The proposed research is motivated by the need to improve the safety and quality of life by developing advanced, economic, and eco-friendly real-time structural health monitoring (SHM) technologies and thereby reducing the cost of replacement, the high overhead, aircraft downtime associated with interventionist manual inspection, chances of failure, and avoiding casualties due to inaccurate monitoring of the modern Defence, Aerospace, Aeronautic, Automotive, and Marine structures, made of advanced composites (sandwiches and laminates).
These advanced composite structures (ACS) combines the highly desirable properties of effective acoustic-insulation, lightweight construction, fire-resistance, high energy-absorption capability and high strength-to-weight ratios. But, various loading and operational circumstances like- hazardous environmental conditions, specialized construction requirements, cyclic loading, aging, and foreign object impact can lead to various types of damage and/or discontinuities (such as, localized inhomogeneity, interfacial-debonding, fatigue-crack, fibre/matrix-cracking, breathing-crack, kissing-disbonds, amongst others) which can significantly jeopardize the safety and integrity of the overall structural assembly. Identification and mitigation of such hidden damage/discontinuities in these structures are of urgent necessity.

Hence it is crucial to ensure the operational health of these structures in safety-critical engineering applications. Ultrasonic guided wave (GW) propagation and acoustic emission (AE) based technique has been shown to be effective in detecting damages in experimental laboratory scale structures (both metallic and composites) based on changing signal characteristics and arrival time. However, the urgent scientific challenge is to provide a robust solution to the ill-posed inverse problem of mapping the piezoelectric transducer (PZT) induced GWs and damage-induced AE signal characteristics to the location and type of damage in operational distributed structural systems in real-time. The multidisciplinary nature of the problem, including the physics-based understanding of the effect of linear and non-linear type of damage responses on ultrasonic GW propagation, computational studies of parametrized models of wave propagation in ACS with multiple damage regions and the inverse identification of damage metrics linked to in-situ AE signal data under significant operational and system-level uncertainty, requires an investigation into a multilevel, hierarchical and holistic framework of damage detection that cascades and assimilates relational damage metrics across multiple models as well as the data-driven inverse identification stages. This is precisely the objective of the project being proposed here.

The project would focus on a two pronged approach – investigation of robust real-time sensing algorithms on one hand and model-informed classification/ characterisation of damage based on calibrated parametrised baseline systems on the other hand. A 2D semi-analytical elastodynamic model will be developed for rapid calculation of far-field time-domain solution for GW propagation in thick (thickness > wavelength) and general ACS to obtain a theoretical time-history response and dispersion characteristics of propagating GW signals. The surface motion will be calculated for both narrowband and broadband excitations and compared with those obtained from finite element model in ABAQUS, for cross-verification. It is an aim of this project to explicitly bring within its purview the Bayesian probabilistic modelling of epistemic (lack of knowledge, controllable) and aleatoric (inherent, uncontrollable) uncertainties around the predictive models and ensemble of experimental data which constitute the active SHM framework.

Smart sensor networks (such as- PZTs, AE-sensors, laser-scanner, thermograph-scanner) will be triggered (based on a signal threshold) and finite windows of filtered synchronised signals would be collected/monitored from the ACS subject to operational loads and will be employed for the real-time AE generation/reception in experimental specimens. Another key focus of the research would be on advanced algorithms for identification of damage characteristics (location and nature) in real-time using a probabilistic Bayesian inversion framework. This is a key area of challenge for this technology where obtaining reliable damage indicators from the AE signals is significantly under-researched. The probabilistic estimation of the smart sensor data-based damage metrics in the presence of uncertainties would help to translate the assessed damage parameters into plausibility/severity of damage and urgency of mitigation.