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Investigating the Performance of Explosives Manufactured by
Alternative Techniques

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Abbreviations

AM	Additive Manufacturing
AMEX	Additive Manufactured Explosives
AMTEM	Additive Manufacturing Techniques for Energetic Materials (EDA Project)
ANSYS	Analysis System (Engineering Simulation Software)
CAE	Computer-Aided Engineering
CL-20	Hexanitrohexaazaisowurtzitane (High-energy explosive compound)
DIW	Direct Ink Writing
EDA	European Defence Agency
ESD	Electrostatic Discharge
FDM	Fused Deposition Modelling
HE	High Explosives
HMX	High Melting eXplosive (also known as Octogen)
IM	Insensitive Munitions
MoD	Ministry of Defence (UK)
RDX	Research Department Explosive (Cyclotrimethylenetrinitramine)
SLA	Stereolithography
SMART	Specific, Measurable, Achievable, Relevant, Time-bound (objectives framework)
SPIFFY	Synchronised Planar Initiation for Flyer Impact (test method)
STL	Stereolithography (file format for 3D models)
TRL	Technology Readiness Level
UK	United Kingdom
UV	Ultraviolet
USA	United States of America

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1. Introduction / Aim and Objectives

This project investigates whether Additive Manufactured (AM) explosives can replicate the performance, reliability, and safety of traditionally produced High Explosives (HE). This is a key challenge as AM technologies continue to develop within the defence sector. The aim is to assess the feasibility of AM explosives by comparing their structural properties, energetic output, and safety characteristics with those of conventional explosives. The project will evaluate explosive formulations, manufacturing consistency, and sensitivity, with particular attention to safety standards and Insensitive Munitions (IM) compliance.

The value of this project lies in the growing interest from defence organisations in AM as a means of improving design flexibility, reducing material waste, and enabling safer production environments. For the project to be successful, it must deliver a focused technical comparison supported by safety analysis and regulatory awareness. The final deliverables will include a detailed literature review, a critical feasibility assessment, and a set of conclusions and recommendations regarding the suitability of AM for HE applications.

SMART Objectives	
1	Synthesise findings from the literature review into a critical summary of AM techniques, materials (e.g. CL-20, HMX), and their potential advantages and limitations in HE applications by August 2025.
2	Compare performance characteristics (density, sensitivity, detonation properties) of at least two AM explosives against traditional formulations using secondary data by September 2025
3	Develop and run a basic CAE model of an AM explosive geometry to simulate detonation effects or stress distribution, with initial results by November 2025
4	To assess regulatory, safety, and ethical concerns, including IM compliance, production hazards, and integrate this into the feasibility section by December 2025.
5	To deliver a critical feasibility assessment and final report that evaluates whether AM explosives are a viable and safe alternative to traditional methods, with conclusions and recommendations written by early February 2026.

Table 1 - SMART Objectives

2. Background / Literature Review

This major project, “Investigating the Performance of Explosives Manufactured by Alternative Techniques”, explores the potential of AM technologies, commonly referred to as 3D printing, for fabricating HE components. This review evaluates current academic and defence literature to contextualise the proposed work.

Several studies have examined the application of AM to Energetic Materials, often with a focus on shaping performance and energy density. Sichuan University of Science and Engineering conducted a comparative review of AM methods, identifying binder jetting and Direct Ink Writing (DIW) as viable for printing explosives such as HMX and CL-20 with acceptable sensitivity levels and strong detonation properties [1]. However, their work remains theoretical and lacks experimental validation, particularly at larger scales.

North University of China developed a CL-20-based ultraviolet-curable explosive ink using DIW, achieving dense (1.80 g/cm^3) high energy prints with reduced sensitivity and favourable combustion characteristics [2]. While the study slightly highlights improved safety and mechanical integrity through UV curing, it did not explore long-term ageing, regulation, or Insensitive Munitions (IM) compliance.

Los Alamos National Laboratory utilised PolyJet printing to fabricate miniature plane-wave lenses and demonstrated precise detonation control using SPIFFY testing, achieving arrival-time jitter below 20 ns [3]. Although their work demonstrates the high accuracy and potential of AM in wave shaping, it was limited to small scale tests and did not address scalability or operational deployment; however, the approach was noted as a valid and effective method for academic investigation, making it highly relevant to feasibility studies such as this major project.

Fritz’s earlier work on traditional explosive lens design introduced inert plastic inserts for wave shaping. Although not AM specific, it offered conceptual value for future 3D-printed lens designs [4]. The use of inert wave shapers may aid in improving safety and reducing the reliance on high-sensitivity materials during prototyping.

Beyond academia, the defence sector has shown strong interest in AM for explosives, with support from the UK Ministry of Defence and US Department of Defence. Cranfield University and several Chinese institutions have also contributed research.

Strategic programmes like AMTEM and EDA initiatives highlight growing international focus, though most remain at low Technology Readiness Levels and lack widespread validation [5].

While the technical potential of AM for high explosives is well recognised, the literature reveals a clear lack of detailed safety analysis, with limited focus on hazard mitigation, IM compliance, or regulatory control. This project seeks to address these gaps by evaluating safety, regulation, and long-term reliability as part of its feasibility assessment. Ethical concerns, such as proliferation and misuse, are also largely overlooked. Despite the clear benefits of AM, such as design flexibility, waste reduction, and complex geometries, significant challenges remain around scalability, validated safety frameworks, and responsible implementation.

3. Project Design

This project will use a combination of qualitative input and technical modelling to assess the feasibility of AM explosives. Interviews with experienced explosives professionals will be carried out to gain insight into practical challenges, safety concerns, and the applicability of AM technologies in the defence sector. Their expertise will help validate assumptions and identify limitations not fully addressed in current literature.

AM methods such as Fused Deposition Modelling (FDM), Direct Ink Writing (DIW), Binder Jetting, and Stereolithography (SLA) will be examined in detail. These processes are central to the study, as the project revolves around their potential use in fabricating HE. Where appropriate, simulations or trial models will be created to assess their suitability.

Bambu Studio will be used for 3D modelling and slicing, as it is a readily accessible tool for visualising and preparing AM geometries. While this project will reference industrial AM processes, it should be noted that the exact software used in high-grade defence applications is not known. Computer-Aided Engineering (CAE) tools such as SolidWorks, ANSYS, or Abaqus may support modelling or stress analysis. Excel will be used for systems engineering tasks. Safety analysis software may be experimented with. Data will be analysed thematically, with comparisons drawn across performance and safety metrics.

4. Resources / Planning

A flowchart [Fig.1] has been developed to outline the structure and progression of the project. Given the broad research potential of the topic, there is flexibility in how the project can evolve. Ideally, the inclusion of a practical trial would significantly enhance the report; however, limited funding may restrict this, making CAE-based simulation a more feasible alternative. Printing with a non-energetic filament that mimics the properties of high explosives is a safe and practical way to demonstrate print accuracy and structural fidelity. If circumstances permit, the opportunity to work with energetic materials would provide valuable insights and strengthen the project's technical depth.

Deliverables will include CAE simulation results, an inert 3D-printed model, a safety assessment and a final feasibility discussion.

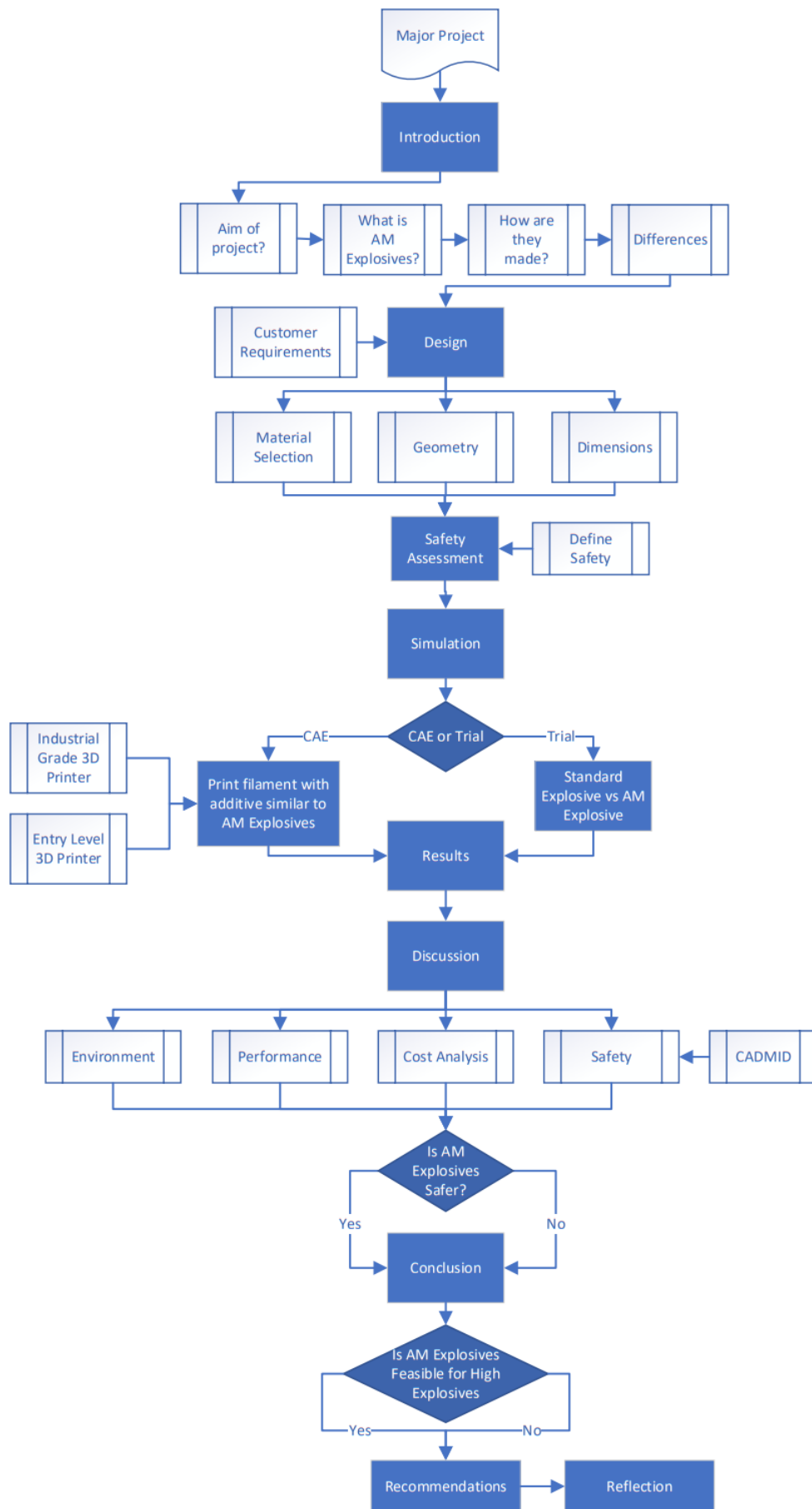


Figure 1 - Major Project Flowchart

5. References

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7. Appendix

Link	Author	Title	Methodology	Materials	Conclusion/Results	Limitations/Gaps	Relation	Safety/Regulatory	Reliability
Link 1	B.Tan, N. Liu	3D Printing for Explosives and Propellants Applications	Literature survey & comparative assessment of AM techniques (FDM, DIW, binder jet, SLA).	CL-20, HMX/TNT, Al/AP composites, polymeric binders.	Demonstrates feasibility of printing energetic materials (CL-20 composites); achieves high-density; noted reduced sensitivity.	Mostly theoretical; lacks full-scale explosive tests; limited practical validation.	Directly aligns: Reviews advanced AM methods for explosives.	Highlights sensitivity reduction; minor mention of sympathetic detonation; lacks regulatory detail.	High: depends heavily on cited literature, not own experiments.
Link 2	S. Kong, D.-j. Liao, Y.-m. Jia et al	Performances and direct writing of CL-20-based ultraviolet curing explosive ink	- Developed UV-curable ink containing CL-20 - Used direct writing printing & UV polymerisation	- CL-20 (HNIW) - Ultraviolet curing polymer -Unsaturated polyester	Uniform, high-energy structures (1.80 g/cm ³) with reduced sensitivity and good performance; improved safety and precision via UV curing.	Did not explore long-term stability, environmental ageing, or full detonation behaviour in large-scale trials	Directly aligns: Evaluates feasibility of 3D printing (direct writing) of CL-20-based explosive ink	Improved safety over raw CL-20 due to matrix embedding; no discussion of full-scale regulatory compliance or IM standards	High: Demonstrated stable formulation and effective curing, but lacks full-scale repeatability validation
Link 3	J. P. Lichthardt, B. C. Tappan, P. R. Bowden, M. W. Olinger, D. L. McDonald	A simple 3D printed plane wave explosive lens based on Fritz parameters	- PolyJet additive manufacturing (AM) - Small-scale plane-wave lens (PWL) - SPIFFY shock initiation testing. - J. Fritz Parameter - Streak camera	- PBXN-110 - Primasheet 1000 - PBX 9407 - Glycidyl azide polymer (GAP) binder	Produced high-resolution (~10s µm) wave shapers; reliable planar shock waves; significantly reduced cost/time; enabled complex lens geometries.	- Small-scale lens demonstration only - No live full-scale detonation tests	Directly aligns: Uses additive manufacturing to create precise, cost-effective explosive wave lenses	- Focuses primarily on lab-scale safety, casting explosives, and small-scale test containment. - - No regulation discussion	Moderate: Reliable in small-scale SPIFFY tests (<20 ns jitter), but unverified at larger scales.
Link 4	J.N. Fritz	A Simple Plane-Wave Explosive Lens	Designed a plane-wave lens using iterative detonation timing corrections; tested physical models and used 2D code simulations (MACRAME).	C-4 (donor), PMMA (inert wave shaper), PBX-9501 (acceptor)	Achieved smooth wave fronts with <50 ns deviation after first iteration; demonstrated reliable shaping using inert plastic insert	Not an AM study; no fabrication method beyond basic machining; limited to planar wave geometry (not full 3D lenses); no scalability discussion	Partially aligned: Explores simplified lens geometry and wave-shaping using inert inserts, relevant to shaping concepts in AM, but does not involve additive manufacturing techniques	Safety is considered through inert materials; lens design avoids fragments; lacks regulatory depth or IM compliance discussion	High experimental repeatability: iterative tuning method proved effective for lens timing and wave shaping
Link 5	European Defence Agency (EDA)	Additive Manufacturing Techniques for Energetic Materials: New Opportunities	Multi-phase R&D project: reviews, material selection, printing & testing of charges; hybrid AM-	Inert and energetic materials (not specified)	AM enables novel geometries, reduced costs for short runs, improved precision and scalability; supports future EU	Ongoing research; low TRL stage; no detailed formulation or full safety/performance	Directly aligns: Focused on developing AM techniques for energetic materials in warheads and propellants	Explicitly targets safety within AM environments; considers IM compatibility and	Moderate: Promising, but currently early stage; full-scale demonstrators and performance data yet to be validated

		for Defence Applications	conventional integration.		capability in 3D-printed energetics	data publicly available		future regulation needs	
Link 6	Xue H, Zhou Q, Xiao C, Huang G	Perspectives on Additive Manufacturing for Warhead Applications	Review-based study; outlines technological gaps, current AM state, and hypothetical applications in warheads.	TNT/nano HMX melt-cast explosive; CL-20	Major design freedom, part count reduction, mass efficiency, and faster prototyping; supports novel warhead concepts (e.g. adaptive, scalable, and complex fill geometries).	No experimental results; mostly conceptual; lacks specific material formulations or real detonation testing.	Directly aligns: Explores AM benefits and challenges for warhead and explosive system design, especially complex geometries.	Identifies critical need for safety protocols in AM energetic processing; acknowledges IM and ESD handling gaps.	Very High: Strong conceptual potential with highly relevant insights; practical reliability expected to improve as AM processes mature.