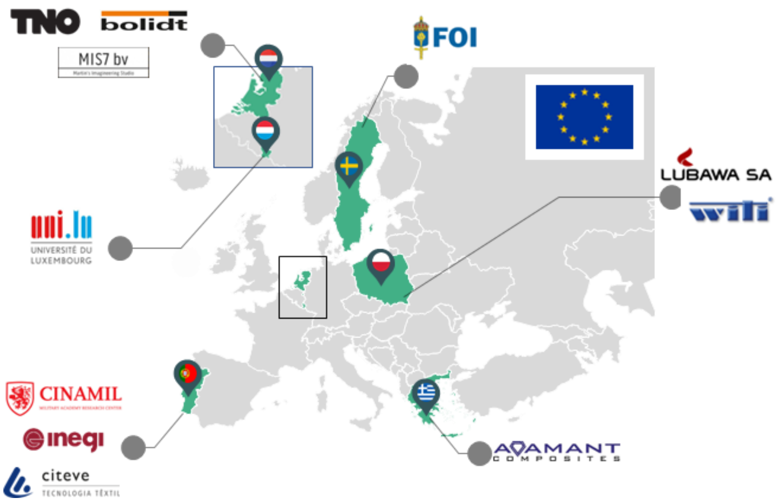
Executive Summary ASCALS I

Advanced Solutions for Camouflage of Land Systems using smart and adaptive materials - I



Blending In: Europe Pioneers Adaptive Camouflage for Today's Military Challenges

Given the increasing sophistication of battlefield surveillance (including multispectral imaging, radar and thermal detection) the development of controllable and adaptive camouflage has emerged as a critical factor for enhancing tactical survivability and operational stealth. ASCALS I activity was conducted to develop materials and processes toward smart camouflage. ASCALS I is a European Defence Agency (EDA)-coordinated initiative bridging CapTech Land Systems and CapTech Materials & Structures, with funding from six Member States: Greece, the Netherlands, Poland, Luxembourg, Portugal and Sweden. ASCALS I focused on the development of smart materials engineered for adaptive camouflage, with the goal of achieving Technology Readiness Level (TRL) 3. The project specifically targeted multispectral concealment for land platforms, emphasizing material innovation, spectral performance optimization and preliminary integration assessments. The activity concluded on March 2025, laying the groundwork for subsequent phases aimed at higher TRL advancements and operational field testing.

The purpose of adaptive camouflage is to confuse, misdirect, delay, or hide from the opponent. Its effectiveness is related to both the shape and the materials of the land platform as well as the context in which it is placed, such as environment, weather, day/night, threat, movement, etc. The camouflage should never be in conflict with the main operation purposes of the land platform; however, their effectiveness can be at odds with one another.

Camouflage aims at impacting the kill chain, interrupting one of the key links before the decision of engagement (detection, classification, identification, tracking). Making the camouflage controllable, adaptable and smart allows an earlier and effective disruption of the kill chain.

The current state of technology in smart and adaptive camouflage is defined by the confluence of advanced materials science, artificial intelligence and the increasing demand for multispectral concealment to counter sophisticated detection technologies. The field is undergoing significant transformations driven by military, aerospace and security needs, as well as interdisciplinary advancements in nanotechnology, photonics or computational modelling.

The effectiveness of adaptive solutions must be benchmarked against traditional camouflage techniques to substantiate their operational value. A traditional camouflage such as nets was assessed to require 10 minutes to be set. An adaptive camouflage shall therefore exhibit levels of controllability between at least two states, which would happen below

10 minutes. A change switch below 1 second is the ultimate target, enabling then adaptive camouflage during mobility settings.

Beyond land systems, the research and technologies developed under ASCALS I also show potential for cross-domain applications in maritime and air platforms. The feasibility of these extensions underscores the strategic importance of the ASCALS I roadmap in addressing multi-domain challenges in modern warfare.

The ASCALS I technologies encapsulate the integration of cutting-edge material science, advanced processing methodologies and novel application techniques to develop smart and adaptive camouflage solutions for military ground systems. The project's scope is firmly rooted in the development of active and adaptive materials that can dynamically modulate their optical, thermal and radar signatures in response to varying environmental and operational conditions.

Considering the numerous technical challenges, specifically the obtention of adaptivity, ASCALS I strategy was to explore as many different materials as possible. Throughout future developments, the number of configurations is expected to decrease the closer we get a product operationally ready.

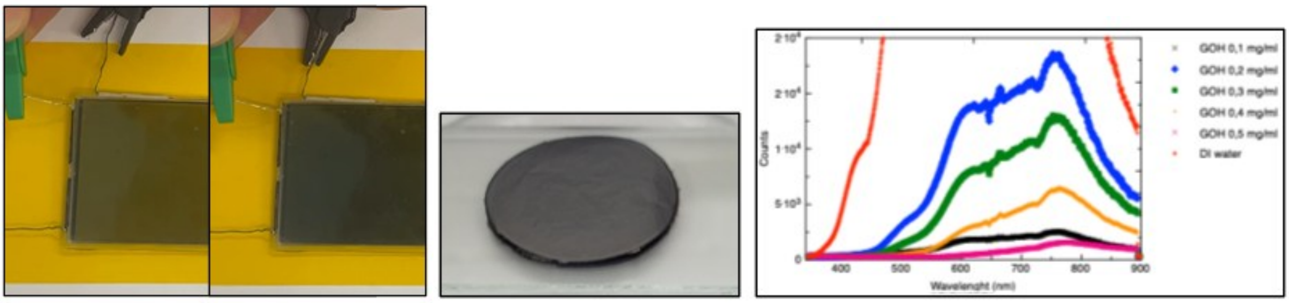
Adaptive Camouflage in Visible: Mastering Concealment Across European Landscapes

Providing concealment in the visible requires knowledge of the environments at stakes. Two main categories are woodlands and urban. European landscape surveys were done by the different national Ministries of Defence and zones were defined, with major colors one should fit to blend in. In the framework of ASCALS I, it was identified that woodlands are usually of more interest and that targeted colors are green, yellow, and brown.

WITI (Poland) first investigated the use of PANI as thermochromic fillers. However, these compounds had several disadvantages such as small operating windows, cycle stability, or low adhesive forces to substrates. For these reasons, liquid crystals were preferred. Liquid crystals can change their alignment and optical properties in response to external stimuli like electric fields, making them useful for adaptive stealth as they can rapidly alter how light interacts with a surface. In ASCALS I, three configurations were investigated: twisted nematic structure, the combination of liquid crystals and dyes (Guset-Host effect), and the use of monochromatic colored filters with liquid crystals. Promising results were obtained with successful electrical control of the optical signature. It was assed that twisted nematic structures can offer camouflage for urban environment while Guset-Host would be more adapted for many natural environments.

The University of Luxembourg (Luxembourg) also targeted the visible spectrum, but using graphene and graphene oxides. From its isolation 20 years ago, graphene has demonstrated to hold exceptional properties. The University of Luxemburg harvests the power of graphene and its related oxides under 3 forms: dispersions, coatings, and free-standing papers. A challenge in all of these forms is to obtain uniformity and stability. By playing on the production process, the University of Luxembourg managed to have satisfying products with good coverage. The visible and IR signatures of various materials were studied. It was for instance shown that the transmission in the visible of a graphene dispersion could be adjusted through changes in concentrations.

Another interesting aspect is that graphene oxide dispersions themselves could exhibit “liquid crystal” properties. Using graphene oxides both as electrode and liquid crystal would allow a better stability. However, further work are needed, in particular on the control of the directionality of the graphene oxide dispersion.



Examples of a liquid crystal cell (left), free-standing graphene oxide paper (middle) and change of transmission in the visible of graphene dispersions (right).

Adaptive Camouflage in IR: Cool Down and Vanish

Materials-based camouflage in the thermal bands requires the possibility to locally play on the surface temperature or the emissivity. One strategy is to bring this functionality into products already in use in military platforms. ASCALS I consortium targeted this spectrum through functional compounds being incorporated into different baselines.

CFRPs and GFRPs (carbon– or glass-fiber reinforced polymers) are widely used for their stiffness to lightness ratio, Doping GFRPs with carbon nanotubes and iron oxides, INEGI (Portugal) was able to modify the emissivity through a synergetic effect. In addition to lower IR emission, an enhanced absorption of radar signals was measured at FOI (Sweden) in the Ku-band (16-18GHz), demonstrating a potential for multispectral stealth. Alternatively, CFRPs were modified by incorporating PEG-based phase-change materials (PCMs) and PEG-functionalized carbon nanotubes. Functionalization of carbon nanotubes improved their dispersion and compatibility within the polymer matrix, ensuring uniform heat distribution. Experimental validation confirmed that these modifications led to improved thermal camouflage by regulating heat dissipation and minimizing IR detectability.

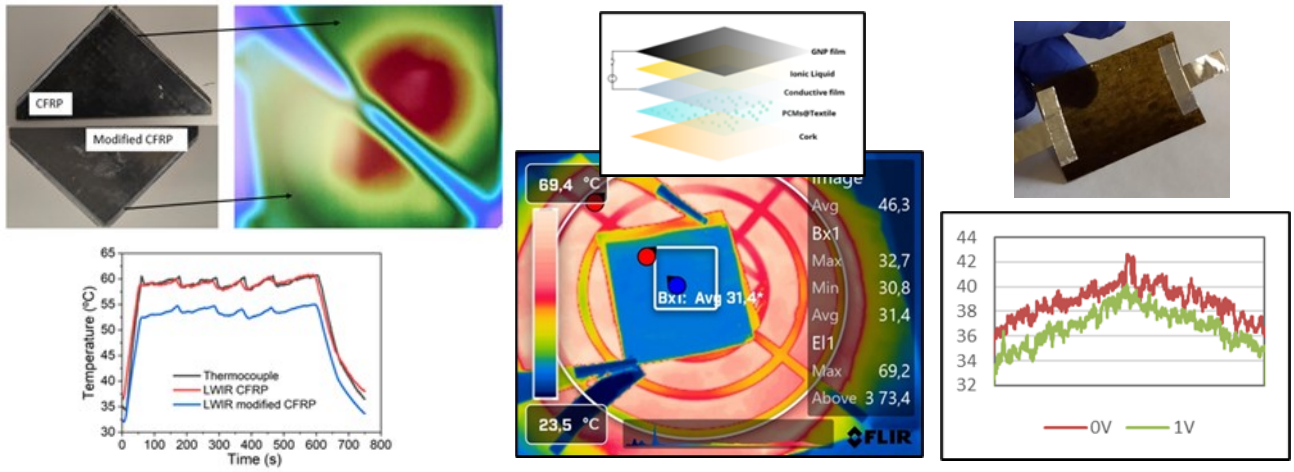
To tackle the challenging objective of adaptive stealth, CITEVE (Portugal)'s strategy was to design a multilayer approach, including:

1. A sandwich assembly made of a conductive carbon layer, an ionic liquid electrolyte, and a counter electrode. The possibility to apply an electrical current to this assembly was added to potentially tune the emissivity.
2. A textile with PCMs, targeting the reduction of the thermal signature at the hot spots. A combination of PCMs to act in a wide range of temperatures (50 – 110 °C).
3. A final layer of a sustainable light material, with very low permeability to liquids and gases, that can withstand compressive deformation without fracture and also provides noise reduction.

Firstly, the layers were tested individually showing IR signature reduction, however even better results were achieved when combined in a multilayer device. The final device was able to decrease the thermal signature of an object from 64°C and 84°C to 26°C and 29°C, respectively . Additionally, some effect was observed in the radar range of 6-16 GHz.

Finally, Adamant Composites (Greece) developed a structural and functional film adhesive, which could be integrated directly within the platform's structure. Such films are ready-to-be-used and easily scalable in production. The films were functionalized using two different type of PCMs:

1. Vanadium dioxide (VO_2) was produced and incorporated into the film. VO_2 presents a metal-insulator transition which can be electrically actuated. The resulting film proved a 2°C reduction upon the application of 1V bias voltage.
2. Organic PCMs with an encapsulation into a silica shell were also used. Considering that organic PCMs undergo solid-liquid transitions, the encapsulation provides a way to counteract leakage risks and enhances durability. Heat transfer capacities were demonstrated through DSC.



Three novel products: Modified CFRPs from INEGI (left), multilayers from Citeve (middle), vanadium dioxide films from Adamant Composites (right).

Adaptive Camouflage in Radar: Avoiding Reflection to Evade Detection

An object is characterize by its radar cross section (RCS), the measurement of its ability to reflect radar signals in the direction of the radar receiver. The interest is therefore to reduce this RCS, or even control the reflected signal, both in amplitude and direction.

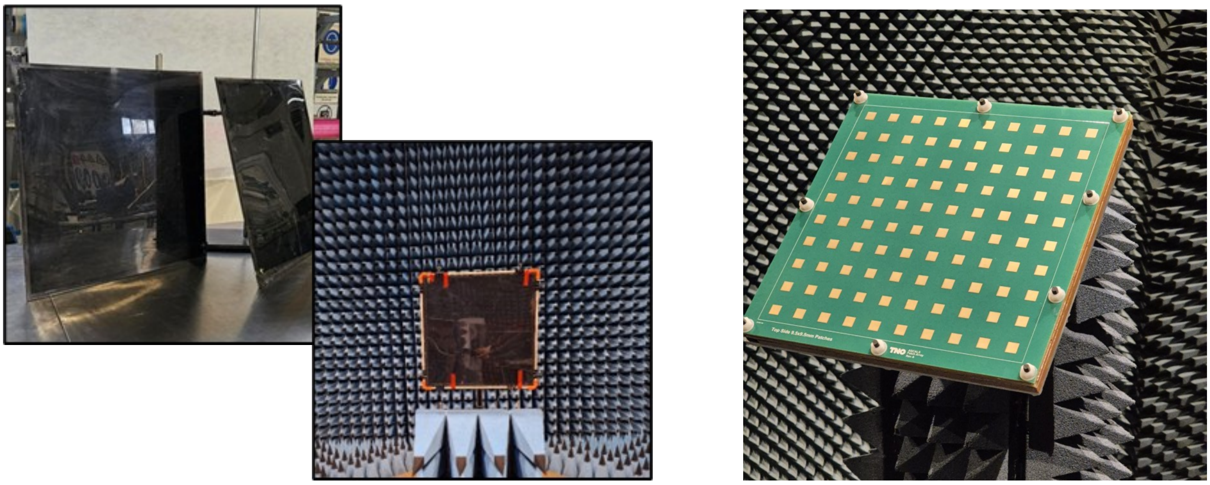
Adamant Composites intended to harvest the interaction of graphene and electrolytes into an "electrographene" assembly. Graphene is intrinsically a material of choice for radar absorption from its excellent electrical conductivity and high surface area. In a sandwich assembly with an ionic liquid, upon the application of a voltage bias, the mobility of the ions from the electrolyte onto the surface of the graphene has an impact on the interaction with radar signals, allowing therefore the modulation for adaptive camouflage. After development of the deposition process of a graphene coating on various radar-transparent substrate, a large 50cm x 50cm sample was produced by Adamant Composites. The sample was tested in the anechoic chamber of Lubawa (Poland). Results show some initial difference above 15GHz between the passive state and the application of a voltage bias. Future developments could include a modular design or different baseline materials to fit operational situations.

Another approach in the RF spectrum within ASCALS I was to develop a controllable metasurface. TNO, MIS7, and Bolidt (Netherlands) have designed, manufactured and tested a demonstrator consisting of the following constitutive elements:

1. A top layer made of a PCB with a periodic array of metallic double stacked patches.
2. A middle PCB that presents a ground plane with slots on the top side and inverted microstips on the opposite side, both aligned with the double patches forming the array. The patches are designed to match the impinging radar wave in a desired band, transferring the energy to the microstrip. Each microstrip has a structure that can control the phase of the signal that will be reflected.
3. A bottom ground plate, representing the metal layer of a platform.
4. A polyurethane compound produced by Bolidt is used to hold the assembly together and provide the optimized distances between the different parts.
5. A control interface developed by MIS7 to set each switch in an ON or OFF position (reflected wave being either in– or out-of-phase).

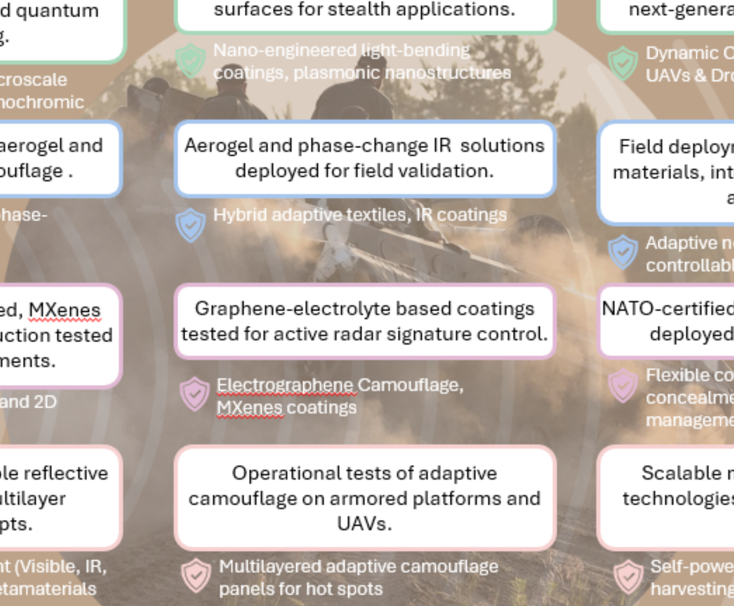
The demonstrator was designed to allow an optimal match of an incoming radar signal over a large bandwidth. The switches were designed and tested to provide a local phase difference of 180° between the two switch states. As each switch can be controlled separately, one can produce a large variety of reflected signals.

After careful optimization of the design, testing was done both at material– and component-levels. Solving challenges in the manufacturing procedure, a demonstrator was ultimately produced and tested in an anechoic chamber in 3 configurations: all switches being ON, all switches being OFF, switches being in chessboard pattern. Overall, a controllable RCS reduction was obtained over a large band, by switching between the 3 different configurations.



The radar spectrum was specially covered by elctrograpehe camouflage and controllable metasurface, both being tested in an anechoic chamber.

Roadmap of the Adaptive Camouflage in Europe



2025 2030 2035 2040

	Phase 1	Phase 2	Phase 3
Advanced Optical Concealment	Research on nano-engineered coatings, plasmonic structures, and quantum optical cloaking. 3D-printed structures, microscale pixel arrays, electro/thermochromic	Prototyping of 3D-printed adaptive surfaces for stealth applications. Nano-engineered light-bending coatings, plasmonic nanostructures	Full-scale production and deployment of next-generation adaptive coatings. Dynamic Optical Camouflage for UAVs & Drones
Thermal & Infrared Camouflage	Concept development for aerogel and heat-absorbing IR camouflage . Hydrogel, silica aerogel, phase-change materials	Aerogel and phase-change IR solutions deployed for field validation. Hybrid adaptive textiles, IR coatings	Field deployment of IR-camouflaging materials, integrated into infantry gear and vehicles. Adaptive nets, low-energy controllable IR coatings
Radar & EM Stealth Solutions	Early-stage graphene-based, MXenes and metasurface radar reduction tested in controlled environments. Metamaterials, graphene and 2D materials	Graphene-electrolyte based coatings tested for active radar signature control. Electrographene Camouflage, MXenes coatings	NATO-certified radar-absorbing coatings deployed across allied forces. Flexible conductive films for EM concealment, active radar signature management
Multispectral Adaptive Systems	Research into programmable reflective metamaterials and multilayer camouflage concepts. Multispectral concealment (Visible, IR, Radar), programmable Metamaterials	Operational tests of adaptive camouflage on armored platforms and UAVs. Multilayered adaptive camouflage panels for hot spots	Scalable multilayer camouflage technologies integrated into military operations. Self-powered camouflage with energy harvesting
AI-Driven Adaptive Camouflage	Development of AI-driven spectral adaptation and networked camouflage integration. AI-driven spectral adaptation	Integration of AI-driven camouflage into battlefield management systems. AI-driven threat detection, integration with networks	Autonomous multispectral camouflage achieving real-time stealth adaptation. AI-enabled real-time camouflage adjustment

ASCALS I

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Project Funding

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Project Partners

- Adamant Composites, GR [Coordinator]
- TNO, NL
- MIS7, NL
- Bolidt, NL
- WITI, PL
- Lubawa, PL
- University of Luxembourg, LU
- FOI, SE
- CITEVE, PT
- INEGI, PT
- MRA, PT

Project Objectives

The primary objective of ASCALS I was to develop and optimize smart materials capable of dynamic camouflage across the visible (VIS), infrared (IR) and radar (RADAR) spectra. These materials are intended for integration into land platforms, enhancing their survivability and reducing detectability under various environmental and operational conditions.