Aviation research at the Belgian Royal Military Academy

Brussels, Belgium, 06/04/2020

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INTRODUCTION

The Royal Military Academy (RMA) is a military institution of university education responsible for the basic academic, military and physical training of future officers, and for the continuing advanced training of officers during their active career in the Defence department. As a military university, the core research of the RMA is directed at solving military problems and security and safety problems. The different research topics studied at RMA in the field of aviation can be broadly categorized in 3 research subjects:

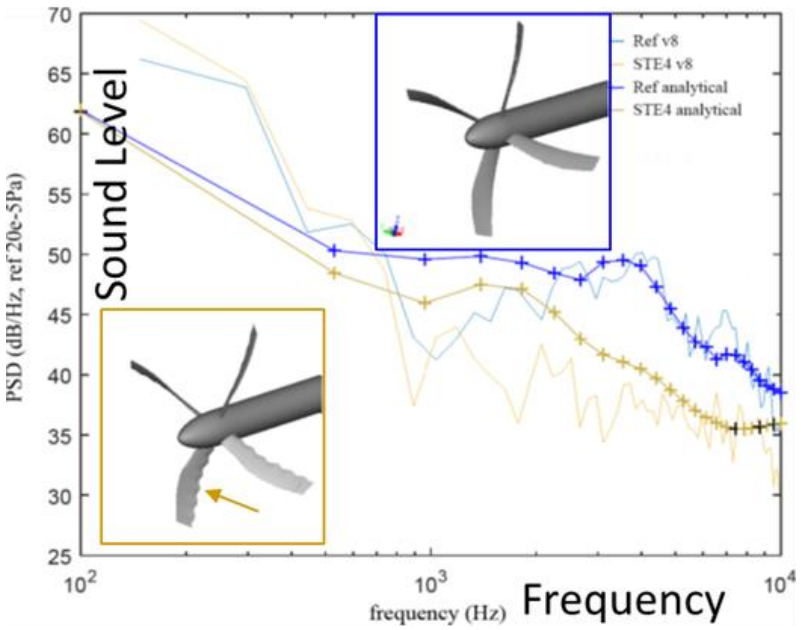
- Optimal aircraft design & propulsion systems
- New opportunities offered by unmanned aircraft systems (UAS)
- Security threats in aviation

Being a small institution with limited resources and a limited staff, the RMA focuses on very narrow niches and integrates its specific knowledge in larger research programs (national and international), seeking complementarities with other research institutions. As a result, RMA is actively involved in EU research projects (including multiple in the field of aviation) and industry collaboration projects.

RMA not only acts as a pure research institute, but is closely committed to the end users and has a proven track record of operating in the field with the end-users. As a testimony of this statement and as a showcase of a successful transfer of research results to the reality on the field, the relief support mission to Bosnia by RMA can be mentioned. RMA deployed an UAS and data processing tools to help with the relief operations after the floods in Spring 2014, together with the Belgian First Aid and Support Team. During this very successful operation, RMA assisted the local civil protection agencies and demining teams and international relief teams and brought them into contact with the advantages of using UAS.

Low-noise Propeller Design

This disruptive study aims at proposing advanced shapes for Single Open Rotors to be used on mini-RPA (Remotely Piloted Aircraft). Noise is currently the main reason behind detection of such RPAs. The shapes should offer high efficiency while satisfying stringent noise emission goals. In the low- and very-low speed ranges, both tonal noise and broadband noise are to be considered since most noise sources result from the interaction between the blade and upstream turbulence or between the blade and the turbulent boundary layer on it. Due to the complexity of the coupled flow/noise mechanisms at play, this is a fundamental study.



Building on previous expertise and inspiring from biology, specific shape determining parameters have been identified as yielding potential noise reduction while maintaining high efficiency and structural integrity.

After implementation and validation of the frequency-domain noise computing code thanks to lattice-Boltzmann time-dependent flow simulations, the effort during last year was to identify the set of promising geometries by introducing leading- and trailing-edge serrations with different parameters.

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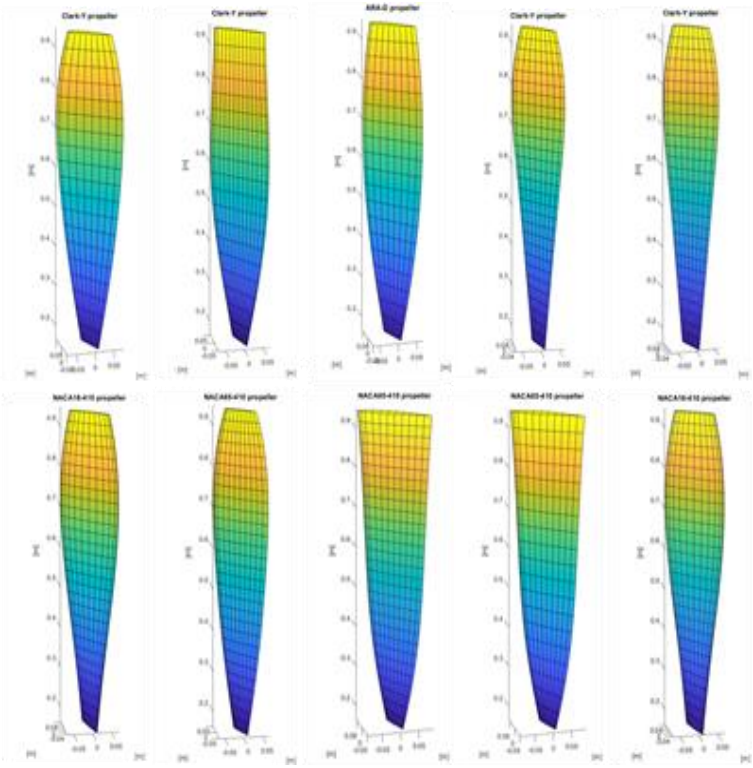
High-Altitude Propeller Design



The RMA side of the High Altitude Pseudo-Sattellite (HAPS) program of work focusses on the propeller for a HAPS Unmanned Aerial System developed by the industrial partners (S^3 Partnership = SONACA (lead) – STEMME - SABENA AEROSPACE TECHNOLOGY). One of the objectives of this project is to design, develop, manufacture and test a stratospheric variable-pitch propeller with optimized performances and able to operate at various altitude. As a first step and risk reducing measure, emphasis will be given on a technology demonstrator operating at 16km altitude. Both the aerodynamics of the propeller blade and the aeroelastics are to be investigated in close linkage. The Tailored High-Altitude Propeller (THAP) study will be in charge of optimizing, designing and validating the stratospheric propeller that will be manufactured and certified by STEMME.

The project is embedded in and supported by the Belgian Defence Triple Helix Research & Technology initiative. TheTHAp's main outputs are expected in the Propeller Preliminary Design (Phase A2) and the Propeller Detailed Design (Phase A3).

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High Intensity Noise Propagation

Present models used for noise impact studies are essentially based on linear propagation. These models fail to predict accurately the propagation of sound from military sources such as jet noise, or impulse noise from firearms, guns, detonations and explosions. The broad spectrum, the directivity and the duration are specific to military noise sources. The large discrepancies observed with experimental data or within results from civilian noise propagation models are related to the non-linear propagation behaviour.

The MilSound study intends to develop a software and the associated methodology applicable to wideband military sources for the assessment and management of military noise emissions. The methodology would be coupled to a geographically informed package to model the propagation over accurate terrain conditions. This way the sound levels and exposure at various locations can be computed. We intend to validate the model by an extensive comparison with on-site measurements.

The software and the methodology can be used to make assessments of the impact from military activities on communities with respect to international and regional regulation and optimize mitigation (by shielding and/or by adapting the procedures).

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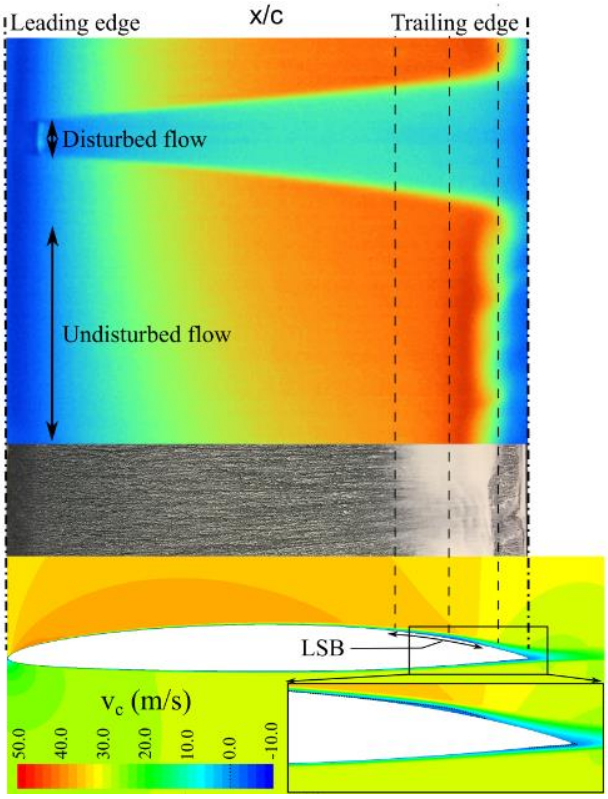
External Aerodynamics & Confined Spaces

Several academic research activities and expertise projects conducted at the RMA pertain to external aerodynamics of low-speed vehicles such as cars, non-lethal projectiles, measurement devices,… or to flows in confined spaces essentially for precise HVAC-related questions in buildings (offices & shelters), ships and aircraft. For these small scale activities, the RMA has two research-grade low-speed wind tunnels, and miscellaneous measurement equipment (Particle Image Velocimetry, Laser-Doppler Velocimetry, Hot-Wire Anemometry, Ultra-sonic Anemometry, Infrared Thermography, Visualization Techniques, Pressure & Temperature Measurement,…) which are used in conjunction with the numerical facilities comprising of a High-Performance Computer and various software packages (Ansys Fluent, StarCCM, PowerFlow, …). Experimental and numerical techniques are thus combined with a strong theoretical background to address those punctual needs and deliver an analysis or a solution based on a scientifically supported set of observations.



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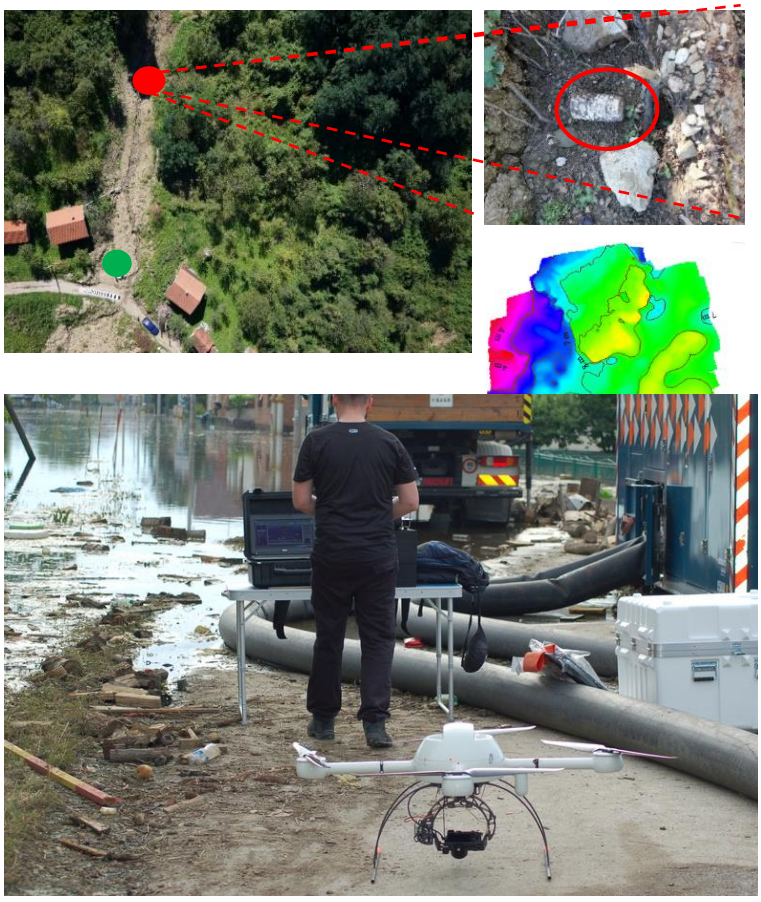
NEW OPPORTUNITIES OFFERED BY UNMANNED AIRCRAFT SYSTEMS (UAS)

Developing UAS and data processing tools for supporting Mine Action



During humanitarian demining actions, operational deployment of small Unmanned Aircraft Systems (UAS)

equipped with different sensors or multi-sensor-heads can enhance the detection process by allowing more precise scanning, which is useful for the optimization of the mine action (MA) processes while supporting mine action teams on the ground. The low cost UAS and their use allows the development of a promising complementary tool for the fast detection of cluster munitions and explosive remnants of war (ERWs) as well as for 3D modeling of the field, surface-terrain models and detection of mine presence indicators. In order to achieve the goals the UAS is equipped with a GPS, a high-resolution RGB sensor, and a near-infrared (NiR) sensor. The developed models allows spatial assessment of new hazardous risk caused by shifting of mines and unexploded ordnance (UXO) to wider areas which had not been mine suspected before.

UAS can play a critical role to save human lives and add value to MA operations. End-users from the Mine Action Community stated that the use of small UAS can/will provide significant impact to their daily work.

RMA developed tools for the use of Unmanned Aircraft Systems for demining in the framework of the EU-FP7 project TIRAMISU (http://fp7-tiramisu.eu/), a 19.5M€ EU research project coordinated by RMA on the subject of mine action. The UAS tools developed by RMA were successfully deployed in Bosnia by the Bosnian Mine Action Centre and B-FAST during massive floods in spring 2014. After this mission, RMA trained local demining operators to work with the UAS and integrate these tools into their standard operating procedures. As a result of this successful transfer of technology from research to end users, a fleet of UAS is now in use by the local demining teams.

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Developing UAS tools for supporting search and rescue operations

Recent dramatic events such as the hurricanes in the Caribbean, the earthquake in Nepal or the floods in Europe have shown that local civil authorities and emergency services have difficulties with adequately managing crises. The result is that these crises lead to major disruption of the whole local society. There is a vast literature on research efforts towards the development of unmanned search and rescue (SAR) tools, notably in the context of EU-sponsored projects. This research effort stands in contrast to the practical reality in the field, where unmanned SAR tools have great difficulty finding their way to the end-users. In response to this, the European Commission decided to fund ICARUS (http://fp7-icarus.eu/), a Research project with a global budget of 17.5M€ which aims to develop robotic tools (including UAS) which can assist "human" crisis intervention teams. The project consortium consists of an international team of 25 partners, formed by industrial players, academia, NATO and end-users and coordinated by RMA.

The ICARUS project proposes to equip first responders with a comprehensive and integrated set of unmanned SAR tools (a.o. UAS), to increase the situational awareness of human crisis managers. The importance of gaining such an overview within the first one to two hours is a strong requirement for end-users. The end-users underline the important role UAS could provide in this context by providing continuous support to coordinators and operators in the field. ICARUS therefore foresees the following scenarios for UAS in SAR operations:

- Mapping of topography and scenario. This information is the basis for situational awareness and planning of both unmanned and manned missions.
- Target observation. This allows an operator to quickly send a camera to a specific position and attitude as a "remote eye-pair" including tracking and following moving targets.
- People search outdoors and indoors. The use of dedicated computer vision algorithms on-board the UAS will allow for the localisation of bystanders/victims and for tracking them. Both features reduce the workload compared to manned search..
- Kit delivery. Once localised, victims may not be quickly reachable by SAR teams due to distance or weather conditions. In this case, UAS can deliver light first-aid kits, such as self-inflating floatation devices to provide the victim with first emergency response.
- Communication relay. Maintaining or deploying a ground communication network in remote areas can become cumbersome or unfeasible; UAS platforms can instead act as relays.

Within ICARUS, among other tasks, RMA is responsible for ensuring the interoperability between the heterogeneous Unmanned Aircraft Systems and optimizing their collaboration strategies.

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Requirements engineering in aviation & the operational validation of these requirements in "tough" environments

One of the problems in the development of Unmanned Aircraft Systems is the lack of adequate test and validation mechanisms to benchmark the performance of the end products. Indeed, it is very hard to quantify this performance in a rigorous scientific manner due to the fact that many variables are out of control in an outdoor environment, e.g. the weather conditions. Moreover, a scientific evaluation requires that multiple trials must be held to validate the statistical significance of the quantitative results, which is not evident when confronted with the evaluation of complex heterogeneous teams in operational conditions, requiring significant logistics for setting up each trial run. Multiple proposals have been made in the past to remedy this problem. Generally, these validation methodologies can be categorized into two approaches: highly standardized test methodologies, and competitions. While both of these approaches are highly valuable and necessary, none of them give an ultimate solution for the performance evaluation problem. At RMA, research is performed on seeking an optimal compromise between the traditional rigorous standardized approaches and the open-ended competitions.

First, it is required to carefully identify and approach the targeted user communities by compiling user requirements in a rigorous manner. Resulting from these user requirements, system requirements and a system architecture can be deduced. A standardized methodology was followed for use-case redaction, leading to a number of use cases. These use cases were then later refined in the form of validation scenarios, containing a detailed scenario. Moreover, each validation scenario contains also a list of capabilities which need to be validated. These capabilities correspond to system requirements for the different tools. Finally, each validation scenario contains a score sheet listing a number of metrics which can be used to quantify the performance of the different tools during operational validation tests. As such, it becomes possible to validate the degree to which each of these system requirements have been attained. The approach followed here towards validation scenario design and quantitative benchmarking aims to keep a balance between highly standardized (but less realistic) methodologies and highly realistic (but less repeatable) methodologies. Following this methodology, we aim to provide operational scenarios and quantifiable validation means which are both scientifically relevant and which also ensure the realistic character of the validation setup. This also means that we incorporate "tough" operating conditions, like flying at night, in mist and with heavy winds. A lot of attention was paid not to validate only the pure technical capabilities of the systems, but also the very important non-technical aspects like human-system collaboration, safe and legal operation and rapid deployment.

Measured Metrics						Performance Targets		
						Min. Accep-tance Level	Goal	Break-through
Capabilities met (/18)					18	13	16	19
Mean electric power draw of C4I tools during test (VA):					600	2000	1000	200
Number of people required to operate the unmanned tools					3	5	3	2
	START TIME (HH:MM)	FINISH TIME (HH:MM)	ELAPSED TIME (MIN)	AREA SIZE (HA)	TIME / AREA (MIN/HA)			
UAS Deployment	9:55	10:38	43			180	120	60
UAS Flight Preparation	13:47	13:59	12			90	45	30
UAS Area Scan	14:00	14:04	4	37	0,1	6	3	1
Area Scan Processing Time	14:04	14:25	21	37	0,56	16	8	4
UAS Sector Scan	14:53	14:55	2	11	0,18	6	3	1

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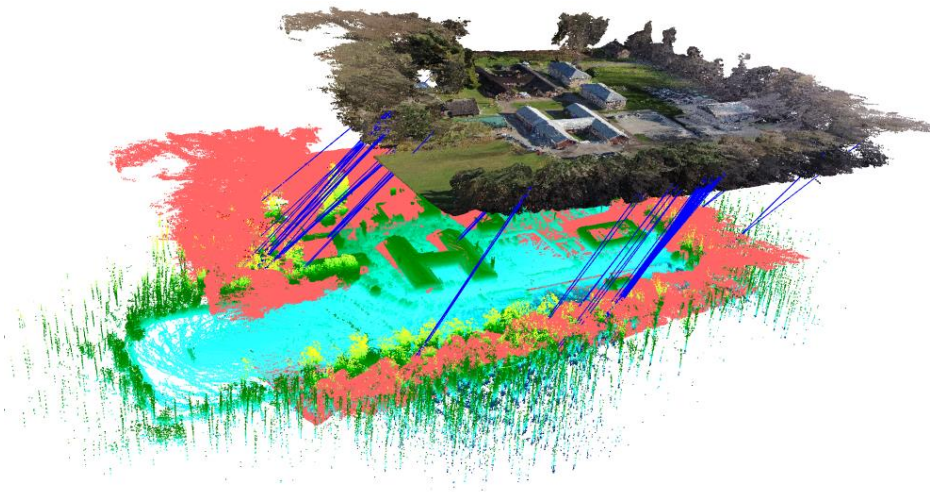
Fast 3D mapping tools, combining data from aerial and ground based assets

As robotics technology is developing, we witness an increased number of robotic systems and certainly UAS being introduced in everyday life. Typically, all these robotic systems gather data about the environment in their own way, either for internal use (navigation) or for external use (environmental data processing). As more and more robotic systems are becoming active, these systems are also being deployed together. This means that the robots sense the same environment. Acknowledging that, the key issue becomes then how to obtain a common understanding of the environment by using heterogeneous robots. The interest of a common operational 3D environment representation has been growing over the last decade and many research efforts have been focused on fusing environmental data from heterogeneous robots, especially Unmanned Aircraft Systems and Unmanned Ground Vehicles.

Combining heterogeneous 3D data models of an environment into a common homogeneous model requires the transfer of properties from one data model to the other. The main concern is how to combine heterogeneous datasets acquired by different multi-robot sensor systems operating in various large unstructured outdoor environments. The problem becomes more complex when the system deals with a-priori unknown large-scale outdoor environments, facing problems of displacement, orientation and scale difference between the 3D data sets. Therefore, the problem of fusing data coming from different robotic platforms and sensors, with the aim to generate consistent 3D models, is becoming increasingly widespread within the research community. In that context, 3D registration becomes a very important part in the matching of 3D data sets and the reconstruction of complex outdoor environments. The most widespread purpose of the fusion of ground and aerial based data is to increase the accuracy and completeness of the generated 3D map, since the data are combined from ground and aerial point of view. Once aligned, the global map is used to perform more high-level processing tasks like ground object segmentation and color segmentation. The process of fusing two heterogeneous 3D datasets is a challenging task. In order to overcome the limitations of dealing with 3D data sets coming from different sensor systems (lasers, cameras) and different perspectives of the environment (ground and air), we develop a semi-automated and robust 3D registration process, that allows us to consistently align two or more heterogeneous point clouds.



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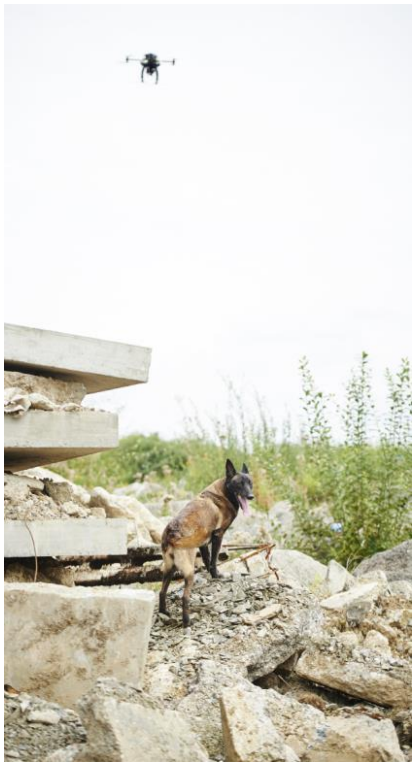
Collaborative strategies between UAS and other unmanned assets or humans

As more and more Unmanned Aircraft Systems are getting used, they are also used more and more in combination in order to optimize the efficient use of the different capabilities of different platforms. Also end user operatives have to develop new standard operating procedures to learn how to work with these Unmanned Aircraft Systems and to incorporate them into their toolset. Therefore, at RMA, research is performed studying how to optimally combine multiple unmanned assets and how to optimally make humans (and other assets, think about rescue dogs collaborating with rescue UAS) collaborate with Unmanned Aircraft Systems.



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Remote Sensing – UAS-based persistence surveillance

Terrorist activities remind us that our security is fragile and depends on critical information. Camera surveillance is particularly well adapted to this as it is an excellent mean to obtain a good situation awareness. However, the amount of images produced keeps increasing and it becomes increasingly difficult for operators to keep up with the vast volume of images. The goal of the study is to perform automatic interpretation of image sequences obtained from airborne (UAS) platforms in a persistent surveillance scenario. In such a scenario, the platform would hoover above the theater of interest, capturing very high resolution pictures at a relatively low frame rate (once or twice per second).

The specific context is that of Improvised Explosive Device (IED) detection and early warning in a convoy scenario. It is not expected that IED can directly be detected using aerial images, however indicators of IED presence may be. In addition, unusual or suspicious behavior of targets (vehicles, people, groups of people), such as a car that turns around of a strategically positioned observer, can also be detected in order to contribute to the global situation awareness. It must be noted that the goal is not to fully replace the operator, but to lower his workload.

Test in simulated but close to reality scenario are foreseen in collaboration with the other international partners.

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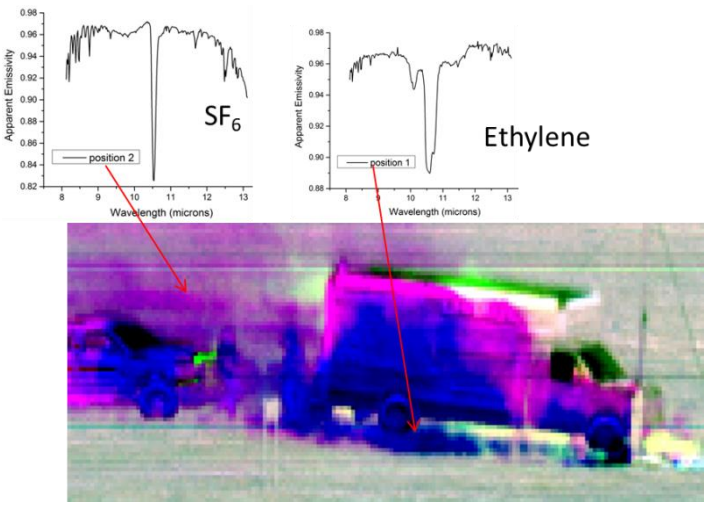
Detection and identification of chemical agents and hazmat using airborne thermal hyperspectral and spectropolarimetric imaging

Remote (e.g. airborne) sensing detection and measurement of Chemical, Biological Nuclear or Radiological (CBRN) agents and hazmat (i.e. HazMat; hazardous chemicals) is becoming more important and is receiving much greater emphasis within military and security communities. The choice of the detection technique depends on the agent being sought, expected background interferences, and the required ranges. Most species can be detected and quantified due to their unique spectral properties in the thermal InfraRed wavelength regions. With tens to hundreds of spectral bands, thermal hyperspectral sensors pose an advantage over traditional open-path sensors in their ability to detect and quantify chemical molecular absorption and concentration along a large area of interest. Novel spectropolarimetric imaging provides complementary polarimetric information in large spectral dimension and therefore allows improving confidence in chemical identification and reducing false alarms rate. These pioneer technical combinations expect to outperform other spectral methods.

This project addresses the detection of chemical elements of CBRN warfare using ground-based and airborne sensors. Specifically, it explores the phenomenology behind the detection and identification of chemical agents and hazmat using thermal hyperspectral and spectropolarimetric imaging. To be able to understand the phenomenology behind the measurements in the thermal hyperspectral and spectropolarimetric scenes, the following methodology is implemented:



- Development of physics based models that aggregate all the parameters in the scene and their combined influence on the retrieved radiance, polarimetry, emissivity and temperature.
- Collection of extensive experimental data with numerous airborne hyperspectral and spectropolarimetry imagers, in-situ ground sensors and ground truth data. During a trial that took place at Suffield (Canada) in July 2014, realistic scenes were set and chemicals of interest were released under controlled background and atmospheric conditions.
- Validation of existing detection algorithms using real hyperspectral and spectropolarimetric data.
- Development of robust methods for the detection and identification of chemicals precursors and spills in the atmosphere.
- Creation of a road map for future technological development of hyperspectral and spectropolarimetric imaging.

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Abnormal event detection using UAS

This research comes in the context of a joint PhD between the RMA and the Polytechnic School of Tunisia.

Nowadays and due to endless technological progress, the use of the Unmanned Aircraft System (UAS) has spread in various fields particularly for surveillance purposes such as borders' intrusion detection and sensitive facilities security. UAS are also employed in search and rescue applications to find victims and even to give the first aid by providing rescue kits. To achieve these goals, the UAS are guided by remote operators in ground control stations or programmed previously to navigate above a well-defined area by defining their waypoints. They are equipped with different kinds of sensors enabling them to navigate and to send information to the ground control station. The modern UAS are able to send, in real time, aerial images captured by the visual sensor on board. However, the flow of information transmitted is huge causing problems of analysis and storage mostly inadequate information or redundant. The purpose of the PhD thesis is to develop algorithms that make the UAS intelligent enough to distinguish between unimportant and important data. The main idea is to select then/before to send only pertinent information that does require human attention to the ground control station. In deed, an onboad and real time with low computation requirements processing is needed in order to detect abnormal/suspicious event.

The growing availability of surveillance cameras lead to extensive research efforts for robust detection of pedestrians using images. However, the surveillance of borders or sensitive facilities poses many challenges including the need to set up many cameras to cover the whole area of interest, the high bandwidth requirements for data streaming, and the high processing requirements. Driven by day and night capabilities of the thermal sensors and the distinguished thermal signature of humans, we firstly propose a novel and robust method for the detection of pedestrians using thermal images. The method is composed of three steps: a detection, which is based on a saliency map in conjunction with a contrast enhancement technique, a shape description, based on Discrete Chebyshev Moments (DCM) and a classification step using a Support Vector Machine (SVM) classifier. The obtained results prove the robustness and the superiority of the proposed framework in terms of true and false positives rates and computational costs, which make it suitable for low-performance processing platforms and real time applications. Furthermore, we proposed a fast and efficient framework abnormal event detection in thermal images based on for pedestrian detection and tracking using the MPEG motion vectors. The proposed framework exploits raw H264 compressed video streams with limited computational overhead. It is driven by the fact that Motion Vectors (MV) are an integral part of any video compression technique. Six different scenarios were carried out and filmed by a small UAS in order to simulate suspicious events.

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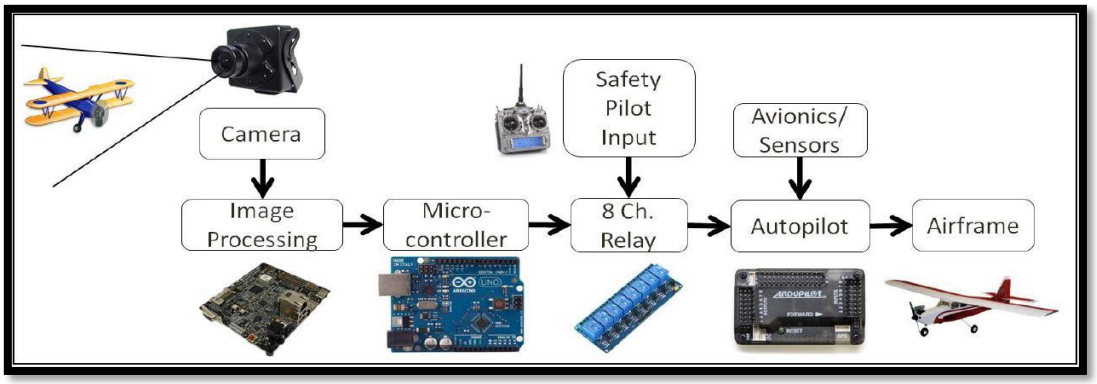
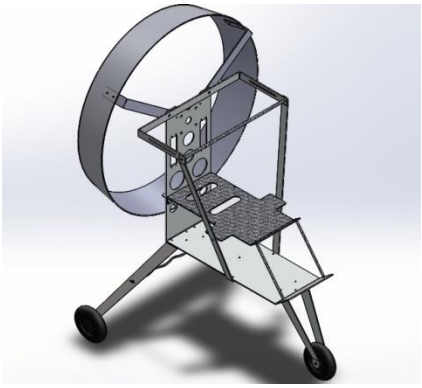
Elaboration of obstacle avoidance algorithms through video processing

The problem of control based on video image processing can be divided into several sub-problems depending on the algorithms and the methods of using the available information to achieve the navigation from a point A to B, avoiding the static and dynamic obstacles.

After studying the available research literature, related to the current subject, the system architecture highlighted in the figure below was adopted:



This overall architecture has created the framework for the further development of the PhD thesis with the following modifications:



1. At present, the design of a mini flying platform was carried out

2. The autopilot that is being used is Navio2, which runs a distribution of Linux

3. The autopilot receives control commands from an image processing board, Nvidia Jettson TK1, on which the algorithm will be implemented.

4. Depending on the images type, 2D or 3D, needed for processing, 2 camera options were chosen: Zed and Xiaomi cameras. One of them will be integrated with the rest of the electronic equipment to achieve a real-time navigation based on video image processing.

5. The intermediary microcontroller block (Arduino Uno) pointed in the above system architecture figure was removed because it introduces an extra delay to the message sent from the processing board to the autopilot. This fact affects the real time operation of the UAS

6. The autopilot Navio 2 needs an USB internet dongle to allow internet communication. Putting all together (Navio2, raspberry Pi3 and USB dongle) brings onboard unwanted additional weight and power consumption. Therefore, a board that allows communication over internet was prototyped and will be part of an autopilot that is currently in progress of development.

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Autonomous UAS control and navigation

Autonomy has been perceived for a long time as the Holy Grail in robotics. At RMA, research is performed in niche aspects of autonomous UAS control and navigation:

- Autonomous control: In-flight launch of Unmanned Aircraft Systems

  Technological advances and the instauration of a legal framework are paving the way for the introduction of Unmanned Aircraft Systems (UAS) for a plethora of applications. However, depending of the application, different types of systems are required: larger vehicles for surveying wider areas and smaller vehicles for indoor operations closer to humans. It is therefore imaginable that we will move to a future where multiple heterogeneous systems will be used at the same and that one vehicle will serve as carrier or launch platform for another one. In this framework, we study the control problem of launching a quadrotor-type micro-UAS from a quadrotor-type mini-UAS.

- Autonomous navigation: Autonomous staircase navigation

  In the quest for fully autonomous Unmanned Aircraft Systems, multiple challenges are faced. For enabling autonomous UAS navigation in indoor environments, one of the major bottlenecks is the capability to autonomously traverse narrow 3D - passages, like staircases. Therefore, we study a semi-autonomous navigation system for a quadcopter, permitting the UAS to detect a staircase using only the images provided by an on-board monocular camera. A 3D model of this staircase is then automatically reconstructed and this model is used to guide the UAS to the top of the detected staircase.

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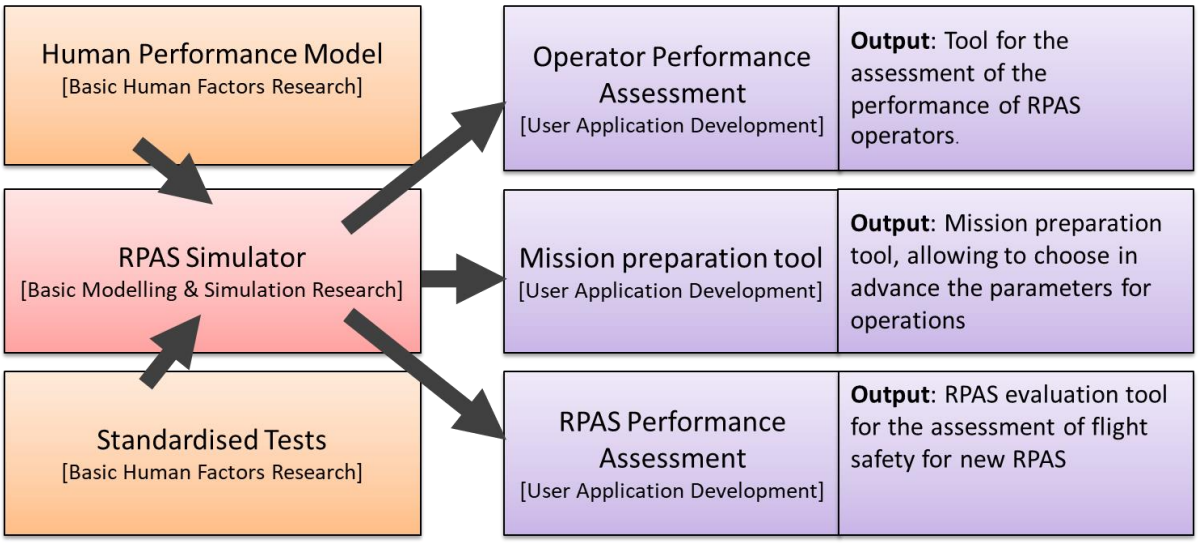
Human factors & human performance modelling for reducing the number of UAS incidents

As Belgian Defence is now in a fast pace integrating new UAS / RPAS systems into its operations, it is developing also a doctrine to manage and deploy these UAS systems in a safe way. This research study seeks to support the actors within Belgian Defence in this process by developing a strategy to incorporate human factors in the evaluation of UAS and UAS operators. A qualitative and quantitative benchmarking tool based on standardized test methodologies will be developed, integrated into a realistic simulation environment. This will enable:

- on-the-job pilot training in a safe simulation environment with qualitative and quantitative assessment of the pilot skills, which will support the military training of Belgian Defence UAS pilots
- a simulation tool for the quick risk assessment for the certification of novel UAS systems, providing support to the Belgian Military Airworthiness Agency
- a simulation tool for commanders in the field to practice for certain risky operations before deploying the real UAS, thereby minimizing risks and operational losses



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IoT swarms of unmanned maritime and aerial unmanned systems

The ultimate objective of this proposal is to develop cost-effective, deployable solutions for the operational implementation of unmanned maritime systems. The use of a fleet of heterogeneous unmanned systems, seamlessly collaborating towards a common, shared goal, is appealing as it allows the end-user to build up an efficient "system of systems" with available, interoperable assets.

Within this research project, we will focus on unmanned maritime systems in the application domain of maritime surveillance. The aim of Maritime Surveillance is to understand, prevent (where applicable) and manage the actions and events that can have an impact on Maritime Safety and Security, search and rescue, accident and disaster response, fisheries control, marine pollution, customs, border control, general law enforcement and defence, as well as economic interests.

The ultimate goal of the work on the heterogeneous team is to consolidate a common command, control and payload interface to be agreed and adopted by all robotics platforms and control ground stations (CGS) involved in an operation. This approach provides a common framework for the development of collaborative unmanned assets, minimizing the integration time and costs by avoiding ad-hoc implementations.

As a key concept, we will develop a heterogeneous interoperability and collaboration framework which is seamlessly interoperable with the existing and future C4I and GIS infrastructure. The interoperability concept consists of a highly modular system of carrier platforms and sensor payloads, enabling straightforward switching of payloads from one system to another.

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Automated take-off and landing with UAS on Belgian Navy vessels

Unmanned aerial systems are more and more being incorporated into maritime military operations, notably due to the advantages they pose for tactical planning. Technological advances have rendered these unmanned aerial vehicles fairly easy to operate for in-flight maneuversmanoeuvres, as now advanced software tools are available to assist the human pilots in order to avoid crashes or to optimize the flight performance or in some cases to completely automate the flight operations. However, in comparison with land operations, one aspect remains a stringent bottleneck for the widespread deployment of unmanned aerial systems for maritime operations: the capability for these unmanned aerial systems to automatically take off and land on vessels in all kind of environmental conditions. Indeed, landing a relatively small aerial vehicle (that is therefore inherently very receptive to wind gusts) on the pitching and rolling deck of a moving ship is a very difficult control problem that requires the careful consideration of the kinematics and dynamics of both the unmanned aerial vehicle and the ship. In response to this requirement, this research study proposes to provide a proof of concept solution and practical implementation for a helicopter-type drone with the capability to land autonomously on the Belgian Navy vessels.

This research project – starting in 2020 - will focus on the development of the automatic take-off and landing capacity, which encompasses the integration of the necessary novel sensing tools and the development of the control algorithms and their incorporation in the MTUAS autopilot.

The objectives and scope for this study are therefore very concrete and tangible: To make the MTUAS platform as shown in the figure below land on the vessel shown below.

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Non-cooperative detection of UAS

UAS and in particular the smaller UAS are, owing to their (very) low cost, more and more widespread. Despites the Belgian legislation that limits their use, many incidents are reported. Indeed, besides the inherent danger of UAS (fall of a UAS on a crowd), a UAS could also be used to carry a payload (explosive, weapon, drugs, …) short-circuiting the ground-base protection measures (fences, …) put in place at the perimeter of a site to be protected (military compound, but also civilian sites such as a football stadium, prisons, …).

Detection systems claiming to be able to detect UASs are already existing and more are being developed using one or more modalities (optical, acoustical, radiolocation and radar). However, very little information is available regarding their performance and intrinsic limitations.

The goal here is to study the factors driving the detection performance and the inherent limitation of such devices in order to deduce best practices and recommendations. The modalities considered are

- Optical (visible and infrared);
- Acoustics, where it is expected that the propeller noise hints at the position of the UAS;
- Radiolocation, where the transmissions from the UAS (video downlink or command and control link) are detected, including the direction of the UAS (Direction of Arrival of the received signal);
- And finally, radar, allowing an all-weather detection, including some classification possibility using micro-Doppler.

It is expected that by combining these different modalities, the detection performance of different UAS types (fixed-wings, multicopters, …) in different conditions (at night, in the presence of fog/smoke, …) can be enhanced.

In addition, based on the direction in which the UAS is located, the feasibility of selectively jam the command and control signal of commercial UAS is studied.

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Development of a multi-modal integrated UAS detector

Recent years have seen the dramatic rise of the use of Unmanned Aircraft Systems by governments, consumers and – unfortunately – also by terrorists and criminals. Indeed, whereas there are a great number of very good applications for the use of UAS, these new technological tools provide also a threat in the hands of people with bad intentions. Indeed, terrorists and criminals are more and more using new technological tools for their activities. These include the use of Unmanned Aircraft Systems for operations such as illegal observation and surveillance and drugs trafficking, or even as attack vector. Currently, it is very difficult for law enforcement and border management authorities to deal with these new threats, as the Radar Cross Section of these UAS is too small to be detected by regular radar systems.

The European Commission noted this capability gap and decided to fund the H2020-SafeShore project (http://safeshore.eu/). SafeShore is a 5M€ EU research project, coordinated by RMA which has as a main goal to cover existing gaps in coastal border surveillance, increasing internal security by preventing cross-border crime such as trafficking in human beings and the smuggling of drugs.

Instead of focusing on singular detection technologies (RADAR, LIDAR, Acoustic Sensing, Radio Sensing, Thermal Sensing and Visual sensing), which each have their own advantages and disadvantages, SafeShore concentrates on developing advanced data fusion methodologies into one detector, in order to maximize the detection ratio. The SafeShore detector is designed to be integrated with existing systems and create a continuous detection line along the coast.

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Securing GNSS Navigation Services

On December 15, 2016, the European Commission, owner of Europe's Global Navigation Satellite System, GALILEO , formally announced the start of Galileo Initial Services, the first step towards Full Operational Capability (FOC). Galileo provides 3 (navigation) service types, the availability of which will continue to be improved: Open Service (OS), Search And Rescue Service (SAR) and the Public Regulated Service (PRS)

The core objectives of the PRS are to be a special Galileo navigation service set up for better management of critical transport and emergency services, better law enforcement, improved internal security, better protection of strategic, economic & commercial activities and safer peace missions. In order to achieve these goals, the differentiators of the PRS navigation service are:

- Advanced (one-way) cryptographic functions and procedures
- More robust signals against radio frequency interference
- Embedded authentication
- Jamming detection on space vehicles up-link
- Access control of PRS users at MS level and System

In order to demonstrate the improved resilience of PRS towards potential threats the European GNSS Agency (GSA) launched a Joint Test Activity (JTA) call to support Member States (Mss) involvement in PRS Pilot Project activities.

Led by Belgian Royal Military Academy, a consortium involving federal agencies and institutions from Germany, Finland, Poland, Sweden and the United Kingdom proposed the **PRS Pilot Project for Demonstration (3PfD)**, a 2 year JTA project. This project will demonstrate the usefulness of the PRS navigation service by performing national pre-tests, a continuous PRS spectrum monitoring to synthesize potential harmful signals for PRS and a big measurement campaign on a large test site with nearly unlimited possibilities to perform jamming, meaconing and spoofing tests of different GNSS navigation services. The results of these tests, after approval by the GSA, shall be the topic of an international conference to create awareness of the added value of Europe's Galileo PRS navigation service.

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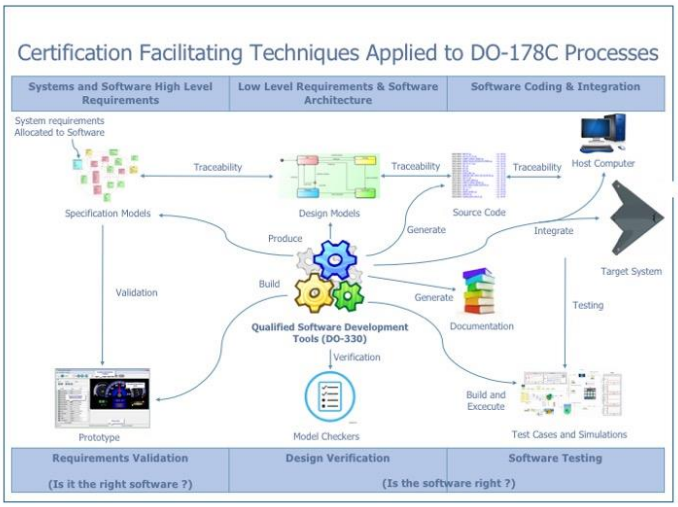
A development method that enables efficient DO-178C/DO-278A certification of 'intelligent' software agents embedded in UAS or integrated in C4ISTAR systems

The research covers a software development methodology enabling an efficient DO-178C/DO-278A certification for 'intelligent' software agents embedded in UAS or integrated in C4ISTAR systems by leveraging following software engineering techniques and RTCA standards:

- Qualified Software Development Tools (DO-330).
- Model-Based Development and Verification (DO-331).
- Object-Oriented Techniques (DO-332).
- Formal Methods (DO-333).
- Integrated Modular Avionics (DO-297).
- Agile Development Methods.
- Software Products Lines.



The research also encompasses the validation of the methodology by applying it to the requirements elicitation, the specification, the design, the coding, the integration, the verification and the certification (DO-178C and its variant for ground systems: DO-278A) of 'intelligent' software agents (utility based agents) integrated in:

- Collision Avoidance Systems implementing sense-and-avoid function in UAS.
- Cybersecurity Systems protecting UAS from cyberattacks (including GNSS spoofing attacks).
- C4ISTAR Systems detecting, tracking and neutralizing (with electronic and kinetic means) a swarm of hostile UAS.
- Target Acquisition and Tracking Systems allowing collaborative Counter-UASto 'engage' a swarm of hostile UAS.

The research addresses the challenge posed by the DO-178C/DO-278A certification of 'intelligent' software agents integrated in airborne and ground aeronautics systems: demonstrate their deterministic behavior although they handle stochastic variables.

Simulations will be based on 'Digital Twins'. SCADE development tools and scade formal notation will be used in the research.

The research takes place in the scope of a PhD thesis in computer sciences undertaken at the University of Namur (PReCISE Research Center) in collaboration with the Royal Military Academy and the Centre d'Excellence Drone of the French Air Force.

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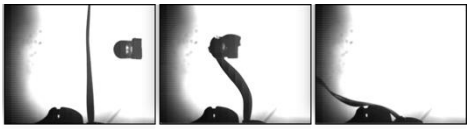
How can we stop malicious Unmanned Aircraft Systems?

The Low Small Slow Unmanned Aircraft Systems (LSS UAS) are the smallest and cheapest category of aircraft without a pilot in-command on-board. Due to a technological gap on detection technologies, these potentially harmful UAS are currently likely to be visually spotted very late by the security teams. In the context of urban environment, technologies such as jammers, lasers, or other high energy devices are potentially unsuitable due to possible strict regulations and a high potential of collateral damage on other equipment. This project, sponsored by the ABAL (www.abal.rma.ac.be) department in the framework of the NATO Defense Against Terrorism Program of Work, discusses the potential suitability of Kinetic Energy Non-Lethal Weapons (KENLW) to neutralize malicious LSS UAS in such conditions. These weapons are designed to minimize permanent or unnecessary injuries when used against human targets.

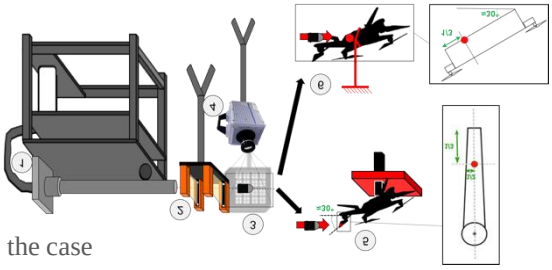


The project different steps are the following:

1) Terminal ballistic study using off-the-shelf antipersonnel projectiles

The objective is to determine if the impact of a KENLW projectile can make the LSS UAS fall. Two different aspects are studied here: the ability to break one of the UAS's propeller and the ability to damage the hull of the UAS. Before these experiments, preliminary tests have shown that breaking one single propeller or damaging the hull was sufficient to make the benchmark UAS fall.

2) External ballistics study (potential of hitting the UAS)



At this stage, the potential of hitting the target is discussed. Firstly, a geometrical study is carried out in order to approximately quantify the probability to hit the propeller when aiming perfectly. Secondly, some considerations on the dispersion and on the projected angle of the UAS are defined and maximum engagement distance for different projectiles are calculated, still with a perfect aiming. Thirdly, the case of a moving UAS and consequences on the ability to aim and hit is considered and some ways of improvement are explored.

3) Collateral damage study (risk assessment of accidentally impacting a human being)

The lethality study consists of studying the impact of the projectile on the thorax of a human target. Two phenomena are studied: the non-penetrative impact, and the skin penetration assessment. The way of working is then a risk assessment method: what happen if the shooter misses his shot and directly impact a human target by mistake.

First conclusions are the following:
The propeller has been identified as a weak point, especially for low-cost LSS UAS. Provoking damage to the hull, breaking critical components is also an option for these projectiles.

Besides, external ballistic studies show the potential to hit the UAS. However, even if not quantified, the case of a moving UAS highly reduces the probability to hit the UAS. In consequence, dedicated aiming system, multiple shots and higher fire rates have to be investigated.

Finally, results show limited risk of injuries if projectiles inadvertency hit persons. A trade-off has to be found between desired effect and the minimizing of the risk of injuries in case of a missed shot. Besides, means have to be developed in terms of aiming systems or multiple projectile launchers to improve the probability to hit a moving UAS.

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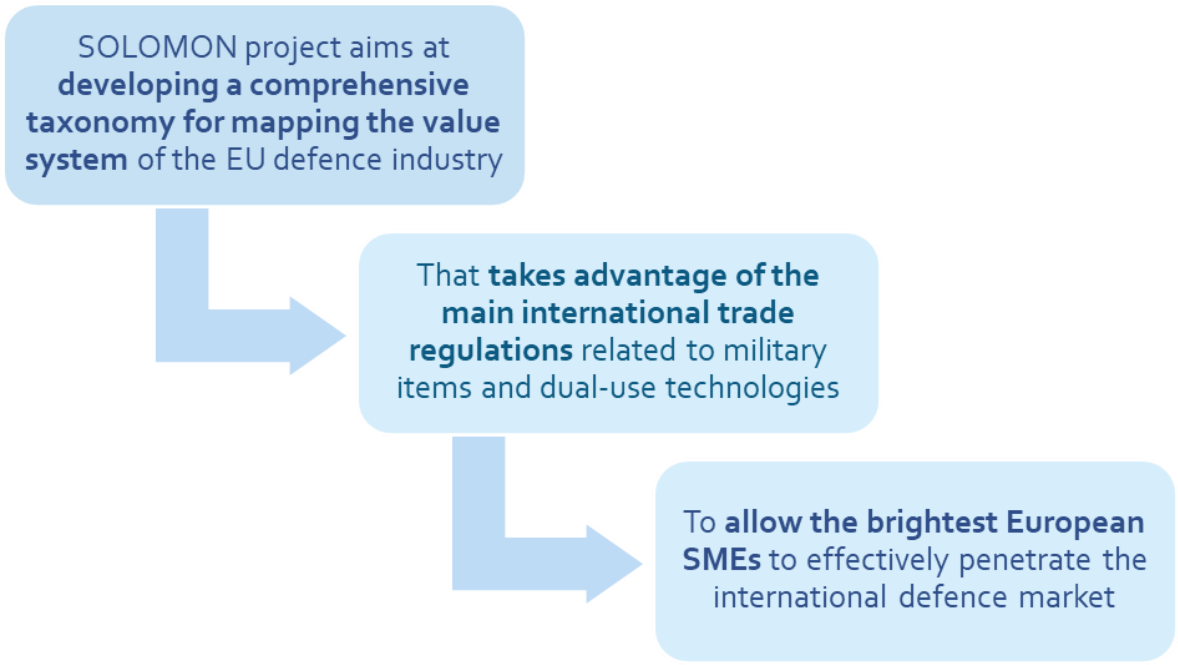
Supply chain risks in the EU Defence industry

RMA participates (with Thales) in the EU-PADR-SOLOMON project (http://www.solomon-padr.eu/), which stands for "Strategy-Oriented anaLysis Of the Market fOrces in EU defeNce". This research project has received funding from the European Union's Preparatory Action for Defence Research - PADR programme under grant agreement No 831379. Within SOLOMON, RMA is specifically active in the research actions related to aviation technologies.

The objective of the project is to provide the methodologies and tools to the EU to ensure that the industries responsible for the delivery of the EU armament systems and services could rely on a trusted supply and that in turn EU, as a whole, could overcome the issues related to critical defence technological dependencies.

SOLOMON project intends to merge the two complementary visions of grand strategy (as it emerges from EU geo/political/economic postures) and business strategy (as it emerges from the Michael Porter's value chain theory) in order to outline the possible roadmaps for tackling the supply risk of the EU armament systems in a world of changing strategies, emerging technologies and mutating government restrictions.



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