

Digitalising Safety Traces for Aircraft-Launched Countermeasure Flare Trials



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Acronyms

AES	Accident Event Sequence
ALARP	As Low As Reasonably Practicable
APPTES	Air Platform Protection Test & Evaluation Squadron
ASD	Aircraft Self Damage
ASEMS	Acquisition Safety and Environmental Management System
ASWC	Air and Space Warfare Centre
AWR	Air Weapons Range
CM	Countermeasure
CompSci	Computer Science
DAS	Defensive Aids Suite
DE&S	Defence Equipment and Support
DCoP	Defence Code of Practice
DIO	Defence Infrastructure Organisation
DSAT	Defence Systems Approach to Training
Dstl	Defence Science and Technology Laboratory
EAD	Expendable Active Decoys
FFA	Functional Failure Analysis
FMEA	Failure Modes and Effects Analysis
ILS	Integrated Logistics Support
KSA	Knowledge, Skills, and Attitudes
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Repository
M&S	Modelling and Simulation
MEB	Maximum Energetic Boundary
ML	Machine Learning
MOD	Ministry of Defence
MTS	Management of Training System
NAWS	Naval Air Weapons Station
RAF	Royal Air Force
RtL	Risk to Life
RTS	Release To Service
SbD	Secure by Design
SME	Subject Matter Expert
SoR	Statement of Requirements
TD-Info	Team Defence Information
TMO	Trial Management Officer
T&E	Test and Evaluation
TNA	Training Needs Analysis
WOW	Weight On Wheels

Executive Summary

1. This paper is the culmination of collaboration between Team Defence Information (TD-Info) and five of its member organisations: AtkinsRéalis, Babcock, TMS Support Solutions, Flare Bright and Chemring. The paper seeks to articulate the problems currently faced by Commands in the Ministry of Defence (MOD) with calculating the safety traces necessary to enable the Test and Evaluation (T&E) of aircraft-launched countermeasure (CM) flares and suggests ways forward to optimise how safety traces are calculated, automate the process, and present the information quickly to the user. The possible safety trace solutions are summarised by using a holistic approach. This methodology consists of optimising how the flare's expected trajectory post-launch is modelled, using digital tooling to automate the calculations and generating an informative display of the safety trace outputs. This is underpinned by a safety analysis of the failure modes to determine worst-case scenarios that the safety trace must consider. The digital safety trace tool will require through-life support and be Secure by Design (SbD). It is recommended that MOD commissions a digital safety trace tool to facilitate continued T&E of aircraft-launched CM flares. This paper aims to facilitate the commissioning of a digital safety trace tool by energising and expediting the procurement process to ensure that a fit for purpose, 'right first time' solution is provided.

Introduction

Background

2. A safety trace is defined as: *"a detailed analysis and model designed to predict the flight trajectory and thus ground impact locations of air-launched flares and their components. The safety trace involves considering various factors such as ejection forces, aerodynamic forces, platform dynamics, and wind conditions. It also includes a failure mode analysis to identify potential hazards from flare components. The primary goals of a safety trace are to minimise risks to second and third parties during flare firings and to ensure that flares and their components always fall within the range boundary or other designated safe zones."* [Ref A]

3. For all UK flare dispensing activity, a flare safety trace is required to provide assurance that any risk of injury to a third-party or damage to property is suitably understood and managed. The purpose of an aircraft-launched CM is to protect the aircraft from an incoming threat. CM flares typically exude large amounts of heat and/or light energy to counter an incoming heat-seeking or infrared-seeking missile. Aircraft can also launch other types of CM such as Expendable Active Decoys (EAD) and chaff. This paper's scope is focused on aircraft-launched flares to counter infrared threats. Flares are designed to burn up in mid-air, with only non-combustible components such as endcaps designed to strike the ground. The safety trace must also account for functional failures of the CM flare, such as non-ignition and flare break up. The worst credible case gives the Maximum Energetic Boundary (MEB) which is taken to be the boundary of the safety trace.

4. [TD-Info](#) is a collaborative association that informs defence information policy and pilots new ways of working. TD-Info's Digital Twin workstream has been active since 2019, has attracted 650+ members, and has explored the introduction of a synthetic environment to support frictionless access of data at appropriate authorisation. The ideal future solution is an ecosystem of Digital Twins across the entire Defence enterprise which enable timely and useful decision, design, and capability support.

5. This is the fourth iteration White Paper output of the TD-Info Digital Twin Community of Practice and an illustration of previous investigations being developed further: Section 5 of the third white paper [Ref B] recounts a visit to MOD Aberporth Range, where the challenges around T&E of aircraft stores was made apparent. As evidenced within the completed investigation, this task has been created as a direct result of its findings and continues the journey to demonstrate practical Digital Twin solutions.

Understanding the Problem

6. MOD has an ongoing requirement to trial new CM flares – as threats to aircraft evolve, so must the aircrafts' Defensive Aids Suite (DAS). These trials are organised by HQ Air and Space Warfare Centre's (ASWC) Air Platform Protection Test and Evaluation Squadron (APPTES) at UK and overseas ranges such as Defence Infrastructure Organisation (DIO) Donna Nook Air Weapons Range (AWR), RAF Spadeadam and Naval Air Weapons Station (NAWS) China Lake. During trials, CM flares are launched at a specified location (Test Point), with the aircraft flying straight and level on a specified heading, airspeed and altitude.
7. The current method of calculating the safety traces causes various issues:
 - a. The current rectangular-shaped safety traces are unrealistic and may be too large to generate a credible safety trace boundary.
 - b. The safety traces take a long time to calculate because they are produced by a single Subject Matter Expert (SME) from Defence Science and Technology Laboratory (Dstl), who has a large workload and is currently stretched across various projects. This results in long lead times (often extending into many weeks) and difficulty arranging CM flare trials.
 - c. Safety traces cannot be quickly recalculated to account for changing circumstances during the trial resulting in aborted trials, with the potential associated effects of significantly delaying operational advice to the Front Line or delaying the release to service to new flares into service. In the event of a delayed or cancelled trial, there are significant associated costs in repeating the T&E event.
 - d. Once the safety trace characteristics have been calculated, the safety trace must be manually plotted onto a paper chart, further increasing the time taken to produce the safety trace. This method also introduces increased potential for human error.
 - e. CM Flare technology is evolving. Performance improvements (e.g. aerodynamic flares or thrusted flares) may not have been modelled previously. Modelling new flare types or incorporating design changes to existing flares adds significant time and cost in calculating the safety trace.
8. The purpose of digitalising the safety trace is to mitigate or eliminate these issues. This paper focuses on safety trace utility during APPTES T&E events only. A digitalised safety trace tool could be expanded to form part of the safety cases and Release to Service (RTS) for operational use of CM flares should a Delivery Team commission a version of this tool for that specific purpose.

Current Method of Generating Safety Traces

9. The Digital Safety Trace Tool Statement of Requirements (SoR) [Ref A] suggests the current worst-case scenario is a standard flare that is ejected correctly but does not ignite, that is, it will travel the furthest because it is ejected from the aircraft but does not burn up in mid-air leading to the full mass of CM flare material striking the ground. However, more detailed modelling must be performed to account for aerodynamic and thrusted flares (including their non-combustible tungsten nose cap). So, any safety trace solution must include the MEB of the flare type in use.
10. The legacy method of calculation generated an oblong-shaped safety trace whose dimensions were specified by two calculated co-ordinates, Max_x and Max_y . Dstl provided APPTES with tables of Max_x and Max_y values corresponding to certain input variables. This gave APPTES some scope to recalculate safety trace sizes using linear interpolation when input variables needed to change. However, this method was slow and could not react to changes in circumstances shortly before trials took place. Once APPTES had conducted the linear interpolation and finalised the safety trace coordinates, the APPTES Trial Management Officer (TMO) manually plotted the safety trace onto a paper chart and 'eyeballed' the safety trace dimensions onto an online mapping package for inclusion in the trial documentation pack. This process was inefficient and could be prone to errors.

11. In the legacy safety trace algorithm, each Max_x and Max_y value assumes a dead-straight direction of travel of the CM flare in either the forwards or sideways direction. This methodology is unrealistic. In reality, the flare will be unable to reach Max_x and Max_y concurrently (i.e. the four corners of the oblong). More accurate calculations based on modelling and simulation (M&S) should result in a lozenge or oval-shaped safety trace area, as illustrated in Figure 1. This paper refers to the current methodology as the 'Physics Approach' and suggests two credible alternatives: the 'Maths Approach' and the 'Computer Science (CompSci) Approach' for optimising the size and generating a representative shape of resultant safety traces.

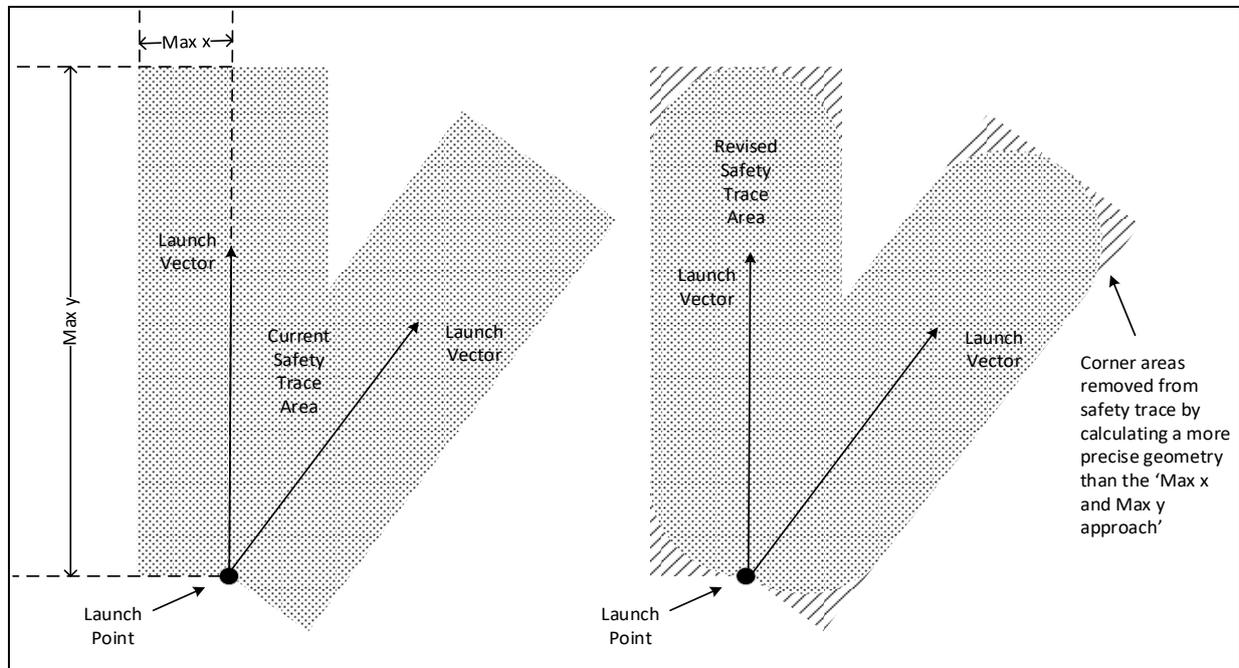


Figure 1: M&S optimisation of safety trace geometry¹

Available Approaches for Calculating Safety Traces

The Physics Approach

12. The Physics Approach defines aerodynamic and mechanics models and benefits from its simplicity; however, this will produce only an approximation to the real world, so an additional safety margin is necessary, leading to conservatively-sized² safety trace areas.

13. The Physics Approach is a validated and approved methodology that could readily be replicated by a physics SME from industry or academia. This would alleviate the workload on a Dstl SME, but would not solve the issue of safety traces being conservatively-sized.

The Maths Approach

14. The Maths Approach would result in a selection of an optimal approach or combination of approaches from within the mathematical realm. Rather than confining the algorithm to the use of classical mechanics, the maths SME(s) may choose to approach the task from an adjacent subject area such as fluid flow modelling. This approach would most likely include the use of computer simulation software.

15. The Maths Approach would require SMEs from within industry or academia. This is a growing domain and MOD may choose to utilise or engage existing research communities such as the [A4i](#)

1. Most military aircraft carry multiple CM flares – i.e. a full DAS rather than a single flare. For simplicity, Figure 1 shows two flares as an example, to show that the overall safety trace is made up as an aggregation of the safety traces for each individual flare. For simplicity, a perimeter is often drawn around the individual oblongs, resulting in a circular or fan-shaped safety trace. Rather than creating an irregular safety trace, the safety trace radius is often taken to be the length of the longest oblong.

2. i.e. too large.

[grant programme](#) or the [Maths KE Hub](#) to obtain the necessary expertise to solve the safety trace problem.

16. Adoption of the Maths Approach would require validation from MOD SMEs, most-probably from within Dstl, and approval from MOD senior stakeholders. However, the algorithm behind the methodology would be relatively simple and auditable. Validating this proposed approach would likely be straightforward.

The CompSci Approach

17. The CompSci Approach would utilise the computing power available through Machine Learning (ML) and would aim to model every conceivable trajectory of every variable of CM flare failure. Through optimisation techniques, the CompSci Approach would then deliver an accurate model of the safety trace, ensuring that it took a realistic form and was appropriately-sized. The CompSci Approach would draw upon the large set of failure mode data generated by a safety technique such as Failure Modes and Effects Analysis (FMEA) and would complement the option for other MOD organisations to adopt the 'risk-based safety trace' concept described in Annex G.

18. Using ML would be a radical change in methodology from the Physics or Maths approaches and would likely complicate validation of the digital safety trace tool. As a result, MOD would need to have confidence that the CompSci Approach with its ML algorithms could be validated and that any safety trace outputs could be checked and assured. This approach would need approval from the relevant MOD stakeholders, including the appropriate Regulator.

19. Wherever performance data from past CM flare trials is available, this should be used as part of the validation of the algorithms behind the digital tool. This data would be particularly useful validating the Maths or CompSci approaches.

Creating a Digital Safety Trace Tool

20. Creating a digital safety trace tool would automate the process of calculating and plotting safety traces. When planning future trials, input variables could be entered into the tool directly, or via an input file that feeds the tool. The tool would calculate the results and automatically plot the resultant set of safety trace coordinates onto a digital map. The tool requires functionality for internal assurance so that the local command chain can check and approve input variables and the resulting safety trace output prior to its use. Further, each approved safety trace output would need to be saved alongside its input variables as an official record for audit purposes.

21. Having such a capability will result in a significant capability improvement in terms of accuracy, brevity and efficiency. It would alleviate the need to specifically employ an SME to calculate each individual safety trace. Since the tool would function on an 'on-demand' basis and would generate the safety trace in near-real time, current long lead times of several weeks for safety trace generation would be reduced to minutes during the trial planning phase. Further, should circumstances change at short notice (e.g. using a different flare type), then the input variables could be dynamically updated (e.g. flare type, aircraft heading, altitude, speed etc.), checked (locally approved) and a new safety trace calculated with minimal disruption to trial planning. Currently, the lack of a valid safety trace can cause the postponement or cancellation of expensive flight trials at short notice.

22. This paper suggests using FME Form to design the process and FME Flow to facilitate its automation, at least for early iterations of the digital safety trace tool. FME's main attraction is its geographic speciality opposed to a more generic Python or other code-based solution. The MOD also has FME software 'in-house' in some areas, so leveraging that expertise could be advantageous. FME could perform the simpler calculations (Physics Approach) using its inbuilt arithmetic calculator. More complex calculations would need to be done outside of FME³ with the

3. Using a COTS M&S tool or code-based solution.

set of coordinates generated from the calculations then being automatically fed into FME, which would plot them on the map.

23. The TD-Info team produced a 'rapid prototype' proof of concept demonstrator in FME to accompany this paper. An indicative output from this rapid prototype is illustrated in Figure 2. It is important to note that the calculations which drove this safety trace are for indicative demonstration purposes only and are not to be used for constructing the real tool. All CM flare and aircraft properties entered were using dummy data, and deliberately did not use input parameters from any specific CM flare or aircraft model. The rapid prototype was merely to demonstrate 'The art of the possible' and show how FME can calculate a set of coordinates and automatically plot a set of coordinates onto a digital map, producing a digital safety trace in minutes rather than weeks. The real tool would have to be built using validated calculation algorithms and would have to be rigorously tested to provide the necessary assurance that it was drawing upon the correct calculations and then displaying those calculations' outputs accurately.



Figure 2: Mock-up Safety Trace zone, with buffers applied based on calculations in FME.

24. Further detail on the proposed FME tool is included in Annex C, including:

- a. Candidate methods of inputting data.
- b. Proposed input parameters:
- c. Geographic information:
 - i. Launch point coordinates.
 - ii. Launch altitude at the launch point.
 - iii. Aircraft heading at the launch point.
- d. Aircraft/ Flare Properties and Configuration:
 - i. Airspeed at launch point.
 - ii. Aircraft type.
 - iii. Launcher fit(s).
 - iv. Flare type(s).

- e. Other variables:
 - i. Maximum wind speed (dependent upon platform).
 - ii. Wind direction (default assumption: wind from all directions - full 360°).
 - iii. Other factor weather conditions.
- f. Workflow type.
- g. Candidate data output methods.

Safety Analysis

Scope of the Safety Analysis

25. This paper's scope covers only the safety trace and not the safety case. It **does not** extend to cover the wider area of CM flare equipment safety cases, aircraft platform safety cases, or aircraft RTS. This paper also only considers the safety traces associated with CM flare trials.

Approach to the Safety Analysis – Functional Failure Analysis

26. APPTES' SoR [Ref A] requested a FMEA to ascertain which components of the flare constitute a valid hazard to 2nd/3rd parties, what represents a reputational risk to the MOD, and therefore what components must be modelled in order to ensure a valid safety trace.

27. FMEA is a bottom-up approach that seeks to identify all reasonably foreseeable failure modes and their effects. It generates a comprehensive list of Accident Event Sequences (AES) of differing severity. Calculating a safety trace using the Physics Approach, and potentially the Maths Approach, does not require the safety analysis to derive an exhaustive list of failure modes/accident event sequences, as the safety trace is geometry-driven by worst credible cases. These worst credible cases will always fall within the safety trace and bound all other cases, as illustrated in Figure 3.⁴ This paper has therefore preceded FMEA by conducting a simple desktop Functional Failure Analysis (FFA), which is one of the approved safety techniques in the Acquisition Safety and Environmental Management System (ASEMS) Toolkit [Ref C]. The FFA has identified those scenarios that result in bounding cases for safety trace calculation.

4. The illustration at Figure 3 is indicative only. The calculated safety trace shape will be dependent upon the input variables and the algorithm employed.

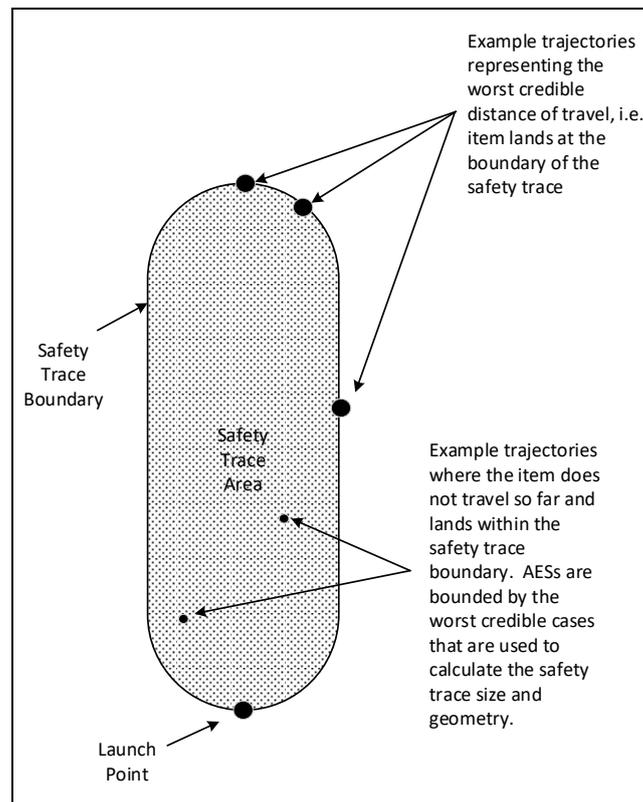


Figure 3: Safety trace illustration showing worst credible CM failure case.

28. To both inform CM flare equipment safety cases and complement detailed M&S, the MOD would retain the option to conduct a full FMEA to inform potential improvements in the accuracy of the digital safety trace output.

Desktop Functional Failure Analysis

29. Formal FFA will be conducted by a specialised team for a specific purpose, so the FFA in this paper (Annex F) is illustrative only. For simplicity, each function and assumption consider only a single CM flare and launcher. In this paper, 'CM flare' and 'launcher' relates to all the CM flares and launchers that make up the DAS.

30. Functions:

- a. Load the CM flare into the launcher with Weight On Wheels (WOW).
- b. Aircraft to carry the CM flare in the launcher to the launch site.
- c. Eject the CM flare from the launcher 'on demand,' at the specified ejection velocity and on a specified vector.
- d. Thruster pellet to ignite at the specified distance from the aircraft (thrustured flares only).
- e. Thruster pellet to burn at the specified rate post-ignition (thrustured flares only).
- f. CM flare payload to ignite at the specified distance from the aircraft.
- g. CM flare payload to burn at the specified rate post-ignition.
- h. Aircraft to jettison any unfired CM flare or carry them in the launcher back to the operating base.

i. CM flare to be unloaded from the launcher if not fired (including misfires and hangups). Aircraft with WOW.

31. The following assumptions should inform the limits and conditions that would be associated with using the digital safety trace tool in practical situations:

- a. CM flare will be launched at the specified altitude (within the specified tolerance).
- b. CM flare will be launched at the specified map coordinates (within the specified tolerance).
- c. CM flare will be launched with the aircraft flying straight and level (within the specified tolerance).
- d. CM flare will be launched with the aircraft flying on the specified heading (within the specified tolerance).
- e. CM flare will be launched only within specified weather conditions, e.g. windspeed and direction (within the specified tolerance).
- f. CM flare will be ejected from the launcher at a specified ejection velocity and on a specified launch vector (within the specified tolerance).
- g. The final version of the digital safety trace tool must be capable of ingesting topographical data to generate a suitably accurate safety trace when being used in regions of uneven terrain. The interim version of digital safety trace tool may be delivered with an assumption of flat terrain to ease the tool's introduction to service.

32. This FFA considers each of the functional failures and their outcomes, providing a solid basis for further detailed risk analysis and definition.

Integrated Logistic Support

33. Integrated Logistic Support (ILS) ensures the supportability of equipment throughout its design, development, service life and disposal. In essence, ILS is a document process that provides the means through which a system (in this case, the digital safety trace tool):

- a. Can be designed for supportability.
- b. Can be maintained and repaired to meet availability and reliability targets.
- c. Can be provided at a minimum whole-life cost.

Delivery of ILS

34. The planning of each ILS element is developed in tandem with the system design effort. Trade-offs between design and supportability elements may be required to develop a digital tool that is affordable, operable, supportable and provided at the lowest life-cycle cost.

35. The most relevant ILS activities to development of a digital tool include:

- a. Design Improvement.
- b. Maintenance Identification (preventative and corrective).
- c. Training and Training Support.
- d. Technical Documentation Development and Support.

- e. Design Interface Integration and Planning.

Computer and Software Resources Support.

Training and Visual Design

A Training Needs Analysis (TNA) can be undertaken to fulfil the bespoke requirements and learning outcomes for trainees, delivering competent operators or maintainers into their organisation as requested by the MOD. APPTES requires a Defence Systems Approach to Training (DSAT)-compliant 'Train the Trainer' solution for the digital tool.

Aligning with Courseware and Media

36. The trainers would possess the knowledge, expertise and understanding of DSAT. This process comprises a well-proven framework including analysis, development, design, delivery and evaluation of success; all of which are key enablers to deliver training to UK MOD personnel and alignment to JSP 822 (Defence Training and Education) [Ref D].

Identifying and Meeting the Training Needs

37. This paper suggests the TNA be conducted in two stages:

- a. TNA Stage 1 – Scoping Exercise.
- b. TNA Stage 2 – Analysis.

38. The TNA will identify the training audience, including APPTES staff, SMEs, end users and maintainers, along with their current Knowledge, Skills and Attitudes (KSA). The TNA process will involve conducting workshops with the training audience and gathering reference information, documentation and other materials. This comprehensive approach will help develop a thorough understanding of the training requirements and how the training device, along with the courseware, can provide an effective training solution. By establishing and delivering clear training objectives (TOs), the training solution will meet the identified training needs. Combining the Management of Training System (MTS) with DSAT activities creates a Training System that meets the mandated DSAT Quality Management Standard.

39. As the Digital Safety Trace platform develops, the DSAT process will enable all those involved in the Analysis, Design, Delivery and Assurance of the training requirement to easily identify and manage elements of the training courseware and media that may need change. This approach is further supported by the modular design strategy that will be implemented to enable training elements to be refreshed as required.

Potential Future Additions

40. As discussed previously, this paper is restricted to the production of digital safety traces for APPTES aircraft-launched CM flare trials. The digital safety trace could be expanded to include other MOD safety trace use cases such as:

- a. Additional safety traces:
 - i. Expanding use of the tool beyond trials to cover aircraft-launched CM flare usage in training or in theatre.
 - ii. The safety trace applied during arming/disarming of the aircraft when it has WOW. This would tackle a safety trace around the aircraft with WOW and its surrounding area. This may help operating bases manage their safety traces.

- b. Additional accident event scenarios for safety cases:
 - i. The potential effect upon the aircraft of premature ignition of the flare, before it has reached a safe separation from the aircraft, resulting in 'Aircraft Self Damage' (ASD).

- c. The safety trace tool could gather data during its use, creating a built-in feedback loop within the broader flare knowledge domain. This loop could track flare performance and integrate the data into a statistical risk model, focusing on worst-case scenarios. By continually updating this model with performance data over time, the tool could enable an evolving risk assessment based on the performance of different flare types.

- d. Link into wider safety cases/RTS and digital twins as part of an overall step forward into a digital and interconnected capability delivery function for the MOD. The tool could function as either an effective example to draw lessons from or a basis for further and differing technical applications of safety and risk modelling.

Conclusions

41. The ongoing production of a safety trace is of paramount importance to APPTES and the wider MOD. It ensures the continued feasibility of CM trials, thereby enabling the continuous evolution of aircraft DAS to effectively counter new and emerging threats.
42. This paper has demonstrated that digitalising the calculation and display of safety traces is both feasible and necessary. The development of a digital tool to calculate and display CM flare safety traces should be swiftly pursued to close the current capability gap.
43. Further, the digital tool could be developed iteratively. Early iterations might use simpler calculations (e.g., the Physics Approach) and include only a limited number of aircraft-flare configurations planned for upcoming trials. This pragmatic approach would allow the tool to be quickly brought into service to support imminent CM flare trials. Future iterations could then expand to include additional aircraft-flare configurations and employ more advanced calculation techniques (e.g. Mathematical and/or CompSci approaches) to optimise the size of safety traces.
44. This paper has been prepared to address APPTES' requirements and has therefore focused solely on safety traces needed to support trials of CM flares. Other MOD organisations use safety traces and the approaches proposed in this paper could also be used to support improvements in how other MOD organisations calculate, display and use their own safety traces.

References

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- G. DSA03.OME. Part 3: Ranges⁵, [DSA03 OME part 3: ranges - GOV.UK \(www.gov.uk\)](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/644443/DSA03_OME_part_3_ranges.pdf).

5. DSA03.OME Part 3: Ranges replaced JSP 403, Handbook of Defence Ranges Safety.

Annex A: Structure of the Flare Landscape and Safety Trace Work

1. There are several organisations across the MOD that are interested in developing a digital safety trace tool including Air Command, Dstl, Defence Equipment & Support (DE&S), ASWC, APPTES and others (Figure A-1). These organisations sit within the CM Steering Group forum and are the intended audience of this paper. Figure A-2 depicts the digital safety trace White Paper working group and details their roles.

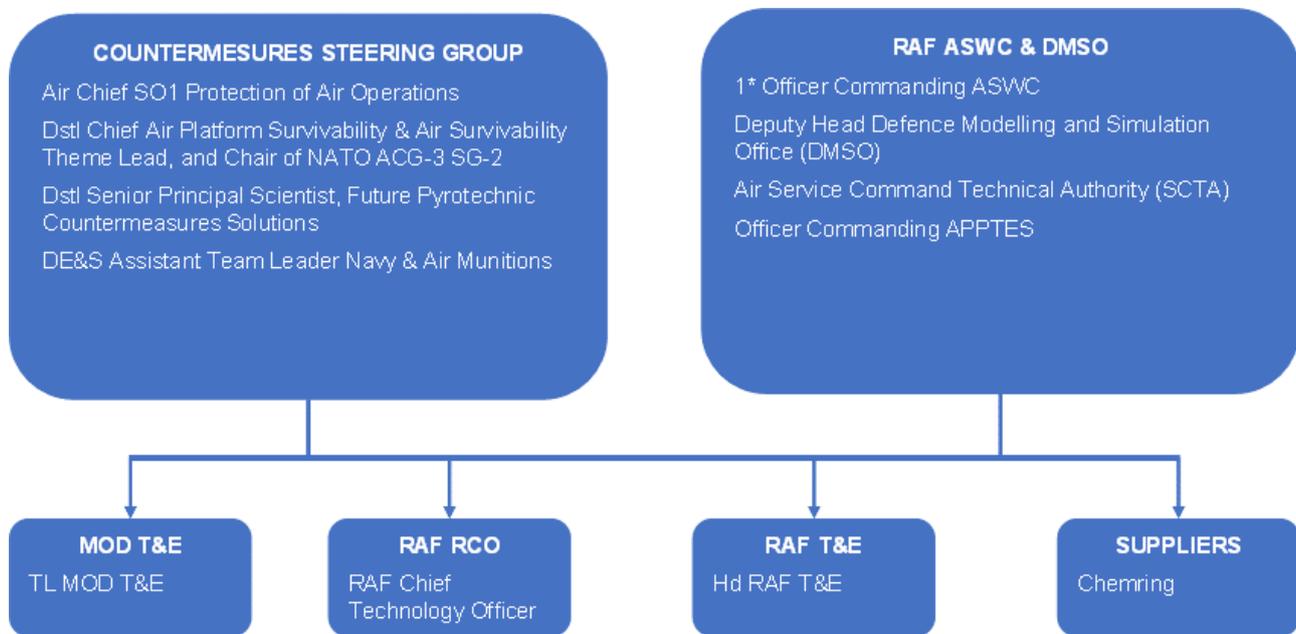


Figure A-1: Stakeholder organisations.

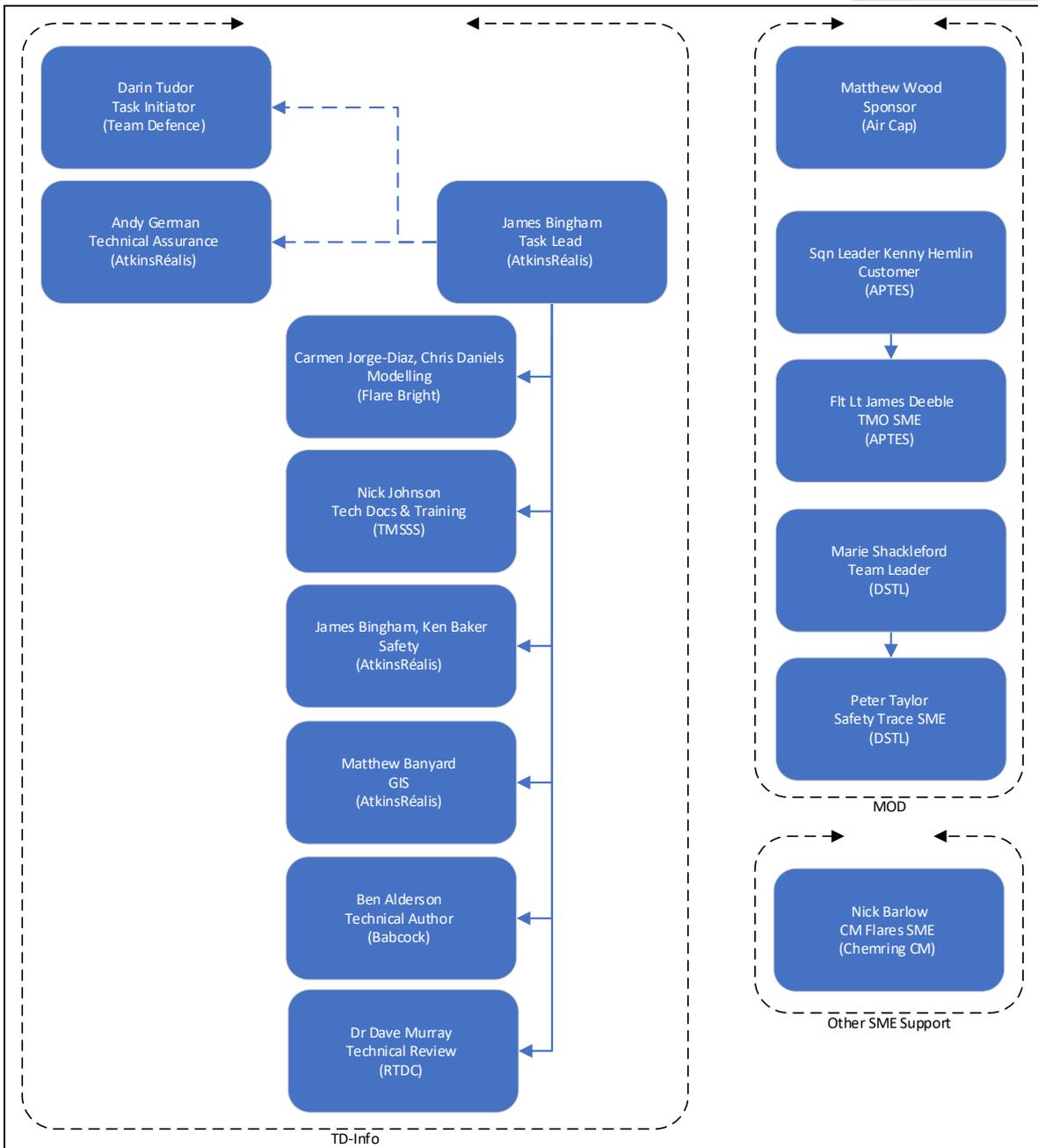


Figure A-2: Contributors and organisations consulted whilst producing this paper.

Annex B: Indicative Digital Safety Trace User Requirements

1. An initial set of potential user requirements for the digital safety case tool has been drafted and is presented in this annex. These requirements could be used to inform the procurement of a digital safety case tool, but should be reviewed and amended by MOD as necessary.

ID		Requirement Text		Requirement Importance
Parent ID	Child ID	Parent	Child	
1.00	1.01	The contractor shall construct a digital tool to enable the user to define a safety trace for an aircraft-launched CM flare by entering the necessary input variables into the tool.	The digital tool shall enable the user to specify the aircraft type (ideally the tool will automatically select the aircraft type based upon the CM flare type, or provide a drop-down list of possible matches from the combinations supplied by MOD)	Mandatory
	1.02		The digital tool shall enable the user to specify the CM flare type (ideally the tool can automatically select the flare type based upon the aircraft type or provide a drop-down list of possible matches from the combinations supplied by MOD).	Mandatory
	1.03		The digital tool shall enable the user to specify the angle of ejection of the flare from the aircraft (ideally the tool will automatically select the angle of ejection based on the user-selected values for aircraft, launcher and CM flare type).	Mandatory
	1.04		The digital tool shall enable the user to specify the mass of the flare (ideally the tool will automatically select the mass based on user-selected values for aircraft, launcher and CM flare type).	Mandatory
	1.05		The digital tool shall enable the user to specify the ejection velocity of the flare from the launcher (ideally the tool will automatically select the ejection velocity based upon the CM flare type).	Mandatory
	1.06		The digital tool shall enable the user to specify the forward airspeed of the aircraft at the point the CM flare will be fired.	Mandatory
	1.07		The digital tool shall enable the user to specify the altitude of the aircraft at the point the CM flare will be fired.	Mandatory
	1.08		The digital tool shall enable the user to specify the relevant atmospheric parameters that would have a significant effect on the safety trace (e.g. windspeed, atmospheric pressure, humidity).	Desirable
	1.09		The digital tool shall enable the user to specify the type of CM flare (standard, aerodynamic, kinematic).	Desirable
	1.10		The digital tool shall enable the user to specify the mass and burn-rate of the kinematic propellant (if used).	Desirable

ID		Requirement Text		Requirement Importance
Parent ID	Child ID	Parent	Child	
	1.11		The digital tool shall be able to model multiple flares launched simultaneously from the aircraft, i.e. model the safety trace for the full DAS.	Mandatory
	1.12		The digital tool shall display the geometry of the safety trace to the user. As a minimum, this will be a horizontal and vertical dimension. Ideally, the geometry will be more defined, in order to optimise the size of the safety trace. Ideally the tool will automatically plot the safety trace onto a digital map.	Mandatory
	1.13		For audit purposes, the digital tool shall save or export each safety trace that is carried forward to support CM flare trials. This will include an auditable record of who entered and checked each input variable, and who approved the resulting safety trace for use.	Mandatory
2.00	2.01	The digital tool shall be subject to sufficient technical review to provide confidence in its results.	The digital model that calculates the safety trace shall be checked/tested by the contractor for technical accuracy and will be in a form that can be assured to MOD's satisfaction.	Mandatory
	2.02		The digital tool shall be checked/tested by the contractor to ensure that it is accurately providing input data to the digital model.	Mandatory
	2.03		The digital tool shall be checked/ tested by the contractor to ensure that it is accurately providing output data from the digital model to the user.	Mandatory
	2.04		The tool must have the ability to save safety trace records for subsequent reference/ audit in the user's risk assessments.	Mandatory
	2.05		MOD/ Dstl shall check and approve the tool before it is used to calculate any safety traces.	Mandatory
3.00	3.01	The tool must be supportable through life.	The contractor shall provide instructions and training to the user how to use the tool.	Mandatory
	3.02		The tool must be SbD.	Mandatory
	3.03		The tool must remain supported through life.	Mandatory
	3.04		The tool must be hosted on hardware and software specified by MOD that the users have access to.	Mandatory

Table B-1: Initial indicative User Requirements.

Annex C: FME Further Detail

1. This paper suggests using FME Form to design the process and FME Flow to facilitate its automation, at least for early iterations of the tool. FME's main attraction is its geographic speciality opposed to a more generic Python or other code-based solution. The MOD also has FME software in-house in some areas so leveraging that expertise could be advantageous. Figure C-1 displays an already existing FME server web-form using a similar format of inputs and outputs.

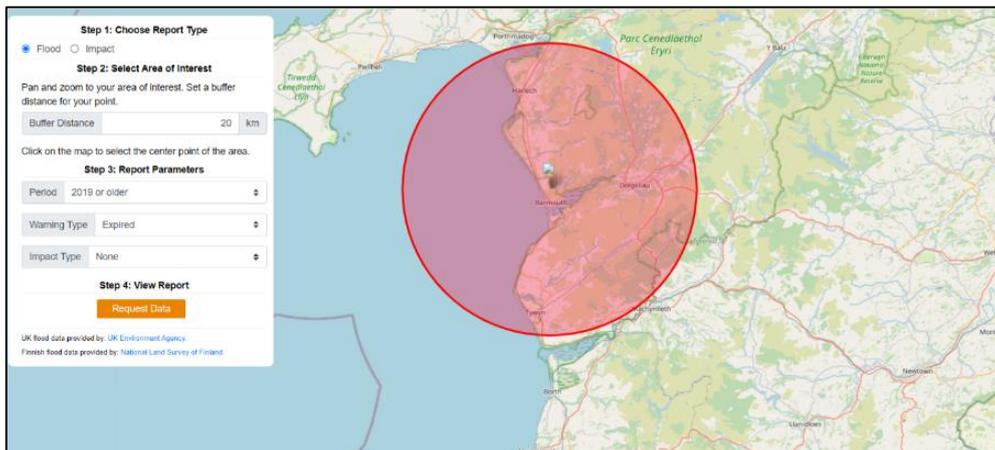


Figure C-1: Example of FME Server Web-Form allowing user capability to select variables and enter a location using a map-picker. This example is Environment Agency Flood Records.

Inputs – Method

2. FME is a workflow software which can read in a variety of different inputs:
 - a. Data entered via an FME Server web-form – this would be a webpage (viewable on computer or mobile/tablet, with secure sign-on if desired) - to allow user to enter the Input Parameters and location (either as set of co-ordinates, or via simple map picker to drag and drop).
 - b. Data being fed into a database or web-service (such as API) – this could co-ordinate with an app potentially made in-house by Appivate.
 - c. A Web-Hook with a prospective RAF App capturing the Input Parameters and passing them to FME via a web-hook URL.
 - d. Input Parameters manually entered via a user (does not require use of FME Flow) and ran manually on a computer (lower cost but less responsive/dynamic, plus no app capability).

Input Parameters

3. Several parameters must be defined by the user or assumed by the software as they will affect the output of the safety trace. These parameters include:

Geographic:

- a. Aircraft Location at the Point of Launching Flare:
 - i. This is a set of geographic coordinates, entered via one of the methods described previously.
 - ii. This forms the centre-point for any safety trace calculations.

- b. Aircraft Altitude at the Point of launching Flare:
 - i. This would be input via one of the methods described previously.
 - ii. This would be the highest point possible the flare would be launched as this would create the largest safety trace area.
 - iii. This forms the height variable for use in the calculations.
- c. Aircraft Heading at point of Launching Flare:
 - i. This would be input via one of the methods described previously – potentially as drawing a line or selecting an angle after the location is selected.
 - ii. This forms the direction of travel for use in any safety trace calculations.
 - iii. For this example, it is assumed as travelling in a straight line and at a level altitude.



Figure C-2: Example of Aircraft Point on Map.

Aircraft / Flare Composition:

- a. Aircraft Speed at point of Launching Flare
 - i. This would be input via one of the methods described previously – either as a drop down of acceptable values for that aircraft type, or free text.
 - ii. This forms the speed variable for use in any safety trace calculations.
- b. Aircraft Type
 - i. Different aircraft will have different available flare configurations. All of these are known and decided beforehand.
 - ii. Different aircraft will also have different capabilities (upper and lower height ceiling, speed, etc.). This data would be used to put validation onto the inputs to ensure no impossible speeds are selected for a certain platform.
- c. Configuration of Flares – Quantity and Angles
 - i. Different Flare configurations will have different numbers of flares.
 - ii. Those flares will be pointing at different angles, both in the X-Y plane and Z plane.

- iii. For the purposes of this initial overview, we will initially focus mainly on the X-Y plane, however Z plane angles could also be calculated.
- d. Configuration of Flares – Type of Flares
 - i. There are 3 main types in this assumption:
 - a. Falling.
 - b. Aerodynamic – these travel further.
 - c. Boosted – these accelerate a short distance before falling.
 - ii. This means the Aircraft Point turns into a set of lines, with the maximum length determined by the capability of the flare type.
- e. Configuration of Flares – Chemical Makeup
 - i. Different Flare Makeups travel different distances during launch and subsequent active lifetime, this may extend the travelled distance further.

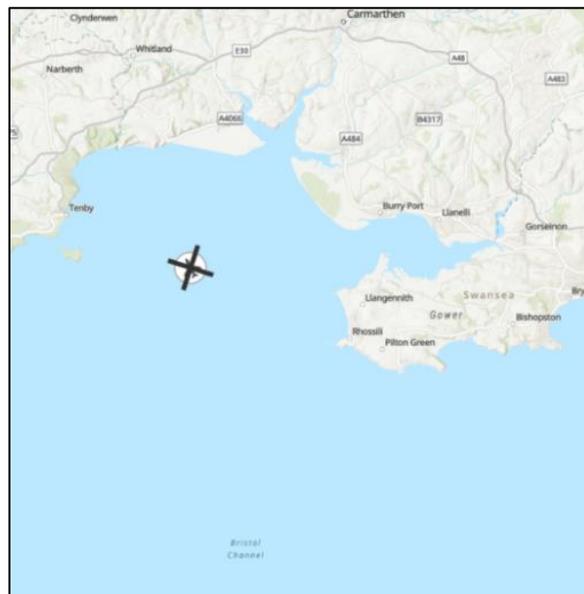


Figure C-3: Example of Simplified configuration. 4 x flares at -45° , 135° etc. from aircraft front aspect.

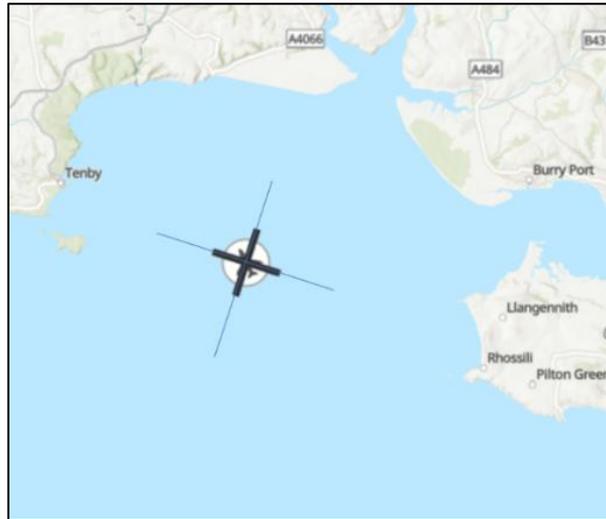


Figure C-4: Simplified flare configuration with lengthened safety trace due to flare configuration.

Other variables

4. **Wind speed and direction.** If wind-direction and wind-gust speed can be directly sourced from a Met Office API (using the nearest weather station), they could be used in live 'drift' calculations to show current safety trace areas. Within the digital safety trace tool, these could be compared with the worst-case safety trace (used in the planning phase to determine the trial risk) to check that current weather conditions remain within the planned safety trace boundary.

5. **Curvature and rotation of the Earth.** If the altitude of the flare launch is high enough and it travels far enough, then both the earth's rotation and curvature could become factors. The effect of these variables would be negligible for the low altitude⁶ launches during trials but could be factored into future models if required.

Workflow

6. FME could calculate the traces based on its in-built arithmetic capabilities [Ref E] (with python code, if required) and more complex mathematics containing an error safety margin. As the safety trace must be produced before the trial can take place (i.e. not in real-time), assumptions will need to be tailored to the flare and platform type in use. Weather and wind will be a universal effect to the trajectory; however, different failure modes will have varying effects on the resultant safety trace. A worst-case safety trace could be constructed simply by using the most energetic or heavy flare in use. Based on this approach, FME would then process the inputs and variables to calculate their effect on the size, location and angles of a resultant worst-case trace footprint and automatically plot the results on a mapping package.

Outputs

7. The FME workflow would give the initial inputs and parameters and allow a facility for calculations to be made (either within FME's native arithmetic evaluator, or via some other code). The intended result would comprise a geographic polygon providing the:

- a. Centre point of aircraft.
- b. Maximum distance from aircraft of flare travel.
- c. Maximum 'drift' zone around that flare.

6. The requirement is understood to be that T&E launches are generally carried out at altitudes of a couple of thousand feet above sea level, certainly no more than five thousand feet above sea level.

8. There are several options for how this information could be distributed. The trace could be:
 - a. Fed directly into a connected mapping client for plotting.
 - b. Emailed to user as an interactive map/pdf/alternative, as required.
 - c. Fed back to an RAF 'App' via text or similar, to be turned back into a graphical representation of the polygon.
 - d. Written out as a geographic file suitable for GIS software.
9. The trace would not be limited to just one option and could be a combination of any or all of them. Ensuring flexibility of output will aid in keeping the tool adaptable and useful throughout its life cycle and makes potential upgrades easier to implement.



Figure C-5: Illustrative Safety Trace plot, with buffers applied based on workflow calculations.

Annex D: ILS Assumptions

Reference Topic	Question	Assumption
Appivate	Is the user device a secure device or can it be placed on a secure mobile device?	Initial assumption is the ASWC SLAN/TEWAN. Potential for MODNet (SECRET). MODNet likely out of scope due to potentially vulnerable data within the app database.
	Is there a security issue of the tool being reverse engineered by threat actors?	The assumption is that the database will contain vulnerable data. Therefore, this will need to be placed on a secure server.
Training	Has the Training Requirements Authority (TRA) been informed who will oversee the training requirement?	It is assumed that in accordance with JSP822, before the TNA takes place. APPTES will need to contact RAF 22 Group and officially request TRA contact details so that a training statement of requirements can be generated and provided to the TRA detailing that a potential training burden may exist for this safety tool.
	How Many users will be required to be trained?	It is assumed that no more than 20 initial users will be required.
	Who will oversee onboarding and offboarding users?	It is assumed that APPTES will appoint an appropriate lead for this task. The onboarding and offboarding process will confirm each users' roles and responsibilities and granted permissions.
	Will the training device be password protected or require authentication to access the device?	It is assumed that the App should only be accessible by authorised users. A password per user would be advisable. Due to the security nature of the project and the SbD principles, two factor authentication will be required.
Functionality	Who can create or view the App?	It is assumed that all authorised users with the required permissions only, will have access to view and create requirements on the App.
	Is view accessible by airfield personnel?	It is assumed that the software plot must be exportable (.jpg / .png etc. for inclusion in trials documentation). Airfield personnel do not need access.
	Who can mark a scenario as invalid or request a safety halt?	It is assumed that if the safety trace plot extends outside the range safety area, the TMO will need to amend the trial plan so that the safety trace plot fits within the range safety area. This will be at planning phase before final sign off is agreed.

Table D-1: ILS Assumptions

Annex E: Relevant Technical Publications for Developing

1. TD-Info's staff can develop Defence Technical Publications to any corporate style and in accordance with any standard not limited to the following:
 - a. Def Stan 00-601 MOD Business Rules – Contracting for Technical Documentation:
 - i. Part 1 – Air S1000D Business Rules.
 - ii. Part 2 – Maritime S1000D Business Rules.
 - iii. Part 3 – Land S1000D Business Rules.
 - iv. Part 4 – Non S1000D Business Rules.
 - b. ASD S1000D International Specification for the Procurement and Production of Technical Publications.
 - c. ASD-STE100 Simplified Technical English.
 - d. MIL-STD-3001 - Preparation of Digital Technical Information for Multi-Output Presentation of Technical Manuals.
 - e. MIL-STD-38784 – General Style and Format Requirements.
 - f. MIL-STD-40051 Preparation of Digital Information for Interactive Electronic Technical Manuals (IETMs).
 - g. MIL-DTL-81927 Work Package Style and Format.
 - h. MIL-DTL-81927C Work Package Style, Format, and Common Technical Content Requirements.
 - i. MIL-M-81929 Preparation of Illustrated Parts Breakdown Figures.
 - j. ISO 22745 Industrial Automation Systems and Integration, Technical Dictionaries and their Application to Master Data.
 - k. ISO 8000 Data Quality Management.
 - l. ISO 29845 Technical Product Documentation – Document Types.
 - m. ISO 7200 Technical Product Documentation - Document Type Fields.

Annex F: Desktop Functional Failure Analysis

Function	Failure Condition (Hazard Description)	Phase	Effect	Classification (Severity)	Remarks
Load the CM flare into the launcher with WOW	Un-demanded ejection on ground	Arming	Flare fired on the ground	Outside Scope	Not carried forward – outside scope. Represents one of worst credible scenarios for ground safety trace.
Aircraft to carry the CM flare in the launcher to the launch point	Un-demanded ejection during flight phases	Taxi / Flight	Flare fired prematurely in flight	Outside Scope	Not carried forward. Safety traces are not generally calculated when aircraft are taxiing or in flight. They are calculated from the point of a deliberate firing.
Eject the CM flare from the launcher on demand at the specified ejection velocity and on a specified vector	No ejection	Launch	Flare remains in launcher. Does not affect APPTES' safety trace, but does result in a safety trace when the aircraft has WOW and the misfired/ hung-up flare needs to be unloaded	Outside scope	Not carried forward as is outside the initial scope. Could be a consideration for future iterations of the tool.
	Misfire/ Hangfire	Launch	Flare does not leave the launcher on demand	Less severe case	Not carried forward – flare would not leave the launcher and hence would not land within the safety trace. Safety case would cover flight back to base (including potential jettison of the launcher) and unloading the misfired/ hung-up store(s).
	Delayed Firing	Launch	Flare leaves the launcher after the aircraft has passed the launch point	Outside Limitations – Inform Safety Factor in M&S	The flare must be launched from a specified point. However, there will inevitably be some variability during flight, and the M&S should build in a suitable safety factor accordingly.
	Incorrect ejection velocity – too slow	Launch	Flare does not reach safety trace boundary	Less severe case	Not carried forward – flare would land within the safety trace area therefore not a bounding case.

Function	Failure Condition (Hazard Description)	Phase	Effect	Classification (Severity)	Remarks
	Incorrect ejection velocity – too fast	Launch	Flare could reach safety trace boundary	Outside Limitations – Inform Safety Factor in M&S	Each CM flare will be supplied with a data sheet, which will include the specified ejection velocity. There will inevitably be some variability across CM flare inventories, and the M&S should build in a suitable safety factor accordingly. The CM flares SME will be able to provide guidance on a suitable safety factor.
	Incorrect ejection angle (aircraft attitude)	Launch	Flare could reach or exceed safety trace boundary due to increased angle of elevation	Outside Limitations – Inform Safety Factor in M&S	The flare must be launched from an aircraft flying straight and level. However, there will inevitably be some variability during flight, and the M&S should build in a suitable safety factor accordingly.
	Incorrect ejection angle (failure or incorrect fit of launcher)	Launch	Flare could reach or exceed safety trace boundary due to increased angle of elevation	Outside Limitations	The fit of each launcher onto each type of aircraft is pre-specified, hence the launch vector of each CM flare is known.
	Incorrect ejection altitude – too high	Launch	Flare could reach or exceed safety trace boundary due to increased distance travelled before striking the ground	Outside Limitations – Inform Safety Factor in M&S	The flare must be launched from a specified altitude. However, there will inevitably be some variability during flight, and the M&S should build in a suitable safety factor accordingly. N.B. MOD should specify whether to consider the double failure of the flare being launched at too great an altitude and then failing to ignite. If MOD decides that such a double failure is not credible, then the safety factor should only consider the trajectories of non-combustible components and can assume that all of the pyrotechnic material will be consumed before the flare strikes the ground.
	Incorrect ejection altitude – too low	Launch	Flare could land within the safety trace boundary – reduced altitudes could mean that not all the flare is consumed during combustion	Less severe case	Not carried forward – flare would land within the safety trace area therefore not a bounding case.

Function	Failure Condition (Hazard Description)	Phase	Effect	Classification (Severity)	Remarks
	Weather conditions affect flare trajectory	Launch	Stronger than anticipated wind could blow the CM flare beyond the boundaries of the safety trace	Outside Limitations – Inform Safety Factor in M&S	Windspeed, direction and other weather conditions will influence the flare trajectory. The flare must be launched within specified windspeeds and directions (currently no account is taken for atmospheric pressure). However, there will inevitably be some variability during flight, and the M&S should build in a suitable safety factor accordingly. Modelling SMEs to advise whether other atmospheric phenomena should be considered in this FFA.
Thruster pellet to ignite at the specified distance from the aircraft (thrusted flares only)	No ignition or only partial ignition	Thrusted Flight	Flare could land within the safety trace boundary – reduced thrust would result in less distance travelled	Less severe case	Not carried forward – flare would land within the safety trace area therefore not a bounding case.
	Normal ignition	Thrusted Flight	Flare would travel specified distance and hence reach the safety trace boundary	Potential Bounding Case	Non-combustible components would reach their maximum credible distance before striking the ground. Pyrotechnic components would reach their maximum credible distance before striking the ground were the payload to fail to ignite.
Thruster pellet) to burn at the specified rate post-ignition (thrusted flares only)	Thruster pellet burns too slowly or breaks up mid-burn	Thrusted Flight	Assumed no effect	Not carried forwards	If combustion is too slow, less thrust will be provided, this is covered by the partial ignition scenario.

Function	Failure Condition (Hazard Description)	Phase	Effect	Classification (Severity)	Remarks
	Thruster pellet burns too fast	Thrusted Flight	Flare would accelerate faster. TBC whether this would result in it travelling further, as it would have had the same amount of energy imparted to it, but with a faster initial acceleration	Potential Bounding Case	<p>Each CM flare will be supplied with a data sheet, which should include the range of credible burn times. There will inevitably be some variability across CM flare inventories, and the M&S should build in a suitable safety factor accordingly. The CM flares SME will be able to provide guidance on a suitable safety factor.</p> <p>Non-combustible components could reach their maximum credible distance before striking the ground.</p> <p>Pyrotechnic components would reach their maximum credible distance before striking the ground were the payload to fail to ignite.</p>
	Premature ignition of the thruster pellet	Thrusted Flight	Potential ASD due to ignition of thruster pellet within the safe separation distance	Outside scope	<p>Not carried forward as it does not affect the safety trace.</p> <p>Having the capability to model this effect upon the ASD hazard could be beneficial to Delivery Teams' safety cases and Duty Holders' Risk to Life (RtL) assessments.</p>
CM flare payload to ignite at the specified distance from the aircraft	No ignition, only partial ignition, or charge breaking up mid-burn	Main Burn	Greater mass than anticipated continues to fall under gravity. Potential to reach maximum distance due to increased mass and therefore increased momentum	Potential Bounding Case	M&S necessary to reveal whether the reduction in burning would result in the CM flare travelling further in the horizontal plane, or simply falling faster under gravity and therefore a larger mass than anticipated striking the ground but within the safety trace boundary.

Function	Failure Condition (Hazard Description)	Phase	Effect	Classification (Severity)	Remarks
	Premature ignition of the CM flare	Main Burn	Potential ASD due to ignition of CM flare within the safe separation distance	Outside scope	Not carried forward as it does not affect the safety trace. Having the capability to model this effect upon the ASD hazard could be beneficial to Delivery Teams' safety cases and Duty Holders' RtL assessments.
	Normal ignition	Main Burn	Pyrotechnic material consumed. Non-combustible components reach their maximum distance	Potential Bounding Case	Non-combustible components would reach their expected distance before striking the ground.
CM flare payload to burn at the specified rate post-ignition	Payload burns too slowly or breaks up mid-burn	Main Burn	Bounded by no ignition of payload	Less severe case	Not carried forwards - bounded by no ignition of payload.
	Payload burns too fast	Main Burn	Assumed no hazardous effect	Less severe case	The CM flare is already designed to be consumed before it strikes the ground. An increased burn rate will not affect the safety trace.
Aircraft to jettison any unfired CM flare, or carry them in the launcher back to the operating base	Undemanded ejection during flight phases	Taxi / Flight	Flare fired prematurely in flight	Outside Scope	Not carried forward. Safety traces are not generally calculated when aircraft are taxiing or in flight. They are calculated from the point of a deliberate firing.
CM flare to be unloaded from the launcher if not fired (including misfires and hangups). Aircraft with WOW	No launch	Unloading with WOW	Misfired/ hung-up flare needs to be unloaded. Risk to armourers and second/ third parties and assets on the ground	Outside scope	Not carried forward as is outside the initial scope. Could be a consideration for future iterations of the tool.

Table F-1: Indicative desktop FFA.

Annex G: Potential Future Option of Adopting Risk-Based Safety Traces

1. Because safety traces are currently based on a worst credible case, the risk to personnel outside the safety trace is effectively negligible. Additionally, the risk to personnel situated in the outer areas of the safety trace will also be very low, and may be either 'Broadly Acceptable,' or 'Tolerable and As Low As Reasonably Practicable (ALARP).' Such risks could potentially be justified and accepted by Duty Holders, provided that a safety argument is produced and is underpinned by a robust set of supporting evidence, including safety analysis and risk assessment. Moving to a risk-based approach would provide the benefit of being able to reduce the safety trace size and hence make trials more geographically flexible. Combined with using the Maths/ CompSci M&S approaches, this could give stakeholders a more realistic safety trace envelope, and a picture of how the CM flares are expected to perform within that envelope post-dispense.
2. The creation of an accurate M&S tool to predict likely trajectories would enable a quantitative risk assessment to be performed and hence enable a shift towards using risk-based safety traces. Having such a resource available would help trials managers and Duty Holders understand the risk levels as the safety trace area is reduced, enabling the Trials Officer and Duty Holder chains to manage safety risk more effectively. However, such a move would be a significant cultural change. SMEs would need to be consulted and all stakeholders, including all interested regulators, would need to endorse such a radical change in approach. It is likely that the DSA02.OME Regulations [Ref F] and their associated Defence Code of Practice (DCoP) [Ref G] would need updating for this to happen.
3. APPTES is not currently considering adopting risk-based safety traces for flare CM trials. Instead, they will continue to calculate safety traces using MEB worst case. However, other MOD organisations may wish to consider the approach for those safety traces that are calculated to support the operational use of flare CM.

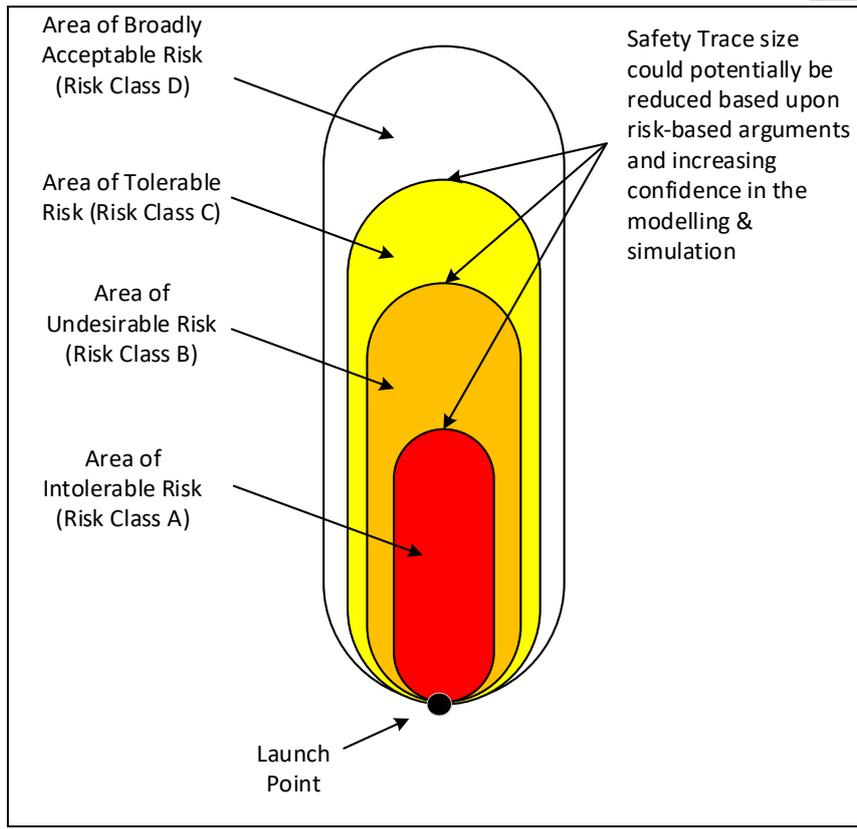


Figure G-1: Option of a Risk-Based Safety Trace.⁷

7. The shape of the safety trace and the risk areas within it has been simplified as illustrated in Figure G-1. The size and shape of any real safety trace and the risk areas within it would need to be underpinned by detailed M&S that has been through an appropriate validation and acceptance process.