solutions which would contain the RPAS and which could be easily installed upon other assets in a plug-and-play approach. Modularity could also facilitate maintenance / upgradability / retro-fitting of the RPAS itself. In that case, modularity would imply that the RPAS is composed of modular sub-systems which could be easily removed and replaced or exchanged with other sub-systems in case of malfunctioning or damage but also in case the RPAS mission is modified (e.g. requiring different types of mission sensors) or a new improved sub-system is made available. In all cases, the use of open standards would disconnect the end-user from the original RPAS/service supplier enabling the end-user to take full control of any future work on maintaining/upgrading the system (most probably at a lower cost for the end-user).

- <u>Cross-sector/Third parties</u>: Most of the interoperability aspects mentioned above would also have an impact on the interoperability of the RPAS with other end-users or third-parties. Such situations may arise in the case where multiple national agencies are using the same RPAS for different but similar applications, thus requiring the RPAS to be able to operate with different mission-sensors and interoperate with different C4 sub-systems. Other situations where such interoperability would be needed could occur in multi-national operations where the RPAS could be required to interoperate with different C4 sub-systems or even storage, transfer and maintenance facilities. Hence once again, standardisation and modularity based on commonly used standards would facilitate such interoperability.

Based on the above considerations the following Criteria could be extracted:

- **Criterion 10**: For the technical solutions (RPAS or RPAS-services) identified in Criterion 9 have you also identified appropriate measures for supporting operations (e.g. logistics, maintenance, upgrade, recovery/salvation) and personnel (e.g. Human Factors, training)?

- **Criterion 11**: For the technical solutions (RPAS or services) identified in Criterion 9 have you investigated interoperability aspects with your existing or future system-of-systems, multiple asset operations or cross-sectorial and multi-national operations? Have you considered standardisation and modularity, and if yes please provide relevant comment?

3.1.5 Whole-life cycle: Decommissioning

Once the operational life of the RPAS system has reached its end, the end-user would need to consider the necessary decommissioning process. The decommissioning effort required would be considerably less in the case where services are procured, since the service provider should take full responsibility for the removal of the RPAS and any sub-systems. Even so, some impact may occur on the existing facilities and systems of the end-users such as availability of previously used space, availability of equipment or software for supporting interoperability, etc. The biggest decommissioning impact is expected to take place in the case the end-user has developed or procured the RPAS, since the end-user would have bigger responsibility. If the end-user has developed the RPAS then they would have the full responsibility for decommissioning but also full possible gains from the extracted material/components/sub-systems. In theory two ways could be used for decommissioning of the RPAS, firstly direct decommissioning by the end-user by full destruction/dismantling and then re-cycling/storage of material/components/sub-systems or hiring of specific services for performing the above. In both cases, hazardous materials would need to be addressed during decommissioning. The bigger the RPAS the more specialised the decommissioning will be, with larger RPAS having to probably follow the same principles as manned aviation aircraft. On the other hand smaller RPAS could be more easily decommissioned. In the case where the RPAS has been procured, then the manufacturer should be contacted for the decommissioning.

3.1.6 Whole-life cycle: Lessons Learned

Lessons learned from the process are bound to drive further conceptualisation and design of new RPAS concepts but also new designs of system-of-systems that could further improve the sustainability of the operations. It is important that such lessons learned already exist prior to significant procurement taking place. Therefore, it would be appropriate if MS with no significant RPAS experience, first contact appropriate Research & Technology (R&T) projects or service procurement to identify lessons learned that could then support them in better defining their requirements based not only on their needs but also on what is technologically feasible or available on the market and their balance of investment.

The use of lessons learned for de-risking of procurement has already been addressed through Criterion 8 and hence it is not addressed further here. The remaining lessons learned would result from real RPAS missions. To be able to extract post-mission lessons learned, measures of effectiveness (MOEs) and measures of performance (MOPs) would need to be established based on the analysis of requirements mentioned in Criterion 8. MOEs could be both qualitative and quantitative and linked to the operational goals. For example, for border surveillance missions a measure of effectiveness would be to be able to detect certain types of targets of interest within an area of interest at 100% probability rate independently of environmental conditions. Another MOE could be the continuous availability of the RPAS for border surveillance operations, while another MOE could be a certain amount of video hours over a certain area of interest every month or year.

The above mentioned MOEs are closely linked to several of the Criteria already described in this document and especially Criteria 1-7 that are closely linked to the operational usefulness. The exact formulation of the MOEs will depend on the scenario and concept of operation of each end-user. What is important to note though is that the MOEs should focus on how well a mission/operation has been performed and not how it was performed. Hence, MOEs should be independent of the technical solution (i.e. the RPAS procured or service supplier used) and could be used to compare the technical solutions.

These MOEs will be supported by a number of MOPs which could also be used to identify causes that may contribute to inability to achieve the MOEs. This is because the MOPs are measures that characterise a particular system, e.g. its speed, its MTOW, its sensor spatial resolution, its maximum altitude, its endurance, etc. MOPs are also linked to the operational Criteria (1-7) already described, based on the RPAS parameters as shown in Fig.9. Using Fig.9 we can see that a number of MOPs could affect the ability of the RPAS to meet the MOEs. For example, the sensor coverage area along with the operational speed of the RPAS would contribute to enabling the detection of certain targets within a certain area of interest, as already described by Criterion 2 but also Eq.3. In general, MOPs should be linked to test- or operational-conditions and their achievement should result in also achieving the MOEs they contribute to. Furthermore, MOEs and MOPs are critical in assessing the post-performance of the RPAS or solution used and enabling the identification of reasons for failure to meet requirements and/or areas of improvement in case of future procurement or development.

As an example, one MOE could be the requirement of 100% detection of certain types of targets within a certain area of interest independently of environmental conditions. If the RPAS chosen to perform the operation has failed to detect a target of interest which was subsequently detected through different means then the RPAS has not met the 100% detection rate and hence fails the MOE. The MOPs could then be used to assess why this failure has occurred. It could be that the RPAS was not operating correctly due to environmental conditions or the RPAS mission-speed was not appropriate or the sensor had not performed according to its specifications.

The above considerations, lead to Criterion 12, which is meant to examine whether the end-user has identified MOEs and MOPs for its envisaged border surveillance operation, based upon the performance of the procured RPAS or RPAS-services would be assessed.

- **Criterion 12**: Have you, based on Criteria 1-8, established MOEs and MOPs to enable the assessment of the proposed RPAS solutions both prior to and after development/procurement of the RPAS or services, thus enabling the extraction of lessons learned for supporting further development/procurement.

3.2 Protection and Safety

3.2.1 Safety

RPAS must be safe for

- any personnel involved in its operation/manipulation
- third party persons and
- the surrounding environment/property.

Safety aspects are linked to regulations and hence will be addressed in the second part of this report. However, some basic elements are provided here for completeness. As mentioned above, RPAS must be safe or at least safer than manned alternatives. The European Aviation Safety Agency (EASA) has been mandated, based on Regulation (EC) No 216/2008 to regulate Unmanned Aircraft Systems (UAS) and in particular Remotely

Piloted Aircraft Systems (RPAS), when used for civil applications and with an operating mass of 150 Kg or more. However, experimental or amateur build RPAS, military and non-military governmental RPAS flights, civil RPAS below 150 Kg as well as model aircraft are regulated by individual Member States of the European Union. Hence, if a governmental end-users wish to make use of RPAS, they should ensure that the RPAS are certified appropriately according to their national rules/regulations/guidelines, set by their own National Aviation Authorities (NAAs). There are currently no European rules on the matter and hence these regulations vary widely from country to country. In some cases, NAAs may allow some types of very small RPAS to operate without any certification, pilot license or restriction as long as some basic principles are followed (e.g. maximum altitude, respecting no fly zones, etc). Other NAAs may not allow this freedom. As the RPAS size increases, the national regulations/rules become stricter but, again in general, the current approach used is to assess the risk of a proposed RPAS operation based on the mission risk (e.g. over populated areas or not, near critical infrastructure or not, etc), the RPAS risk and the RPAS pilot risk. As the RPAS size approaches a normal aircraft size then the NAA rules applied should resemble those for manned aircraft as the risk is considerable during the different parts of the operation.

Currently, many European and international aviation authorities are working on harmonising such rules through the Joint Authorities for Regulating Unmanned Systems (JARUS) initiative. JARUS is developing recommended requirements for:

- Licensing of remote pilots;
- RPAS operations in Visual Line-of-Sight (VLOS) and beyond (BVLOS);
- Civil RPAS operators and Approved Training Organisations for remote pilots (JARUS-ORG);
- Certification specifications for light unmanned rotorcraft and aeroplanes below 600 Kg;
- Performance requirements for 'detect and avoid' to maintain the risk of mid-aid collision below a tolerable level of safety (TLS) and taking into account all actors in the total aviation system;
- Performance requirements for command and control data link, whether in direct radio line-of-sight (RLOS) or beyond (BRLOS) and in the latter case supported by a Communication Service Provider;
- Safety objectives for airworthiness of RPAS to minimize the risk of injuries to people on the ground; and
- Processes for airworthiness.

Work on special topics may be undertaken by the direction of the JARUS Leadership Team. Special Topics may include e.g.:

- Recommendations and considerations involving the impact/effect of
- Human Factors (HF) on the design, certification, maintenance and
- operation of UAS and related support equipment;
- Development of a classification scheme for UAS;

- Safety Management System (SMS) considerations;
- Definition of model aircraft

Despite the present fragmented view in terms of regulations, the use of RPAS is currently possible in Europe, as long as authorisation from the relevant national authority is provided. Furthermore, governmental end-users usually have higher priority over commercial airspace users and hence, if required, special means can be used to ensure that governmental operation can take place (e.g. by creating a no-fly zone over a certain geographic location to enable segregation of manned traffic and the unmanned operation). Therefore, the basic principle before the use of any RPAS for any border surveillance purpose is to contact the national aviation authority of the end-user, which will be able to provide support for the operation. Additional support may be offered by EASA and hence, especially for large and cross border RPAS operations. Thus, contacting EASA is advisable, despite the fact that the Agency is not responsible for governmental RPAS operations.

Once the JARUS initiative succeeds, it is possible that the current division between below and above 150kg will cease to exist for RPAS operations. Preliminary JARUS results seem to hint towards the creation of three categories similar to the ones mentioned above. Namely:

- **Open**: Low risk and hence no RPAS airworthiness certification or operational authorisation and pilot/crew/operator license requirements for any element of the RPAS.
- **Specific**: Higher risk RPAS and operations which would require a relevant risk assessment and issuance of an authorisation for the RPAS operation.
- **Certified**: Very high risk RPAS and operations that would have similar requirements for RPAS airworthiness certification, operational authorisation and operator license as manned aircraft. This would include also relevant certificates/licenses linked to ATM insertion, maintenance, Command & Control systems, Detect and Avoid systems and other support systems.

The above aspects can be considered generic for any type of operation and hence will be analysed further at the second part of this report. The analysis will also include insurance aspects linked to insuring RPAS operations against accidents. Even so, one element which is mission specific and hence would need to be analysed with regards to surveillance missions is the aspect of protection/survivability of the RPAS.

3.2.2 Protection/survivability

In general, to increase the RPAS mission survivability three elements would need to be addressed, the RPAS susceptibility, vulnerability and recoverability. These three elements are detailed below using a similar terminology to that used for military assets [2]:

- **Susceptibility**: Is a measure of the capability of the RPAS, mission critical systems, and crew to avoid and or defeat an attack and is a function of operational tactics, signature reduction, countermeasures, and self-defence system effectiveness.
- **Vulnerability**: Is a measure of the capability of the RPAS, mission critical systems, and crew to withstand the initial damage effects from conventional and other attacks or accidents and to continue to perform its assigned mission, without any risk for the crew or third parties.
- **Recoverability**: Is a measure of the capability of the RPAS and crew, after initial damage effects, whatever the cause, to take action to contain and control damage, prevent loss of a damaged RPAS, and minimize and risk towards personnel or third parties; and restore and sustain primary mission functions.

To facilitate our analysis of RPAS protection we will use the “survivability kill chain” which combines elements of susceptibility, vulnerability and recoverability into a single chain [3]. In more detail, the chain consists of the following five elements:

- **Threat Suppression**: This element is linked to susceptibility. It determines if an active threat is present. If the threat can be suppressed or eliminated in advance, the survival condition is met and the RPAS element can perform its mission fully.
- **Detection Avoidance**: This element is linked again to susceptibility. Assuming that a threat does exist then the second element determines the detectability of the RPAS to the threat. If the RPAS element can avoid detection, it should survive the possible threat.
- **Engagement Avoidance**: This element is linked again to susceptibility. If the RPAS cannot avoid detection then the third element determines the possibility that the RPAS element could avoid its engagement in any combat activities, thus again surviving.
- **Hit Avoidance**: This element is linked again to susceptibility. It determines the chances that the RPAS will be affected by the threat (i.e. kinetically, electronically, etc.). If the RPAS can avoid the threat effects, it will again survive the engagement.
- **Hit Tolerance**: The final element is linked to both vulnerability and recoverability. It indicates the magnitude of the attack including effects on other RPAS elements. If the RPAS is able to sustain or absorb/recover from the attack, it survives and continues its mission with no danger to the personnel or third parties. Otherwise, it’s destroyed or it may become a hazard itself.

If any of the survival conditions of the first four elements are met, the threat will be completely negated. If not then survival condition is uncertain. Hence, it is essential to understand the possible threat and its capacities. In normal circumstances, a possible threat for the RPAS should be low given that border surveillance is a civilian operation and the targets of interest are not expected to possess sophisticated means of defence against RPAS surveillance, including both detection and countering of RPAS. In addition, it is expected that third states on the other side of the EU border would be informed of the RPAS presence and operation and that the RPAS would remain inside the permitted area of operation thus not compromising the national security of third states.

Based on the above assumptions, the protection analysis will focus on the threat posed by targets of interest and on the effects on the RPA itself and not on the support or control station system, which is assumed to be at a safe distance from the place of a possible incident. This of course depends on the application and whether the RPAS support of control station systems are located inside the SAoI or not. But as the RPA should be the only element of the RPAS coming in contact with the target of interest, then this assumption remains valid.

Looking at the threat, it is not expected that the targets of interest would possess nor means of long distance air-detection such as radars or other sophisticated detection mechanism (EO/IR/acoustic). Hence, the prime detection risk is expected to be visual or acoustic human sensors, which have a limited range capacity. With regards to countering means, the targets of interest are also not expected to possess sophisticated means of RPAS countering such as physical means (e.g. surface-to-air weapons) or electromagnetic means (jamming or electromagnetic pulse weapons or communications/cyber-attack means). Recent incidents [4] though indicate that the targets of interest may include armed personnel whose armoury could include short range, relatively unsophisticated weapons such as machine guns, rifles, etc. Our survivability analysis will thus focus on these unsophisticated RPAS-detection and RPAS-countering threats and the "kill-chain" described above.

- **Threat Suppression**: At this moment in time, the European borders are facing a number of targets of interest which wish to enter illegally into EU territory. In the blue (maritime) border case targets of interest include those that aim at transporting illegal or unregulated goods or persons. Such targets include mostly vessels though in exceptional cases single person intruders (e.g. divers) could also be considered. The same applies to green (land) borders though in this case persons trying to illegally cross the border on foot are a more regular target of interest. Suppressing the presence of such targets of interest is simply impossible under current geopolitical situation. The question would then be if the threat posed by the targets of interest could be suppressed. This could be done by reducing their capacities to curry a threat for the RPAS, which as mentioned above should be primarily through unsophisticated weaponry. Again, given the current geopolitical situation, this is not considered possible as it would have to be controlled at the place of origin of the targets of interest. In the long term, more stability, democracy, financial and education opportunities and increased collaboration between such countries of origin and the EU may lead to improving the situation but the threat is not expected to be phased out completely. Hence, the RPAS Threat Suppression element cannot be met.

- **Detection Avoidance**: The next element is how to avoid detection of the RPA from the threat. This is the first element linked to the RPA and its concept of operation. Given that the detection means of the targets of interest should be relatively small (as mentioned above, primarily human sensors), then the following should be considered:
    - The altitude of RPA operation: The higher the altitude the more difficult it would be for the target of interest to detect the RPA independently of the RPA visual/acoustic aspects. Therefore, the threat would increase depending on the concept of operation. Namely if the RPA is meant to only detect a target then the threat is low. But if it is meant to also identify the target, then the RPA would have to descend closer to the target of interest unless it possesses more powerful sensors. Therefore, from this perspective the bigger, higher flying RPA are more protected than the low altitude ones.
    - The visual and acoustic characteristics of the RPA: The visual and acoustic signatures of the RPA should be reduced taking into account a cost-effectiveness balance. Therefore, bigger-size RPA should not be operating near a target of interest and all RPAs should be made to have low visibility against their background in different conditions so as to be less detectable. Finally, the RPA should be as silent as possible.
- **Engagement Avoidance**: If the RPAS cannot avoid detection then the third approach should be to avoid its engagement in any combat activities. The main way to enable this would be for the RPAS to detect, before it has itself been detected, if the target of interest possesses armory. If yes, then the RPA should immediately stop its operation and return to base. If no armory is present then the RPA can continue its mission. This would affect the concept of operation of the RPAS as such an approach could be deemed inappropriate/non-useful for the purpose of the RPAS mission. For example, the RPA itself, due to its limited value, could be considered an acceptable loss against the possibility of protecting a high value unit or persons lives. In such a case, the CONOPS could include the use of the RPA as a first element of an engagement, as any attempt by the target of interest to engage the RPA would provide information on the possible threat that other end-user high value units and their personnel would face. This concept of operation would be most appropriate for RPA that are able to descend closer to the target of interest (e.g. primarily rotary wing RPAs).
- **Hit Avoidance**: If the RPA cannot (or should not) avoid engagement due to its concept of operation or its sensing capacity then the next approach would be to avoid being hit during engagement. Several ways could be perceived to enable this. The first would be for the RPAS to be able to detect whether a threat (i.e. weapons) exist on the target of interest and if yes to maintain the RPA at a safe distance from the target of interest (making some assumptions on the possible threat range). The second would be for the RPAS to be able to detect that the RPA has been detected and if yes to again maintain the RPA at a safe distance.

Another approach would be to constantly maintain the RPA at a safe distance. What exactly is the safe distance would depend on the armory of the target of interest which of course would be difficult to identify, but also the size of the RPA (the bigger it is the bigger the possibility of a hit). Hence, a balance should be reached taking into account the possible armory, the possibility of successful engagement (hit) and the distance/altitude of the RPA from the target of interest. Finally, another approach would be to enable the RPA to perform evasive manoeuvres in order to avoid or at least decrease the probability of the hit. This should be more feasible with smaller single- or multi-copter RPAS than fixed wing RPAS.

- **Hit Tolerance**: Finally, if the hit cannot be avoided, then the last possibility is for the RPA to sustain and absorb/recover from the hit. If this is the case then the RPA should possess significant levels of internal protection and system-redundancy. This could be possible, but at a price both in terms of cost but also size. Therefore, yet again it should be a matter of cost-benefit assessment if the RPA should include expensive protection and recovery systems or if the RPA should be cheap and its loss acceptable in case of engagement. If none of the identified solutions are acceptable then the above four protection approaches would need to be revisited in order to appropriately design the concept of operation and select the RPAS.

The diagram of Fig.12 provides a graphical representation of the design approach that could be used to increase the probability of RPAS survival specifically for border surveillance operations. The first element of the design is linked to Criteria 3 mentioned above, i.e. the definition of the Concept of Operations. Based on whether the RPAS would be used for detection, classification, identification or tracking the minimum RPAS altitude required should be identified. The next step would be to make an assessment of the possible threats for the RPA and their range. This assessment can only be based on assumptions about the capacity of the target of interest to curry armoury. If the range of the threat would be expected to be longer than the minimum altitude, then the concept of operations would need to be re-examined and a decision taken on whether the minimum RPA altitude should be raised or whether other measures should be taken for reducing the possibility for detection or successful engagement by the target of interest. This would include sensors for threat detection, RPA-signature reduction, reduction of size or other design options for reducing hit probability such as appropriate C2 modes for evasive action or hit tolerance measures. The above, would have an impact on the size and cost of the RPAS as mentioned above. This impact cannot be assessed directly from the currently existing data and would need to be done on a case-by-case approach by directly approaching manufacturers or by a relevant survivability study of possible RPA solutions. If the cost- or size-increase required for enabling the RPA survivability, are deemed unacceptable then again the initial CONOPS and all possible measures mentioned above would need to be re-examined. As this approach is directly linked to the Criteria 3 on the Concept of operations, no additional criteria is required for protection.

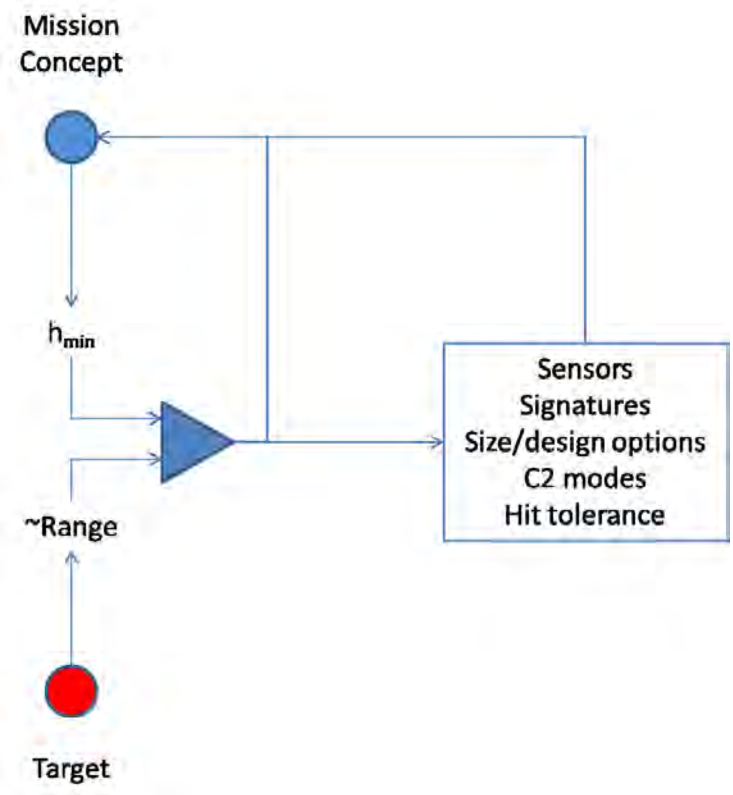

Fig.12 Graphical representation of a design approach for enabling a higher probability of RPAS survival specifically for border surveillance operations.

3.3 Command and Control in RPAS missions

An important element in managing the RPAS mission is the Command and Control (C2) sub-system of the RPAS. The C2 sub-system importance increases as more mission-flexibility is needed by the end-user. Hence, in operations where no flexibility is needed, the RPAS could be pre-programmed to follow a certain route and then launched. The RPAS would then follow the route based primarily on GPS navigation and no real-time exchange of data would take place between the operator and the RPAS during the mission. In such extreme examples, if the RPAS is used for surveillance, then the video/images could be taken and stored internally within the RPAS. Once the RPAS has finished its mission, the images could be retrieved and analysed thus resulting in near-real time surveillance. In such a case the only requirement for data exchange between the RPAS and the Control Station would be in case of an emergency, in order to be able to command the RPAS to abort the mission. This very simple approach is currently used when the RPAS remains within VLOS of the RPA pilot. If the RPAS mission needs to be reconfigured or the RPA pilot is required to maintain continuous control of the RPA, then a more sophisticated C2 sub-system would need to be used. Such a C2 sub-system should include the RPA C2 component, the C2 communication data-link and the Control

Station C2 component, which could consist of several sub-components such as Man-RPAS interface, visualisation components and decision support components.

At this point it is also important to distinguish between communication required for Command and Control of the RPAS and communication needed for transfer of payload sensor data (e.g. images or videos). As mentioned before, for Command and Control (C2) the required bandwidth is low (56kbit/sec is sufficient) as the amount of data exchanged is low and consists either of commands from the control station to the RPA or telemetry and navigation-sensor data from the RPA to the control station. This C2 data-link can be achieved via a tele-controller (for Radio LOS) or mobile network communication and even satellite communication (for Beyond Radio LOS) links. More elaborate communication strategies for Beyond Radio LOS could be designed using multiple RPAS or assets where data is relayed from the control station to the mission performing RPAS using other RPAS or assets.

The actual control station may be placed on the ground (e.g. at the EU Base) or at the transit vehicle/vessel used to taxi the RPA to the GAoI. Other possibilities exist where the control station is placed at a different geographical location or asset (air, land or maritime) which needs direct access to the data collected by the RPAS. Technically, the control station contains the Man-RPAS interface which enables commands from the pilot to be sent to the RPAS thus modifying its mission according to updated requirements or emergencies (e.g. other approaching air-space users, etc). The Man-RPAS interface is linked to a visualisation mechanism enabling visualisation of the current status of the mission and navigation parameters (e.g. position, time, altitude, etc); as well as RPAS sensor/image/video information that can be used both for assessing the normal RPAS operation and for detection of targets. In some cases, the same information is processed by decision support components enabling for example the identification of errors or threats related to the RPAS execution of the mission (obstacles, low RPAS fuel, difficult environmental conditions, etc) or the detection of targets of interest within the sensor/image/video data provided by the RPAS. The identified elements can then be visualised by the end-user through the Control Station visualisation component or through any C2 system of the end-user (assuming interoperability has been achieved). The pilot and end-user may then use the information provided and decision support mechanism to take decisions about the RPAS mission (proceed, abandon, modify) and provide necessary commands to the RPA.

The complexity of the control station could vary from a simple portable device (e.g. commercially available smart-phones) to a containerised system which includes visualisation, decision support and sophisticated communication components. In general, the more expensive and heavy the RPA is the more sophisticated is its Control Station in order to reduce possible incidents but also to enable the maximum use of the RPA navigational capacities. For example, if the RPAS would need to engage in detection but also additional classification, identification and tracking (CIT) operations then regular exchange of information and commands with the pilot and end-user would be required especially if the RPAS is meant to change altitude and approach the target of interest (based on the Concept of operation of Criteria 3) thus increasing the risk for third parties/property. The reliability and robustness of the C2 communication would be highly critical for operations of larger RPAS that would need to operate in the future in an integrated manner with manned air traffic, under so-called Instrument or Visual Flight Rules (IFR/VFR). In such cases, the remotely placed pilot would need to have continuous C2 capacity over the RPAS though in reality, even if communication links fail, the RPAS would need to have enough Sense and Avoid capacity to avoid both potential incidents but also eventual collisions with other air-traffic.

Taking all the above into consideration, we could conclude that part of the complexity of the C2 system and C2 communication link required for managing the RPAS mission would depend on the operational aspects already discussed (e.g. Criterion 3 – CONOPS, Criterion 7 – SAoI and even Criterion 11 – Interoperability). However, some elements of the C2 system would need to be addressed in advance and in particular the visualisation and decision support mechanisms of the system. Hence, the end-user would need to clarify in advance what the expected end-product of the RPAS mission would be, which would then facilitate decision making, not only for the RPAS mission but also for the use of additional assets. Such end products could be raw images, processed images, or full analysis reports from the RPAS operating team or service provider. This clarification would be needed in order to ensure that the end-user is able to make full use of the RPAS end-products, especially in time-critical situations. Therefore, based on the above, the following Criterion is established:

- **Criterion 13**: Have you identified the end-product required by the RPAS mission in order to support relevant decision-making? Have you also considered the full process chain for delivering this end-product to the decision maker?

Section 4 Analysis of Information collection from RPAS Sensor Network: Communication capabilities

This section addresses the communication issues arising from the requirement to transfer relevant surveillance sensor data from the RPAS to the Control Station and hence the end-user. It does not address the Command and Control aspects of communication that have already been addressed in the previous section. The communication of surveillance sensor data from the RPAS to the Control Station is interrelated to the RPA autonomy/processing capacity but also the Concept of Operation (CONOPS) and the distance of the SAoI from the Control Station. Starting with autonomy, the amount of surveillance information sent to the control station could be reduced if the RPA possesses enough processing capacity to perform on-board detection but also classification and even identification analysis. In such a case the information communicated to the control station could be small (i.e. a simple image of a vessel/vehicle detected with data on its classification or even identification instead of continuous raw video images). This type of surveillance approach would demand both sophisticated processing equipment but also energy, thus increasing both the MTOW and the cost of the RPAS. On the other hand, as the number of sensors on the RPAS is increasing, so is the amount of surveillance sensor data. The available spectrum for transmitting such data is becoming limited and hence in the case of multi-sensor surveillance using a single RPA, some level of image pre-processing on-board would be required.

The exact opposite situation, has already been partly described in the previous section. This is the situation where the CONOPS does not require any real-time surveillance data. In such a case, during the mission, the RPA could register relevant images/sensor-data in an internal memory which can be retrieved once the RPA is recovered. Such surveillance operations could be linked to non-time critical surveillance, e.g. general mapping or examination of specific area to identify changes over time on relatively immobile elements (e.g. infrastructure).

In the case where the CONOPS requires real-time surveillance data transfer from the RPA to the control station then different strategies can be used for such a transfer depending on the distance of the RPA to the control station. The bandwidth required for the communication of the payload sensor data is much larger than the bandwidth for C2, going up to 8-10 Mbit/sec for a high quality video link. Large RPAS may require a bandwidth higher than 100Mbit/sec. This bandwidth is not readily available for RPAS. Some RPAS use the Industrial, Scientific and Medical (ISM) bands at 433MHz, 2.4 GHz (WLAN 802.11, i.e. WIFI), 5.8 GHz and 20 GHz. Other RPAS make use of different bands including satellite communications but also mobile phone networks. The use of different means for transferring real-time data depends on the CONOPS and the capacities of the RPAS.

The simplest case occurs at short distances between the Control Station and the SAoI, with Very Low Level (VLL) operations (below 500ft) and with an RPAS below 125kg of MTOW where VLOS could be used. In such a case the transfer of data can be made with direct radio links based on the bands mentioned above. Assuming again the same VLL operations and RPAS limits but an operation with BVLOS (due to larger distance between the Control Station and SAoI) then two possibilities could exist. The first that communication is enabled via a radio link with beyond the horizon capacities or that the communication is enabled via multiple assets. This last option entails the use of other land, air, maritime or even space assets capable of relaying the data from the RPAS to the control station in a network configuration (see Fig.13). Such assets could include fixed or mobile relay stations on the ground, maritime vessels or even buoys and unmanned maritime systems at sea, but also aircraft including other RPAS on the air and satellites in space.

Fixed land relay stations and satellite communications are currently very common for larger RPAs. Fixed land relay stations could be as simple as GSM relay stations which communicate with the RPA in the same way as mobile phones, as long as the RPA remains with the network coverage. Such approach, though quite easy to achieve, limits the operational range of the RPA operation. Satellite communications are the best option in case the SAoI is at a very long distance from the control station and no other assets can be deployed. Even so, the size of current equipment for RPAS SATCOMs is large (though decreasing), thus increasing significantly the RPAS MTOW which could cause problems for VLL operations. In addition, access to SATCOMs has a significant cost. For the in-between solutions, the use of additional assets to enable communication between the RPAS and the control station increases the complexity of the operation, unless the other assets can take additional roles. In such a case, multiple assets surveying a large area could also work together as a network, enabling communication of different assets with their control station while also performing a surveillance mission.

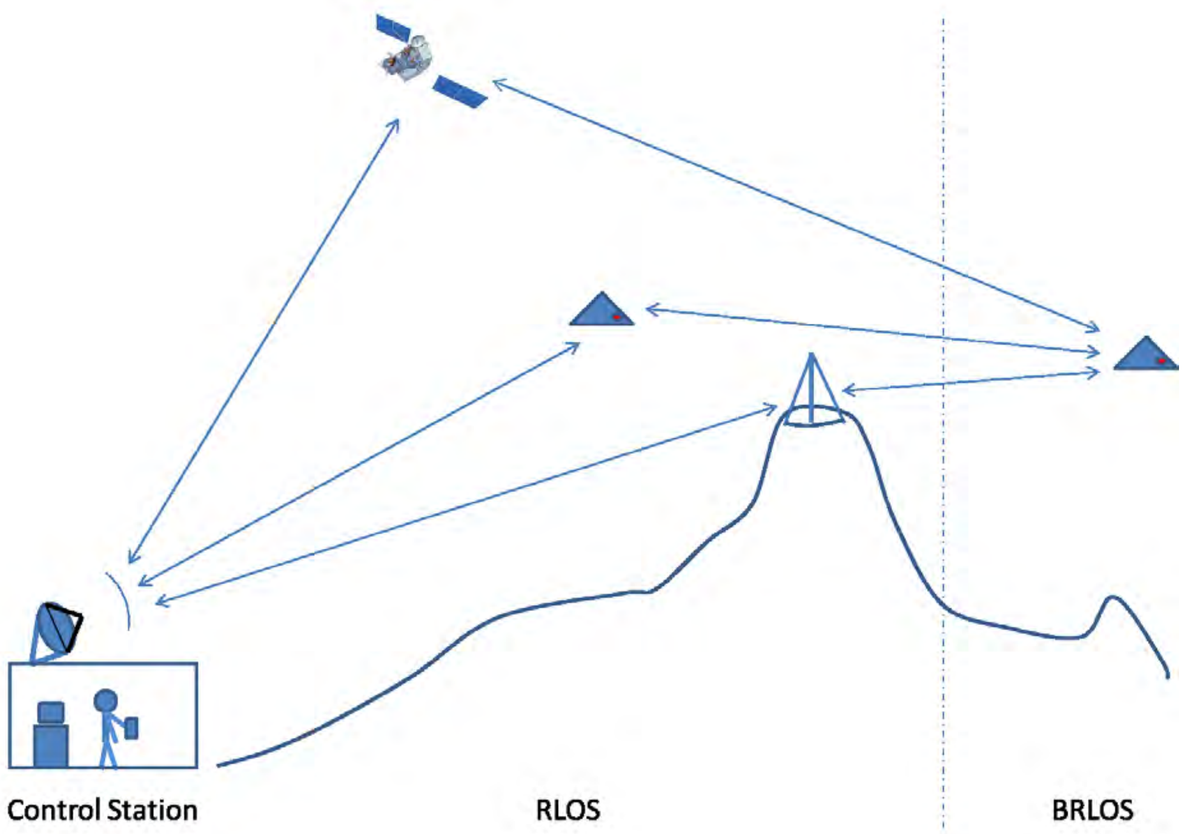

Fig.13 Use of multiple assets for enabling Beyond Radio Line of Sight communications between the RPA and the control station.

Higher level operations, using Instrument/Visual Flight Rules (IFR/VFR), taking place above 500ft, would need to make use of larger RPAs. These larger RPAs are meant primarily for BVLOS and BRLOS operations and would need to be integrated within the Air Traffic Management system. This integration is not expected to take place before 2030 as a number of issues are still to be addressed (this will be analysed further in the regulations part of this report). Therefore, such high-level operations currently take place only in segregated airspace in order to avoid the possibility of air collisions, especially between manned and RPA aircraft. The large size of the high-level RPAs allows the use of multiple sensors and as a consequence high amounts of sensor data are produced. If the data cannot be processed on-board then due to the bandwidth demand, the transfer of surveillance sensor data is made via dedicated radio links or satellite communications in a similar way as for VLL operations.

Looking specifically at different border surveillance scenarios, in the case of green border surveillance, the RPAS would be expected to be always in direct contact with a ground relay station. In some cases, satellite communications or even GSM network communications could be used but the latter may pose security issues or may not be available in remote areas. If VLL operations are needed, e.g. small RPAS hovering over a fixed border area or handheld RPAS launched by patrols to enable beyond the horizon scanning, then even VLOS communications could be used with sensor data either transferred directly to the control station or via relay antennas placed at specific locations along the border. In the case of high-level operations, aiming at large area coverage or RPAS operations with significant levels of endurance, BRLOS operations would be expected to be the norm and hence relay antennas, networked assets or satellite communications could be used.

In the case of blue border surveillance, the distances may become too big for fixed ground stations. In such case the use of VLOS would work for small RPAS launched from a nearby EU Base or from a transit vessel. For larger RPAS in high-level operations, multiple assets or satellites would need to be used. Multiple assets could include maritime vessels but also maritime aircraft working as single relays or within a network configuration.

Information about the capacities of different RPAS with regards to the transfer of surveillance sensor data should be available from the manufacturer/supplier of the RPAS or RPAS-services. This should include the different types of communications (radio links, GSM, satellite, etc) as well as the wavelengths used for enabling communications and relevant standards for interoperability that could enable the RPAS to operate in a network. Some RPAS may also be reconfigurable enabling the RPAS to adapt to end-user needs/scenarios, in some cases switching from VLOS to BVLOS operations. The end-user should be able to obtain this information from the manufacturer/supplier but two elements would need to be addressed by the end-user.

The first aspect is interoperability, especially in the case where the RPAS would need to operate in a network with other assets. This aspect has been addressed by Criterion 11 and hence no further Criterion is needed. The second aspect is spectrum availability for the operation of the RPAS. The end-user would need to ensure that relevant communication means could be made available in case that they are not provided by the manufacturer/service supplier (e.g. GSM or satellite communications). In addition, the end-user would need to ensure that the spectrum used by the RPAS is available for use and that no interference would take place during operations which could create complications for both the RPAS operation but also other local RF-users. This leads to the following Criterion:

- **Criterion 14:** Have you considered relevant communication means for the RPAS operation (including costs)? Have you investigated issues linked to spectrum availability and Electromagnetic Compatibility of the RPAS within the GAoI?

Section 5 Conclusions

This report provided an analysis of the possible use of RPAS for border surveillance / monitoring, communications and signal detection (especially mobile phone communication signals). The analysis took into account not a single RPAS operation but the full spectrum of related capabilities including, Deployment, Sustainability, Information/Communication, Control and Protection (Engagement was not considered as relevant).

- With regards to Deployment, the analysis provided a step by step approach for enabling the design of an appropriate RPAS (or RPAS service) solution based on the parameters of the mission (e.g. the possible target of interest, the SAoI, the mission conditions, the mission priority and the CONOPS) and of the transit to the SAoI.
- Following this, the report provided an analysis of the management of deployed RPAS sensor networks, looking in more detail into sustainability, protection and Command & Control capabilities.
    - For sustainability issues, a whole life-cycle approach was used to analyse three possible options for obtaining RPAS capabilities. These were development of RPAS, procurement of RPAS and procurement of RPAS services. Advantages and drawbacks of these options were identified along with a qualitative comparison of these options.
    - For protection issues, different options for improving the protection of the RPAS during operation were provided, based on the assumption that the target of interest is not expected to curry sophisticated detection and weaponry systems.
    - For Command & Control, different approaches for enabling the RPAS Command & Control were described.
- Finally, RPAS communication aspects were addressed based on different type of distances between the SAoI and the RPAS control station.

Based on the above analysis, a series of criteria have been identified that could be used for assisting the design/procurement of RPAS for border surveillance operations. The list is not meant to be used as an exact assessment tool but more as a check list in order to ensure that the end-user has taken into consideration all the appropriate elements before deciding to proceed with development or procurement of RPAS/RPAS-services. The exact solution for each of the Criteria listed will of course depend on a number of parameters which are specific to the end-user and its operational scenario, including missions of interest, target of interest, geographical area of operation, etc but even non-operational aspects, such as industrial interests. The Table 2 below includes the full list of identified criteria.

Finally, a more detailed qualitative analysis of the detection of mobile phone signals via RPAS was provided, concluding that the detection of such signals could be valuable in completing the Maritime Picture as long as detection of such signals can be correlated with other available intelligence data or with cooperative signals (e.g. AIS, VMS) or the absence of such signals.

Number	Criteria
Establishment of RPAS sensor networks (Deployment)	
Criterion 1:	Define the target you wish to detect in terms of type and size (S_{TAR}) and speed (V_{TAR}). The size as mentioned above would need to be the size of the smallest element of interest, even if embedded in a larger vessel (i.e. human beings in a fishing vessel).
Criterion 2:	Define the dimensions and shape of the SAoI (e.g. for a rectangular area = A = width w * length l).
Criterion 3:	Define the operational concept. More specifically, will the RPA be used for detection; and if yes: o Would the RPA be required to proceed with classification, identification or tracking of detected targets or o Would other means/assets be used for the classification, identification or tracking of detected targets while the RPA continues its detection mission.
Criterion 4:	What is the density in time and space in the SAoI of the possible targets of interest?
Criterion 5:	In what visibility/detection conditions do you wish to be able to operate in?
Criterion 6:	In how challenging environmental conditions to you wish to be able to operate in?
Criterion 7:	Where is the SAoI and from where and how are you planning to send the RPA to the SAoI?
Management of RPAS sensor networks (Sustainability, Protection, Command)	
Criterion 8:	Have you performed a detailed requirements analysis and relevant feasibility study, taking into account not only the first seven Criteria but also cost, life-cycle, logistics, organisational and personnel aspects, impact on overall system; and other impact due to the operation of the RPAS for Border Surveillance? If yes, did this include relevant RPAS tests and were they satisfactory? If not, do you plan to contact further R&T&D on the above aspects?
Criterion 9:	Have you considered and compared different options (development, procurement) for meeting your operational requirements? If yes, have you identified different sub-options in terms of technical solutions or suppliers (of RPAS or services), and if yes how many (if below three then please provide some justification)? Independently of the option

	chosen, please specify if you have considered the possibility of collaboration (either cross-sectorial, European or international) and what was the outcome of this consideration?
Criterion 10:	For the technical solutions (RPAS or RPAS-services) identified in Criterion 9 have you also identified appropriate measures for supporting operations (e.g. logistics, maintenance, upgrade, recovery/salvation) and personnel (e.g. Human Factors, training)?
Criterion 11:	For the technical solutions (RPAS or services) identified in Criterion 9 have you investigated interoperability aspects with your existing or future system-of-systems, multiple asset operations or cross-sectorial and multi-national operations? Have you considered standardisation and modularity, and if yes please provide relevant comment?
Criterion 12:	Have you, based on Criteria 1-8, established MOEs and MOPs to enable the assessment of the proposed RPAS solutions both prior to and after development/procurement of the RPAS or services, thus enabling the extraction of lessons learned for supporting further development/procurement.
Criterion 13:	Have you identified the end-product required by the RPAS mission in order to support relevant decision-making? Have you also considered the full process chain for delivering this end-product to the decision maker?
Information collection from RPAS Sensor Network (Information/Communication)	
Criterion 14:	Have you considered relevant communication means for the RPAS operation (including costs)? Have you investigated issues linked to spectrum availability and Electromagnetic Compatibility of the RPAS within the GAoI?

Annex 1: Detection of mobile phone communications using RPAS

As mentioned in section 1.2 of this report surveillance/monitoring and SIGINT missions do not largely differ from each other. The prime difference is the type of signals detected and hence the sensors required to be used in order to perform the appropriate detection and if possible classification, identification and tracking. In this Annex we will provide a more in depth analysis on the possible use of RPAS for the detection of mobile phones. The analysis will take into account different types of mobile phones, border surveillance scenarios and RPAS.

A.1.1 Mobile phones background

There are two types of widely and commercially available mobile phones which are of interest for border security surveillance. These are normal terrestrial Global System for Mobile Communications (GSM) phones (otherwise known as cell phones) that only make use of ground/land networks as they usually work in close ranges from a connecting network tower. The second type is satellite mobile phones which make use of both space segments (satellites) and relevant ground segments for communications.

A.1.1.1 GSM/cell phones

GSM/cell phones use a number of frequency bands to operate such as 900MHz and 1800Mhz frequencies, for Europe, Asia and Africa; and the 1900Mhz frequency for North and South America. These phones are meant to be used in connection with a nearby ground station. Hence their range is not meant to exceed a certain range as it is expected that the curvature of the earth or other land features would in any case block/absorb/scatter the phone signal. Even so, long distances between the ground station and the phone may occur in non-urban areas. On average, the GSM/cell phones have enough signal power to reach a cell tower of up to 45 miles away. Depending on the technology of the phone network, the maximum distance may be as low as 22 miles because the signal, otherwise, takes too long for the highly accurate timing of the phone protocol to work reliably. Even so, typically these types of phones are not meant to operate at such long distances.

An additional element to take into consideration is that these phones do not emit continuously when they are on stand-by mode. Therefore, if they are not in use (e.g. for voice-calls of text message transmissions), they remain passive unless interrogated by a ground station or required to provide a regular location update. In such a case there is short exchange of information between the ground station and the phone. Such exchanges could take place periodically on a regular basis that could range from minutes to tens of minutes. The exchanges are very short (ms). In addition, while voice-calls require long data transmissions, text message transmissions could be very short.

In the case where the mobile phone is switched off, no transmission from the phone occurs, other than spurious transmissions due to the internal electronic components. These transmission are low power ones and most probably not useful for long range (>km) detection unless special environmental conditions are present (see PERSEUS outcomes later in this Annex).

A.1.1.2 Satellite phones

Satellite communications are used in areas where other networks may not be available. This includes non-urban, remote areas on land but also maritime areas, especially those outside littoral areas. A number of commercial systems are available including Iridium, Globalstar, Thuraya, Inmarsat and others. Each mobile satellite system has various levels of coverage. For example, Iridium has a global coverage (pole to pole) [5] while Inmarsat covers most of the non-pole areas [6] and Thuraya has coverage of most of Europe, Africa, Asia and Australia [7]. The typical architecture of a mobile satellite system consists of the three segments: user segment, ground segment and space segment (satellites). The ground segment is composed by gateways or Fixed Earth stations (FES), the network control centre (NCC), which is used to control the overall systems and the satellite control centre (SCC), which is used to control the satellites themselves.

The user segment is represented is the mobile terminal or satellite phone. Modern satellite phones are handheld devices with relatively low weight and size and they can be carried easily on small boats. The Thuraya phone operates in the 1626.5-1660.5 MHz frequency band [8] and emits a maximum power of 2 Watt. The antenna provides additional gain and during communication the user should roughly point the antenna phone towards the satellite. Any solid structure (buildings or other obstructions) may block the signal. Satellite phones may not work inside buildings, in vehicles or underground. If surrounded by tall structures, in a city setting for instance, reception might also be hard to obtain. As in the case of GSM/cell phones, satellite phones do not emit continuously when in stand-by mode but provide either ad-hoc or regular location updates to their network in order to facilitate any eventual call connection [9].

Due to the fact that satellite phones are meant to communicate through satellites at high orbits (almost 40.000 km in case of geostationary satellites, e.g. Thuraya and Intelsat or about 800km for low orbit satellite systems like Iridium) the range of these phones is much higher than that of GSM/cell phones described above. To improve possibilities of detection of the satellite phone signals, the curvature of the earth but also the presence of objects, should be taken into account. Hence, elevated sensors would be the most useful for such detection.

A.1.2 Border Surveillance Scenarios

In this section we examine two different border surveillance scenarios. These are the Green (land) Border and Blue (maritime) Border scenarios:

A.1.2.1 Green Border scenario:

In this scenario, the end-user wishes to survey a certain Green Border SAoI, which in theory should be well defined and have a stretch type surface shape; and detect within this SAoI the presence of illegal/unauthorised activities, including attempts to illegally cross the border. In this scenario it is assumed that mobile (GSM/cell) phone towers could be available in some cases but not always near the SAoI. It is also assumed that distances are relatively small in one dimension (possibly a km long) and longer along the border direction (possibly up to several 10s of km). Another assumption is that the prime targets of interest would be ground targets (particularly people on foot) though air targets could also be involved (e.g. drones transferring illegal cargo) but for air-targets, the detection of mobile phone signals is not considered to be an optimum approach for detection as a radar would be sufficient. Therefore, in the Green Border scenario we will concentrate on ground targets performing or aiming to perform illegal activities. The detection of such targets of interest using mobile phone transmissions would depend highly on the presence of other legal activities in the area and the ability of the end-user to distinguish the legal from illegal activities through some type of anomaly detection process or correlation with previously gathered intelligence information.

Different types of "events" may be defined as anomalies based on the presence of other activities in the SAoI:

- Normally, low level of activity within the SAoI: In such a case the detection of the presence of mobile phone signals within the SAoI could trigger an investigation of the signal source.
- Normally, high level of activity within the SAoI: In such a case the detection of the presence of mobile phone signals within the SAoI will not be sufficient for triggering action as other legally behaving actors may be operating in the area using mobile phones. More information would be needed to classify the detected signal as a possible target of interest. This information could include the direction of the mobile phone displacement (heading towards the border) or speed variations. But even so, the high level of activity will render the classification of possible illegal activities, based on mobile phone signals, very difficult unless specific information is available from the service provider (e.g. indicating the identity of the owner which could then be correlated with other intelligence information; it is noted that such identity data cannot be readily obtained at present).

A.1.2.2 Blue Border scenario:

In this scenario, the end-user wishes to survey a maritime SAoI; and detect within this SAoI the presence of illegal/unauthorised activities, including attempts to illegally reach the end-user coast-line or to enter within the end-user's maritime economic zone. Activities which may trigger a search and rescue operation could also be included in this scenario (i.e. large number of migrants on small fishing vessels). The shape of the SAoI could vary significantly depending on the geographical location of the maritime SAoI. The position of the SAoI could be near the end-user's coastline or further out in open seas or near a third-country coastline. It could also involve high or low levels of activity as in the case of Green Border above:

- Normally, low levels of activity with the SAoI: As in the case of Green Border, the detection of mobile phone signals in a SAoI where normally low level of activity occurs should be able to trigger a further investigation on the source of the signals. This would be the case, especially, if no other information is available about the source of the signals (i.e. no correlation can be made with other cooperative data like AIS or VMS signals) independently of the position of the SAoI. Such low levels of activity should occur primarily in open seas and areas where there is no dense maritime traffic. Near the end-user coastline, areas of normally low activity could also be identified but such classification of areas is sometimes difficult given the possible presence of vessels for many different purposes (leisure, fishing, sports, etc). Even the patterns of movement near the coast-line could be difficult to assess of whether they represent an anomaly or not. However, given the normally low levels of activity, a further investigation could be triggered in case of mobile phone signal detection assuming resources are available. Such triggering could be supported by additional possible information such the mobile phone-owner information (mentioned above) or other intelligence information. Finally near the coast of third countries, the detection of mobile phone signals would not provide added value unless intelligence information exists. Such intelligence could include, existing knowledge on the presence of illegal activities in nearby shores; existing knowledge on the possible departure of targets of interest from third country shores; or the classification of the SAoI as an extremely sensitive area, combined with the lack of correlation of the mobile phone signals with other cooperative signals (e.g. AIS or VMS). At this point, we note that it would be difficult to assess, especially near the coasts of third countries with unstable political / security conditions, whether the lack of such correlation is indeed an indication of illegal activities.
- Normally, high levels of activity within the SAoI: As in the case of Green Border, the detection of mobile phone signals in a SAoI with normally-high levels of activity would be very difficult to trigger any type of further investigation unless information on the owner of the mobile phone or other specific intelligence is made available.

A.1.2.3 Overall scenario discussion

As we can see from the previous discussion, an important common element is identified in all cases, which is that any detection of mobile GSM/cell or satellite phone signals should be used in correlation with other signals (cooperative) or with intelligence, in order to complete the Maritime Picture. In other words, the detection of a mobile phone signal by itself will most probably not be of any value unless the area examined is very specific, in the sense that there is normally "no" or "extremely low" activity within it.

A.1.3 Detection of phone signals

Given the scenarios mentioned above, the detection of mobile GSM/Cell or satellite phone signals could be useful for surveillance mission for both Green and Blue Border surveillance. Hence, here we provide more information on how such signals could be detected. Firstly, in order to explore different detection options, we need to understand the state at which the phones may be. Firstly it is true that persons involved in illegal activities could be currying mobile GMS/cell phones or satellite phones. However, the presence of such phones could be limited due to various reasons. This may include the financial capacities those involved (e.g. poor immigrants) or actions from those organising the illegal activities (e.g. traffickers seizing mobile phones from immigrants). Furthermore, in both the case of Green and Blue Borders these phones could be switched off until a certain critical point within the illegal operation (i.e. simply at the point where the traffickers wish to actually inform the authorities about the presence of a vessel full of immigrants that they have just abandoned in order to trigger a search and rescue operation from the authorities). If the mobile phones are emitting, then their emissions could be transmitted towards all directions (assuming no obstacles). Hence, passive sensors would be sufficient for their detection, especially in the case of satellite phones. For detection of GSM/cell phone signals in areas with no network availability (e.g. open seas) the creation of a "network" would be needed in order to trigger the GSM/cell phone to transmit a response.

Based on the above, we investigate below two cases. In the first case, one of the persons involved in the illegal activity is currying a mobile (GSM/cell) phone which is at minimum at standby position and the other case a satellite phone is curried which is again at minimum standby position. Both Green and Blue border cases would be examined.

A.1.3.1 Green border: As mentioned earlier, in the case of green border, the main SAoI where mobile phone signal-detection could be of interest, is in areas of low activity; and the SAoI should be well defined and normally in a stretch shape. In such a case, sensors for detecting both GSM/Cell phone and satellite phone signals could be placed on strategic positions within the SAoI in order to detect communication broadcasts. In fact, the sensors could be combined with actual or simulated network transmitters which would trigger an active response from the mobile phones. Legal and market issues would need to be addressed for this approach but the presence of such activating networks would ensure that phones on standby mode may also be detected, especially when no network towers would normally exist in the area (e.g. because it would not make sense commercially to have a GSM phone network tower in that position).

The range of detection would depend highly on the landscape of the SAoI. Recent tests performed in the EU funded project PERSEUS [10] indicate the possible detection of mobile phones in a range of 25km for flat land areas (i.e. in Ireland), while much smaller ranges were achieved in areas which are not flat (e.g. Switzerland, the range was only the size of the valley involved in the test). The sensors used were the LBASense long (1.2kg) and short (<300g) range sensors. For satellite phones, the range would only be different in the case of flat-land SAoI and the presence of elevated detection sensors. Otherwise, the curvature of the earth and/or the presence of elevated objects would lead to similar ranges as the GSM/cell phone mobile phone detection range.

A.1.3.2 Blue border: In the case of Blue Border the SAoI could be of arbitrary size and its shape highly depended on the geography of the SAoI. Furthermore, its location, as discussed above could be near EU coastlines, open seas and third-state coasts. We look at each case separately:

- EU coastlines: In this case, the detection of signals from mobile GSM/cell phones but also satellite phones could be possible just in the case of land border detection. The flatness of the sea should allow the maximization of the detection range. As the SAoI would be in proximity to the EU shoreline, the best option for detection would be to place detection sensors and any triggering network emitters near the shore and at as high altitude as possible as in the case of land-borders described above. The PERSEUS project described above examined the possible detection of GSM/cell phones operating near the shores of Ireland and obtained detections within a range of 45km. For satellite phones, a JRC study was contacted in 2010 [8]. The JRC team was able to detect the satellite phone signals both at activation of the phone but also when sending a short message.
- Open-seas: In the case of open seas the detection of GSM/cell phone signals becomes more difficult than satellite phone signals, though in the case of satellite phones, an elevated detection sensor would facilitate detection, with the best options being the placement of the sensor on an air-platform. This was also the conclusion of the JRC study on the detection of satellite phones. The reported range of the JRC study detection was 10km but the study recommended that beyond the horizon detection methods are used to avoid issues due to the curvature of the earth. With regards to GSM/cell phone signals, one would expect that long-range detection of such signals would be impossible. Even so, the PERSEUS project mentioned above, tested the possible detection of GSM/cell phone signals at sea in order to improve radar tracking of small vessels emitting

the signals (the sensing was reportedly performed using the LBASensors mentioned above which apparently operate only in GSM phone frequencies (GSM-900MHz and GSM-1800MHz) and not in the satellite phone frequencies (e.g. 1600MHz)). Surprisingly, given certain optimal environmental conditions, the detection range reported was of the order of 300km (from the Greek island of Crete to Cyprus). The official report is not yet available and hence we will need to examine the PERSEUS report once available in order to provide further information on the subject. Furthermore, an issue would be that the GSM/cell phones will not emit unless a network is available and hence the detection system would need to also include an emitting "network" that would cause the activation of standby GSM/cell phones.

- Third-state coasts: In the case of third-state coasts (assumed to be far from EU coastlines and assuming no access to information from the third-state shore) the detection sensors would need to be placed strategically near the third-state coasts. Placing the sensors on an aerial platform would enlarge the possible detection range of both GSM/cell and satellite phones (in particular the latter). Even so, the issue with aerial platforms is that unless they are lighter than air or are energy-wise self-sustainable and unmanned, then their persistence at the area of operations would be limited. Therefore, sea-based platforms may need to be used if increased persistence is required. This could be in combination with air-platforms or not and could include both manned and unmanned sea-based platforms. These solutions will be further discussed below in the RPAS part of this Annex.

A.1.4 The role of RPAS in detecting mobile phones

Given the above considerations, we can conclude that elevating sensors could be useful in detecting both GSM/cell and satellite phone signals in both green and blue border scenarios but that issues related to the persistence of the surveillance capability would need to be taken into account. Therefore, as suggested above, aerial platforms could be extremely useful in covering both large SAoI (though this would apply more for the Blue border scenario) and small ones. Looking at the different scenarios:

A.1.4.1 Green border scenario: As mentioned above, the SAoI would most probably be a type of stretch of possibly 1 km width and several km long.

- Valley: If the SAoI is situated in a valley surrounded by accessible, elevated ground within the range of GSM/cell phones then there is no real need for using an RPAS for detection unless the wish is to accelerate classification and even identification of detected targets by using the RPAS as a first means of investigating a detected target. This would imply that the RPAS would need to be both mobile and easily maneuverable and hence relatively small RPAS could be used. Given the size of the detection sensors in PERSEUS and JRC studies and assuming that these sensors could be further optimized in size and weight, then relatively small (e.g. micro RPAS, see Annex 4 RPAS table) could find use in such surveillance missions. One similar example has already been demonstrated by the Swiss EPFL's Mobile Communications Laboratory, where a Swiss made, commercially available micro RPAS, the SenseFly eBee, was used to detect Wi-Fi signals [9]. The purpose of the exercise was to demonstrate the possible use of RPAS and sensors for the detection of people buried under ruble following a natural disaster, given that these people may be currying mobile phones. The eBee RPAS has a capacity of 45min endurance, 3km range and 630g of MTOW. The use of larger RPAS could enable the addition of other sensors including different mobile phone signal detectors, optical and IR cameras, depending on the CONOPS of each type of mission. Given that the main advantage of using an RPAS would be to facilitate maneuverability, it would be best to use RPAS up to the Short/Close range category and probably copter type which would enable hovering of the RPAS over a detected target.

- Flat land: If the SAoI is situated in a flat land which well exceeds the GSM/cell and satellite phone range (due to power or earth curvature) then it may be difficult to provide network towers as the absence of elevated ground would mean these towers would need to be repeated along the whole border stretch. In that case, an option could be to replace such stations with strategically positioned, low maneuverability but high endurance RPAS (e.g. aerostats) or use a higher altitude, high endurance RPAS. When comparing the different possibilities in the table of Annex 4, a Close/Short range RPAS should be sufficient for covering a significant length of border since some of these RPAS could climb up to 3km of altitude (giving approximately 400km coverage, i.e. 200km on either side of the RPAS). Moving to the other side of the RPAS altitude range, an option would be to use MALES or HALES which could reach up to 14km and 20km altitude respectively. The advantages of using these types of RPAS would be the increased detection-range but also the capacity to curry additional sensors and the higher endurance of the platform. Even so, the cost linked to these types of RPAS (MALE, HALE) is considerable. Hence when deciding on which RPAS to opt for, the cost-efficiency aspect would need to be taken into account depending on the geography of the SAoI (i.e. how long this flat land is) but also the CONOPS of the mission. In our view, for this type of border surveillance, more localized solutions should be the optimum ones and these solutions could combine both static platforms (e.g. aerostats or static towers) as well as more mobile RPAS but low cost RPAS.

A.1.4.2 Blue Border scenario:

- EU coastlines: If the SAoI is near the EU coasts, then the end-user should be able to make use of already existing infrastructure, adding mobile phone detection sensors on fix or low maneuverability (e.g. aerostats) platforms. The use of more mobile RPAS could be considered as optimum in case the SAoI extends well beyond the EU littoral areas.

- Open seas: If the SAoI includes open seas away from the EU coast, then assets currying detection sensors would need to be deployed. In the maritime environment, these assets could curry a variety of sensors including not only mobile phone-signal detection sensors but also AIS, VMS or other cooperative system sensors as well as radar and/or electro-optical/IR sensors. RPAS could be used but the exact solution would depend on the answers to the Criteria 1-7 described in the main part of the report, e.g. the target of interest and its parameters (e.g. speed), the density of targets, the position and size of the SAoI, the CONOPS, etc. Different solutions could include the use of maritime sea platforms which could deploy aerostats or small RPAS to increase their detection range but also the use of larger RPAS launched from the EU or a base in the GAoI. The first solution would be the most efficient solution if the SAoI is relatively small as the increase of detection range of an already sea-based platform using a low cost Short/Close range RPAS or an aerostat would be both a cost-efficient and persistent solution. If on the other hand the SAoI is relatively large then a higher altitude RPAS (such as MALEs or HALEs) would be a better solution as it will enable a longer detection range (directly for satellite phone signals and through the RPAS displacement for GSM/cell phone signals) on a persistent basis and without the need to launch sea-based assets. Even so, the persistence of a MALE/HALE RPAS would be limited in comparison to those of sea-based assets and hence again the optimum solution would depend on the CONOPS and the specificities of the SAoI.
- Third-state coasts: In this case, it is assumed that the Third-state coastline is far from the EU or GAoI base from where an RPAS could be launched. In addition, as mentioned above, it would be difficult to identify anomalous behavior given the political conditions within the third-state. Hence, unless the mission is extremely urgent and focused, the use of large RPAS launched from the EU directly would provide very limited outputs. Therefore, most probably, the use of sea-based assets would be the most cost-effective solution. These sea-based assets could then act as launching platforms for RPAS that would enable an increase in the range of detection of the sea-based assets. The type of sea-based asset used would also have an impact on cost-efficiency. If the operation is long term then the use of large manned platforms could prove very expensive. This could give rise to solutions using robust unmanned maritime platforms. Such platforms may not require high speeds especially if the SAoI is limited (e.g. near a coast usually used for launching illegal activities) and could act as a first line of intelligence. Such assets could be placed strategically in order to enable detection of targets with certain parameters (heading, speed, etc) along with other signals (e.g. mobile phone, AIS, etc) or the absence of cooperative signals.

A.1.5 Conclusions

In this annex we have analysed the use of mobile phone detection for different types of phones (GSM/cell or satellite) for both Green and Blue border surveillance. Different forms and locations of SAoI were also taken into consideration as well as different levels of activity within the SAoI. Finally, the use of RPAS was also considered for the detection of such mobile phone signals. Based on the analysis we could conclude that:
Mobile phone detection could be useful, as long as it is correlated with other information such as intelligence or cooperative signals (e.g. AIS, VMS) or the absence of such cooperative data.

The detection of mobile phone signals should be of greater value if achieved in a SAoI with relatively low activity (i.e. where not many other mobile phone sources could be present). This would be the case in relatively remote Green border areas or open seas.
The detection of satellite mobile phone signals is significantly easier than GSM/Cell mobile phone signals for phones in standby mode in areas where no GSM/Cell phone networks are available. Furthermore, the range of detection of satellite phones is much larger than those of GSM/Cell phones in both stand-by and operating modes assuming that the detection sensors can be elevated.

Existing results showed a potential for this type of detection. RPAS could be used to curry relevant sensors both for Green and Blue borders. It is not possible to define in advance the most optimum solution (e.g. small or large RPAS) as this would depend on the specificities of each scenario, target of interest, SAoI and CONOPS. Even so, smaller RPAS should be more efficient solutions in cases where other detection means could also be deployed (e.g. fixed detection stations, sea-based systems, etc) or in cases with relatively small and well defined SAoI. On the other hand, larger RPAS could be used when such other systems cannot be efficiently deployed, but at a cost to the persistence of the surveillance mission. In all cases, a combination of assets could prove to be the most cost-effective solution.

Annex 2: Test Case Request from MS

This Annex provides a test case of our surveillance RPAS assessment methodology using the first seven operational Criteria. For ease of use, the seven criteria are listed below. The information received from the MS is also listed below and then mapped against the Criteria. The end conclusion is that the information provided is insufficient to enable an assessment of the operational usefulness of the request.

A.2.1 Operational Use Assessment Criteria for Surveillance Missions

- Criterion 1: Define the target you wish to detect in terms of type and size (S_{TAR}) and speed (V_{TAR}). The size as mentioned above would need to be the size of the smallest element of interest, even if embedded in a larger vessel (i.e. human beings in a fishing vessel).
- Criterion 2: Define the dimensions and shape of the SAoI (e.g. for a rectangular area = A = width w * length l).
- Criterion 3: Define the operational concept. More specifically, will the RPA be used for detection; and if yes:
    - Would the RPA be required to proceed with classification, identification or tracking of detected targets or
    - Would other means/assets be used for the classification, identification or tracking of detected targets while the RPA continues its detection mission.
- Criterion 4: What is the density in time and space in the SAoI of the possible targets of interest?
- Criterion 5: In what visibility/detection conditions do you wish to be able to operate in?
- Criterion 6: In how challenging environmental conditions to you wish to be able to operate in?
- Criterion 7: Where is the SAoI and from where and how are you planning to send the RPA to the SAoI?

A.2.2 Test Case request from MS:

- Purchase of two short range Unmanned Air vehicles (UAVs) that will be used along with the mobile surveillance platforms, to complement the complete coverage of the coastline. Please note that navigation of the 2 small UAVs will be carried out as according to the national aviation regulations and also that these small UAVs will not be flying over 300 meters above ground.
- The UAVs (drones will be of small range approximately 30Km) without the ability to transfer load besides the observation cameras. Below is a brief description of their characteristics.
- ‘’The two (2) UAV systems shall be used for real time video surveillance and shall include both electro optical and IR gyro stabilized sensors for day and night

observation. Some key features include: simple one person operation, fixed wing airframe, electric compulsion, catapult take off, parachute landing and a video/data range of at least 30 Km. Additionally, provision should be taken in order to allow easy integration of the UAV ground control station into the surveillance vehicles of the paragraph 4(b).''

No	Operational Criteria	Information	Assessment
1	Define target in type and size (S_{TAR}) and speed (V_{TAR})	Not provided h=300m	Insufficient but given the height then the following could be achieved with small camera (<kg): Day-time E-O and night-time IR detection and classification of People, Vehicles and Vessels (unless altitude is reduced for enabling identification).
2	Define SAoI	Not provided	Insufficient
3	Define the operational concept	Not provided but two UAVs will be used.	Insufficient
4	Density of targets (in SAoI and time)	Not provided	Insufficient
5	Visibility/detection conditions	Time: Day or night Other visibility condition (fog, clouds, etc): Not provided	Partly sufficient: E-O and IR included
6	Environmental conditions	Not provided	Insufficient
7	Where is the SAoI and how do you transit?	Where: Coastline – 30km range Transit: Using mobile platform; and L&R catapult take off, parachute landing. Comms: BVLOS and up to 30km.	Sufficient: Could be achieved with Close (CR) or Short Range (SR) RPAS. Costs are above 50k Euro for Close Range and above 100k Euro for Short range. MTOW could be up to 100kg (CR) and 200kg (SR). Hence sophisticated sensors could be used. Max flying altitude could reach up to 3km.
	Overall		**Insufficient information for assessment. Based on info provided the RPAS could be used at minimum for detection and classification of people/vehicles/vessels but given the range/size (CR or SR) additional/sophisticated sensors could be used enabling identification.**

Annex 3 Derivation of equations

This Annex includes the mathematical derivations of the equations provided in the main document.

A.3.1 Equation: Time for mission execution

The time T_m required for the RPAS to cover its mission path is given by:

$$T_m = \frac{X_m}{V_m} \qquad \text{Eq. A.3.1}$$

where X_m is the mission distance required to be covered once the RPAS is fully in the SAoI and V_m is the mission speed of the RPAS. The approximate mission distance can be calculated through Fig. 7 which depicts a simple orthogonal SAoI (the equations could also be adjusted for other types of SAoI areas). In this simple case, the RPAS has a sensor coverage diameter of size d and needs to cover the SAoI which has an area of size A with dimensions w and l. The CONOPS uses a scanning approach as shown in Fig.7 (again other types of scanning modes would produce similar equations). Based on the above the mission distance X_m can be described as:

$$X_m = (l - d)\frac{w}{d} + (w - d) \qquad \text{Eq.A.3.2}$$

Hence,

$$T_m = \frac{(l-d)\frac{w}{d}+(w-d)}{V_m} = \frac{A/d-d}{V_m} = \frac{A-d^2}{d\,V_m} \qquad \text{Eq.A.3.3}$$

A.3.2 Equation: Mission speed for 100% probability of detection

Eq.A.3.3 indicates the time required for the RPAS to cover its whole mission area. In order to enable the 100% possibility of detection of a target of interest crossing this SAoI, the RPAS would need to perform the whole scanning of the SAoI quicker than the target of interest can cross a single RPAS scanning line. Hence, the mission speed of the RPAS can be derived as follows,

$$T_m = \frac{X_m}{V_m} = \frac{A-d^2}{d\,V_m} \leq \frac{d}{V_{TAR}} \qquad \text{Eq. A.3.4}$$

where V_{TAR} is the speed of the target of interest within the SAoI and is assumed constant. The velocity of the target of interest is assumed to be such that it minimises it's time to cross the SAoI. Using Eq.A.3.4, then we can derive that the mission speed of the RPAS should be,

$$V_m \geq \frac{(A-d^2)\,V_{TAR}}{d^2} \qquad \text{Eq. A.3.5}$$

which could then be reduced to,

$$V_m \geq \frac{A\,V_{TAR}}{d^2} \qquad \text{Eq. A.3.6}$$

assuming that in the most difficult cases $d^2 << A$.

If this speed mission is not achieved, then the probability of detection of a target of interest will not be 100%. Probabilistic approaches can then be used to identify the probability of target detection but in real life such calculations would depend heavily on the parameters of each RPAS and its sensor, each scenario, as well as the capacity of the sensor-data analysis methodology. Hence, it is not intended to provide a full mathematical derivation of this probability in this Annex.

Even so, what is interesting to observe is that if a 100% probability of detection is required then three options exist: increase the speed of the RPAS, increase the area covered by the RPAS sensor without compromising detection resolution; or reduce the SAoI. The above indicate that the best option for a 100% probability of detection is to use larger RPAS capable of currying high resolution sensors with large area coverage and at higher speeds. Therefore, for large SAoI (as those in open seas), larger RPAS would be preferable.

Annex 4: RPAS types and parameters

Classes	Categories	Acronym	MTOW (kg)	Max flight altitude (m)	Speed km/h	Endurance (h)	Range (km)	Comms type	Access	Estimated Price (€)	Type	Deploy
Tactical	Nano	n	0,025	100	<40	<1	<1	LOS	All	>10	RW	RW from anywhere
	Micro	Micro	5	250	15 to 70	<1	<10	LOS	All	>100	RW, FW	RW from anywhere
	Mini	Mini	30	300	<370	<2	<10	LOS/BLOS*	All	>10000	RW, FW	RW from anywhere
	Close range	CR	150	3000	<350	2 to 4	10 to 30	LOS/BLOS*	CC, CG, Mil	>50000	RW, FW	RW from anywhere
	Short range	SR	200	3000	<1000	3 to 6	30 to 70	LOS/BLOS*	CC, CG, Mil	>100000	RW, FW	RW from anywhere
	Medium range	MR	1250	5000	<950	6 to 10	70 to 200	LOS/BLOS*	CC, CG, Mil	>1M	RW, FW	RW from anywhere
	Medium range endurance	MRE	1250	8000	<800	10 to 18	>500	LOS/BLOS*	CC, CG, Mil	>1M	RW, FW	RW from anywhere
	Low altitude deep penetration	LADP	350	50-9000	<1000	0,5 to 1	>250	LOS/BLOS*	Mil	>1M	FW	Special deploy
	Low altitude long endurance	LALE	30	3000	<200	>24	>500	BLOS	CG, Mil	>1M	FW	Special deploy
	Medium altitude long endurance	MALE	1500	14000	<900	24 to 48	>500	BLOS	CG, Mil	>10M	RW, FW	Special deploy*
Strategic	High altitude long endurance	HALE	15000	20000	TBD	24 to 48	>2000	BLOS	CG, Mil	>100M	FW	Special deploy*
Ref.	UVS	UVS	UVS	UVS	FAA, UVS	UVS	UVS	Partly FRONTEX	Partly DG ENTR		UVS	*Due to size
								* Could be modified to use BLOS				

Annex 5 List of acronyms

AIS: Automatic Identification System (for maritime vessels)
BRLOS: Beyond Radio Line of Sight
BVLOS: Beyond Visual Line of Sight
C2: Command and Control
C4: Command, Control, Communication, Computers
CAST: Common Application of Surveillance
CIT: Classification, Identification and Tracking
CONOPS: Concept of Operations
CR: Close range RPAS
EASA: European Aviation Safety Agency
EO sensors: Electro-optical Sensors
ESP: European Situational Pictures
FAA: Federal Aviation Association (USA)
FES: Fixed Earth stations
GAoI: General Area of Interest
GSM: Global System for Mobile communications
HALE: High altitude long endurance RPAS
HF: Human Factors
IFR: Instrument Flight Rules
IR: Infrared
ISM: Industrial, Scientific and Medical
JARUS: Joint Authorities for Regulating Unmanned Systems
L & R: Launch and Recovery
LADP: Low altitude deep penetration RPAS
LALE: Low altitude long endurance RPAS
MALE: Medium altitude long endurance RPAS
MOE: Measure of Effectiveness
MOP: Measure of Performance
MR: Medium range RPAS
MRE: Medium range endurance RPAS
MS: Member States
MTOW: Maximum Take of Weight
n: Nano RPAS
NAA: National Aviation Authority
NCC: National Coordination Centre
NCC (for mobile networks): Network Control Centre
NSP: National Situational Pictures
RLOS: Radio Line of Sight
RPAS: Remotely Piloted Aircraft Systems
SAoI: Specific Area of Interest

SCC: Satellite Control Centre
SIGINT: Signature Intelligence
SR: Short range RPAS
TLS: tolerable level of safety
UAV: Unmanned Aerial Vehicle
UVS: Unmanned Vehicle Systems International
UxV: Unmanned x (=aerial/ground/maritime) Vehicle
VFR: Visual Flight Rules
VLL: Very Low Level
VLOS: Visual Line of Sight
VMS: Vessel Monitoring System (for fishing vessels)
VTOL: Vertical Take-off & Landing
WLAN: Wireless Local Area Network

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European Commission
Joint Research Centre – Institute for Protection and Security of the Citizen

Title: Identification of current limitations for the use of unmanned aerial systems for border surveillance
Part A: Analysis of possible use for surveillance/monitoring, communications, signal detection

Author(s): Solon Mias

2015 – 76pp. – 21.0 x 29.7 cm

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