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# Time to Stem Lightweight Approaches and Focus on Real Minefield Data?

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EDITORIAL

# TIME TO STEM LIGHTWEIGHT APPROACHES AND FOCUS ON REAL MINEFIELD DATA?

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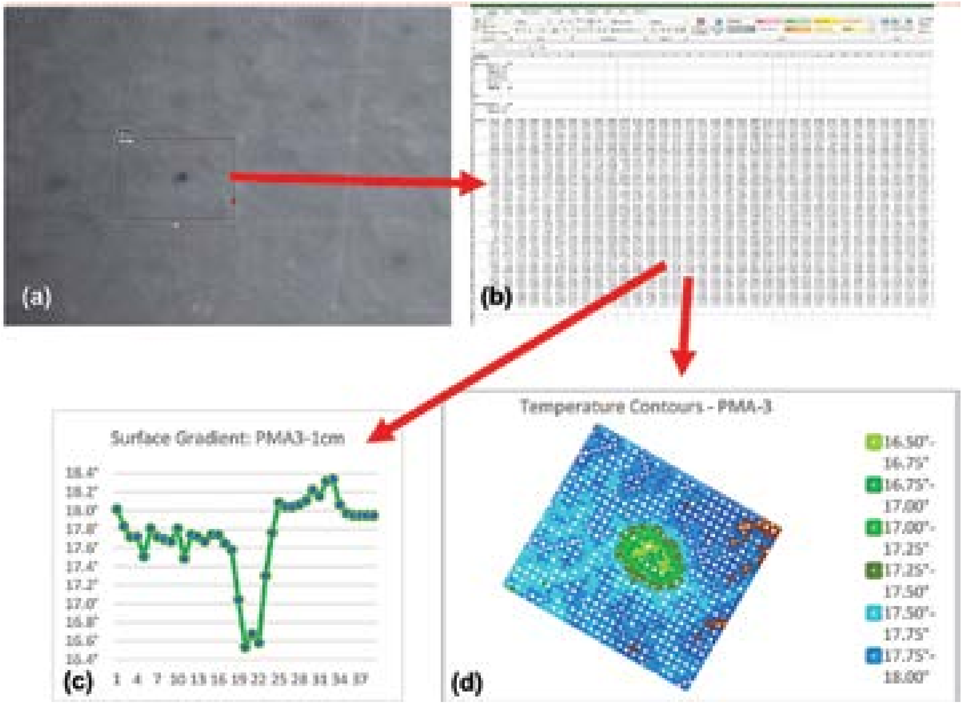

Figure 1. An example of thermal/LWIR data from real landmines in the desert captured by the author: (a) is a thermal image straight from the sensor; (b) is data exported, with every pixel indicating a temperature; and (c) and (d) are visualizations of the surface temperature anomaly created by a buried PMA-3 landmine. More research projects should be capturing field data like this.
*All graphics courtesy of the authors.*

Over the past twenty years thermal/long-wave infrared (IR or LWIR) imaging, also known as thermography, has progressed insufficiently from research to field deployment in the humanitarian mine action (HMA) sector. While preparing for airborne IR thermography fieldwork as part of the Odyssey2025 Project between Humanity & Inclusion and Mobility Robotics in Chad, a comprehensive literature study conducted by the authors to determine what was state-of-the-art knowledge indicated this trend. Background knowledge for this article is based on lessons learned during airborne thermal/LWIR imaging work from small drones in desert minefields during October 2019. Experience gained in locating temperature anomalies allowed authors to identify the position of thirty-year-old legacy buried anti-personnel and anti-tank landmines at in-situ minefields using airborne IR thermography.

From the literature reviewed, the authors identified a disconnect between thermography-related research projects and practical, real-world HMA operations. The literature review also indicated that research topics have been duplicated without sufficient evidence to indicate if buried landmines could (or could not) be located under actual minefield conditions using IR thermography as an enhanced survey technique.

## BACK TO THE FUTURE

IR thermography technology has been available for many decades, with a "think we can" summary published by Bowman et.al[1] in 1998 explaining the potential for the use of airborne cameras to identify color or temperature differences of the ground to locate surface and buried landmines. Over two decades later, similar research articles covering known techniques continue to appear without substantially progressing usable research, and not moving forward to practical next steps.

## DEFINITION OF THE "FIELD"

Ambiguity exists regarding how to define the *field*, with some researchers' outdoor tests at university or government/military facilities labelled as controlled field tests. However, HMA considers field operations as those where real minefields exist or are suspected to exist in situ. Part of a Cambridge Dictionary definition states the field as "a place where you are working or studying in real situations, rather than from an office, laboratory, etc."[2]

Our definition of a controlled (static) field trial is the use of production landmines with explosives intact but rendered safe with detonators removed and buried within a 100 km radius of actual minefields. The reason for a 100 km radius is to closely match natural (geophysical) environmental and weather variables at in-situ minefields. Tests

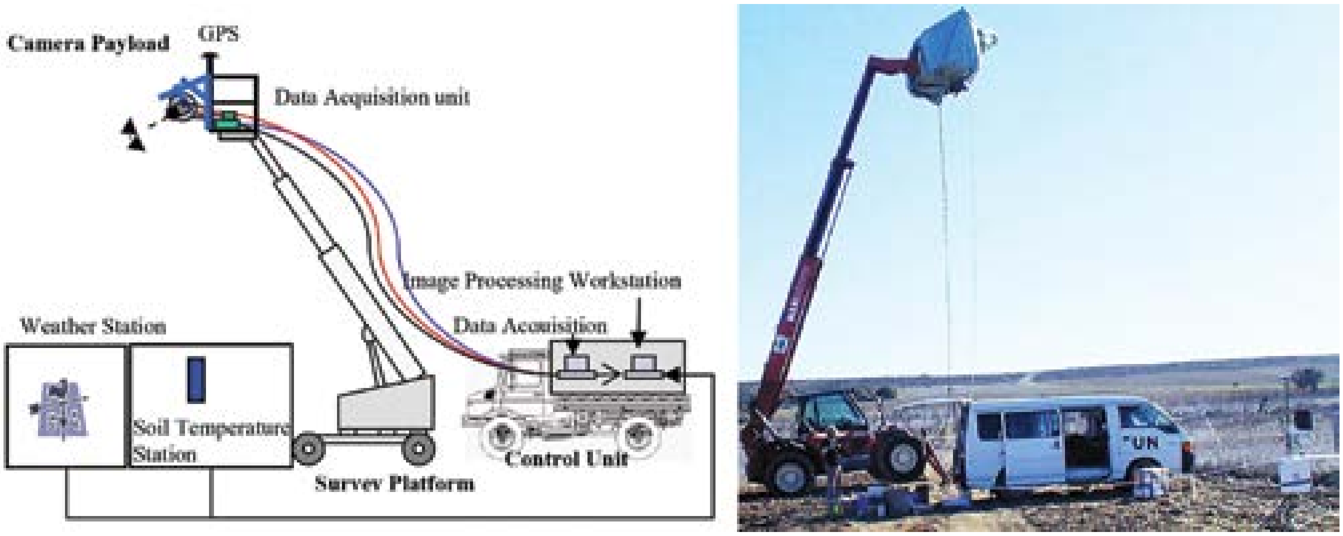

Figure 2. The CLEARFAST thermal/LWIR imaging system over a real minefield in 2005, a precursor to drone capabilities today.

at a university or government site in countries without real minefields should be identified as occurring at an *outdoor laboratory*, not field tests or field trials. With similarities to the concept of technology readiness levels, Table 1 provides a summary of research milestones (or levels of proof) required to determine if IR thermography might or might not be feasible at specific legacy minefield locations under actual field conditions. The outdoor laboratory trial ultimately has limited applications in the path to field deployment.

## LACK OF VALIDATION

An apparent trend in thermography research projects is not progressing further than outdoor laboratory trials to later steps in the field (Table 1). Furthermore, Table 2 provides a summary of the literature examined by the authors, a review of forty-seven articles published over the last twenty-five years that discuss a range of elements affecting the feasibility of locating buried landmines using thermography. A further six IR thermography research articles were reviewed by Makki et.al[3], bringing the total to fifty-three articles reviewed. From the literature examined, only one project progressed to a static field trial. Column headings in Table 1 show the different steps in field research/validation that establish enough proof for HMA actors to gain confidence and justify investing in such a technology. From a practical perspective, HMA actors may view many of the articles reviewed as outputs from obscure academic experiments, lacking real-world credibility from a field perspective. Many of these articles were published in specialized academic journals, often intended for a limited audience of niche subject-matter experts, who fall short of connecting with real-world HMA practicality, and without the authors' understanding the larger picture.

Across the literature reviewed, the only project that captured IR thermography data at a real minefield was by Cremer et.al.[4], during 2005 in Cyprus. In a later article, Thành[5] from Cremer's team stated that thermography research projects were being run without any real minefield data. Their solution was to deploy a cherry picker-style crane and United Nations minivan to collect data under actual field conditions in Cyprus. In 2005, deploying a large mechanical boom was the best possible method for mounting heavy sensors at an elevated position next to a minefield. The boom was connected to a minivan housing computing equipment that operated within the data processing constraints of the time.

Data captured was then used by the same group to develop impressive numerical models regarding how buried landmines interacted with the environment, Thành et al.[5,6,7] These articles discuss how weather and environmental factors can affect the variability of results, elements that affect the strength and timing of temperature anomalies from buried landmines, mathematical modelling of factors in play, automated data processing, sensors, and the complexity of the underlying science. Learning from such work should be a starting point for any research into IR thermography for locating buried landmines because of the comprehensive approach undertaken. A point of difference is that Cremer and Thành et al.

| Activity | Storyboards | Simulations & Indoor Trial | Outdoor Laboratory Trial | Static Field Trial | Initial Field Trial | Field Validation | Field Deployment at Scale |
|---|---|---|---|---|---|---|---|
| Number of Real Mine Field Locations | None | None | None | Low | Low | Medium-High | Very High |
| Temporal Resolution of Real Mindfield Data | None | None | None | Medium-High | Medium | High | High |
| Accurate Weather Variables | None | Low | Low | High | High | High | High |
| Accurate Environmental Variables | None | Low | Low | High | High | High | Very High |
| Production Landmines | None | None | None | High | High | High | Very High |
| Movement | None | Low | High | Low | High | High | Very High |
| Optimal Operating Parameters | None | Low | Low | Low-Medium | High | High | High |

Table 1. Level of real-world proof (legacy in-situ minefields).

A 2019 upgrade to the system appearing in Figure 2. Here, the author uses small drones to fly thermal/LWIR sensors over legacy desert minefields in Chad. Sadly, real-world thermal/LWIR data has been scarce since 2005.

also ground-truthed theoretical results against in-situ data recorded at real-world minefields.

Since 2005, computing/processing power has increased exponentially and sensors have grown smaller, to the point of fitting in the palm of your hand. Deployment of thermal/LWIR sensors over minefields became easier around seven years ago, when miniaturized units could be flown on small drones. However, articles continue to appear without any field data.

## A DISCONNECT IN THE SECTOR?

Let's face it, setting up a sandpit at a university or government facility for outdoor laboratory trials is not very difficult. However, there are challenges in travelling to locations where legacy minefields exist, especially places of most interest for IR thermography—arid locations. Even so, this is not a valid excuse for a disconnect between research projects and HMA.

A more holistic approach would be to include at least one HMA operator in the feedback loop and, ideally, for a national authority/mine action center (MAC) to share priorities for each country of interest. The best approach is to gain specific information: coordinates for the location(s) of minefields, as well as a list of actual landmine models found in these locations. For example, certain minimum metal anti-tank landmines could be prioritized along extensive stretches of closed roads in Afghanistan. Collaborating with HMA operators and MACs is vital in determining priorities. Linking practical innovation to beneficiary needs is how to make a difference in post-conflict communities affected by residual contamination, rather than conducting research purely for academic purposes.

## RED FLAGS

Hinting at a lack of understanding by researchers, the first red flag often observed is with the use of the words *detection* and *survey*. Both words carry very specific and different connotations regarding risk and operational parameters under international and national mine action standards, i.e., in HMA, the phrase "landmine detection" means a near 100 percent detection rate with very few false alarms. Misuse of terminology can indicate signs of both a lack of understanding regarding HMA processes and a lack of collaboration with HMA actors. The term survey is more general and does not always infer a near 100 percent detection rate, e.g., non-technical survey.

The second red flag is a lack of and/or questionable data. The first test should involve the following questions: Which particular landmine model(s) were studied, and in what specific location(s)?

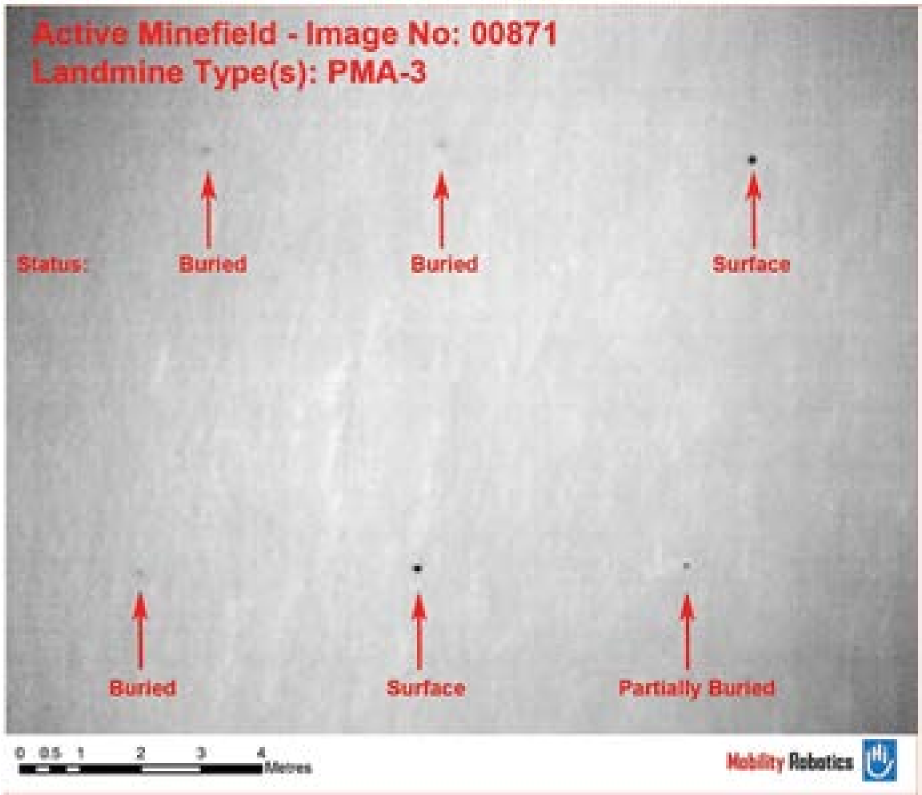

Figure 3. Thermal/LWIR image of two rows of active PMA-3 landmines in-situ, captured by the author thirty years after the conflict.

| Title | Topic Relating to Buried Landmines | Publication Year |
|---|---|---|
| Characterization of diurnal and environmental effects on mines and the factors influencing the performance of mine detection ATR algorithms[i] | Surrogate design, time of day/night (diurnal cycle) | 1995 |
| Improved Landmine Detection Capability (ILDC): Systematic approach to the detection of buried mines using passive IR imaging[ii] | Route clearance using LWIR on ground vehicles to find buried landmines | 1996 |
| Hyperspectral infrared techniques for buried landmine detection[iii] | Soil and sensors | 1998 |
| Thermal Imaging for Landmine Detection[iv] | Microwave heating of the surface | 1998 |
| Sophisticated test facility to detect land mines[9][v] | Outdoor laboratory design | 1999 |
| Impact of soil water content on landmine detection using radar and thermal infrared sensors[vi] | Sensors and soil/sand/ground | 2001 |
| Modeling transient water distributions around landmines in bare soils[vii] | Soil and water transport | 2001 |
| Modeling transient temperature distributions around landmines in homogenous bare soils[viii] | Soil and environment | 2001 |
| Measurements and modeling of soil water distribution around landmines in natural soil[ix] | Laboratory tests, simulations, surrogate landmines | 2001 |
| An analysis of thermal imaging method for landmine detection using microwave heating[x] | Laboratory tests, heating and cooling | 2001 |
| Land mine detection in bare soils using thermal infrared sensors[xi] | Ground water/moisture time of day/night (diurnal cycle) | 2002 |
| CNN-based 3D thermal modeling of the soil for antipersonnel mine detection[xii] | Numerical modelling, deep learning | 2002 |
| Detecting and locating landmine fields from vehicle and air-borne measured IR images[xiii] | Image processing, deep learning | 2002 |
| Image Processing-Based Mine Detection Techniques: A Review[xiv] | Image processing, deep learning | 2002 |
| Thermal Analysis of Buried Land Mines Over a Diurnal Cycle[xv] | Time of day/night (diurnal cycle) | 2002 |
| Littoral Assessment of Mine Burial Signatures (LAMBS) – Buried Land Mine/Background Spectral Signature Analyses[xvi] | Sensors, spectral signatures, sand, soil, weather and environment | 2003 |
| Fusion of polarimetric infrared features and GPR features for landmine detection[xvii] | Sensor fusion | 2003 |
| Effects of Thin Metal Outer Case and Top Air Gap on Thermal IR Images of Buried Antitank and Antipersonnel Land Mines[xviii] | Numerical simulations | 2003 |
| Soil effects on thermal signatures of buried nonmetallic landmines[xix] | Soil and environment | 2004 |
| Controlled field experiments of wind effects on thermal signatures of buried and surface-laid landmines[xx] | Impact of wind | 2004 |
| A controlled outdoor test site for evaluation of soil effects on landmine detection sensors[xxi] | Outdoor laboratory design | 2004 |
| A review of satellite and airborne sensors for remote sensing based detection of minefields and landmines[xxii] | Airborne sensors on manned aircraft, ground sign indicators | 2004 |
| Experiments of thermographic landmine detection with reduced size and compressed time[xxiii] | Laboratory heating tests | 2004 |
| Improved Thermal Analysis of Buried Landmines[xxiv] | Mathematical modelling & deep learning | 2004 |
| Parameterisation of non-homogeneities in buried object detection by means of thermography[xxv] | Laboratory tests | 2004 |
| DSTO Landmine Detection Test Targets[xxvi] | Dummy/surrogate landmine design | 2005 |
| Stand-off Thermal IR Minefield Survey: System concept and experimental results[xxvii] | Real minefield data, deep learning | 2005 |
| Strength of landmine signatures under different soil conditions: implications for sensor fusion[xxviii] | Complexity of soil properties | 2005 |
| Analysis of a thermal imaging method for landmine detection using heating of the sand surface[xxix] | Surface heating | 2005 |
| Thermal infrared identification of buried landmines[xxx] | Soil, sensors, modelling | 2005 |
| Numerical and Experimental Investigation of Thermal Signatures of Buried Landmines in Dry Soil[xxxi] | Soil and sensors | 2006 |
| Finite-Difference Methods and Validity of a Thermal Model for Landmine Detection With Soil Property Estimates[xxxii] | Sophisticated modelling, including the use of real minefield data from [3] | 2007 |
| Image processing of landmines[xxxiii] | Sensor capabilities for route clearance | 2007 |
| Heat Transfer for NDE: Landmine Detection[xxxiv] | Deep learning | 2007 |
| A thermal infrared hyperspectral imager (tasi) for buried landmine detection[xxxv] | Manned aircraft deployment of sensors | 2007 |
| Signature Evaluation for Thermal Infrared Countermine and IED Detection Systems[xl] | Computer simulations | 2008 |
| Modeling of TNT transport from landmines: Numerical approach[xxxvii] | Simulations, transport of landmine chemical signatures | 2009 |
| FPGA computation of the 3D heat equation[xxxviii] | Hybrid hardware/software, infrared thermography | 2010 |
| Detection and characterization of buried landmines using infrared thermography[xxxix] | Image processing, numerical modelling, heat equation | 2011 |
| Passive infrared technique for buried object detection and classification[xl] | Simulations & numerical modelling | 2011 |
| Role of moisture and density of sand for microwave enhancement of thermal detection of buried mines[xli] | Modelling & influence of ground moisture/water content | 2012 |
| Remote detection of buried land-mines and IEDs using LWIR polarimetric imaging[xlii] | Sensor design | 2012 |
| Soil moisture and thermal behavior in the vicinity of buried objects affecting remote sensing detection: Experimental and modeling investigation[xliii] | Soil moisture, temperature transfer and environment | 2013 |
| Experimental Validation of an Active Thermal Landmine Detection Technique[xliv] | Heating tests and laboratory design | 2014 |
| Buried and Surface Mine Detection From Thermal Image Time Series[xlv] | Time of day/night (diurnal cycle), deep learning | 2017 |
| Diurnal Thermal Dormant Landmine Detection Using Unmanned Aerial Vehicles[xlvi] | Time of day/night (diurnal cycle), small drones, surrogate objects | 2018 |
| Multi-Temporal IR Thermography For Mine Detection[xlvii] | Time of day/night (diurnal cycle) | 2019 |

**Table 2.** Table representing a summary of twenty years of research using thermography to locate buried landmines.

Storyboards, goals, or outdoor laboratory tests with irrelevant buried objects tested in completely different weather and geophysical environments from actual field locations do not prove that you could employ the same methods and find buried landmines in specific post-conflict locations. Field data that holds up to scrutiny is needed to provide confidence in the real world.

A third red flag involves preparedness so as not to duplicate previous research. Questions to ask include

- Has a comprehensive literature review been performed?
- What can researchers learn from previous efforts and how can these be incorporated to further knowledge?
- Have researchers worked in the field? Can someone be an “expert” and innovate without ever visiting a minefield?

Understanding practical real-world requirements and challenges is essential. How is research novel? In what ways can it overcome problems where similar previous research failed to reach field implementation? How transferrable are findings from pre-testing at outdoor laboratories to a particular post-conflict location? Visiting minefields helps researchers achieve a practical understanding of what the real world looks like. Many complex variables are actively at play, and omitting just one can result in a major research floor. Minefield visits can reveal quirks associated with the types of contamination present: the terrain, natural environment, and weather conditions in a specific location—these may not be clear from a desktop study. Claims are sometimes made that a certain research project will revolutionize HMA, but can this be said without practical empathy regarding how demining and survey staff work in each country, analogous to the phrase, “walk a mile in his shoes?”

## GARBAGE IN, GARBAGE OUT?

Popular topics currently include the use of drones, and/or automated data processing, often both together. Computer algorithms need comprehensive training data to be effective, often thousands of data points as a minimum. Without data from real minefields, one could ask if the output might follow the old computing saying “garbage in, garbage out,” particularly if data does not contain accurate landmine anomaly signatures. How could one defend the validity of outputs without any ground truthing under actual field conditions? See the second flag in this regard.

## CONFIDENCE IS ESSENTIAL IN A RISK-BASED CULTURE

And finally, no matter how sophisticated the research, can there be proof without field trials and validation? How can researchers be sure they have not missed a variable that renders their work untenable? Theory and hypothesis stacked upon theory and hypothesis does not mean that research will work in actual field conditions. Legacy minefield data is the end point, or perhaps it should be the starting point?

Therefore, the importance of *real* fieldwork, the significance of undergoing a literature review before starting your own research, and the need for researchers to work in conjunction with HMA operators are all essential, not only to those working in HMA, but—more importantly—to the post-conflict communities the sector strives to help.

Pre-requisites for research projects should include the following:

- Researchers meet with HMA operators and MACs to produce a list of the most important priorities for an individual country.
- Provide funding for an HMA technical adviser to help mentor a project.
- Visit the field during initial scoping stages of each project and report back regarding how real-world conditions will affect methodology and to determine where field trials will take place.
- Concentrate on specific landmine models and practical HMA operating requirements.
- Implement a feedback mechanism to gain HMA scrutiny and peer review regarding if research proposals are novel, practical, and have the potential for real-world impact.

Ideally, donors and research councils should mandate the pre-requisites mentioned before granting funding and assess projects based on practical outcomes for affected communities, post-project completion.

The only way to provide confidence for such a risk-averse sector such as HMA and to increase the uptake in the use of IR thermography in arid environments is with solid proof, which has been very light over the last two decades. Perhaps the impact of this editorial might be to stem lightweight approaches that continue today, foster practical collaboration with HMA actors, and divert energy toward capturing real minefield data.

*See endnotes page 64*

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John Fardoulis is a scientist, remote-sensing practitioner, aerospace engineer, and “methodology designer.” He was the specialist in small drone research, fieldwork, and training on the HI Odyssey2025 Project in Chad. Having worked in HMA, academia, and as a commercial drone service provider (with CAA accreditation in the U.K.), he is in a unique position to add value at every level of research and small drone operations. Fardoulis has a Bachelor of Business from the University of Western Sydney (AU) and a MSc in Aerospace Engineering from the University of Bristol (U.K.).

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**Humanity & Inclusion**

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