Team Defence Information Digital Twin Community of Practice Flares Investigation

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Strand Statement of Requirements Pack

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Aircraft Countermeasures (Flares) Digital Twin Development Exercise

Strand 1 - Flare Safety Trace – Statement of Requirements

Introduction

1. This task is to develop and verify a model / tool that can predict the flight trajectory and ground impact location of in-flight ejected flares and associated components for both burning and non-burning flare countermeasures. The aim of the model is to accurately predict the flare flight path (trajectory) based on from ejection forces, aerodynamic forces and influence of burn material. The aim of the flare safety trace is to ensure that safety is maximised when conducting flare trials and flare firings. As such, if calculated and applied correctly it should ensure two things; Trials risks are minimised to 2nd and 3rd parties, and components of the flare should remain outside areas that are accessible to the public. The safety trace must always fall within the range boundary or other designated safe zones.

Failure Mode Analysis

2. The flare safety trace is the calculated area of ground into which flare components will fall. The current assumption for these calculations is that for generic single stage flares, the worst case is based on a flare pellet that fires (i.e. is ejected from the cartridge) but does not ignite. However, recent trials with newer store types have demonstrated the need for additional factors to be considered. The first of these is to consider a failure mode analysis for trial flares and consider all components post a potential in-air failure. Future flare safety trace modelling must consider a failure mode analysis of flares to ascertain potential components that may require analysis, especially very light weight components that will drift further in the wind. It is recommended that an analysis is conducted 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. It is highly likely that the flare manufacturer will be required to support this analysis. Some of these may be inert components left over after a flare has burnt out. A solution will therefore need to model both the burning pellet and the inert components.

Thrusted Flares

3. The other factor to be considered is newer thrusted flares, as demonstrated by the MJU-57 (new US flare for P-8A). Thrust is generated to accelerate the flare past the ac trajectory for a short period involving significant flare dynamics. This flare has a number of components, including a tungsten nose cap. Ground trials at a UK test facility have shown that the tungsten nose cap can fly a significant distance post-ejection as the flare operates, and this to must be factored into the flare safety trace calculations. It is likely that additional ground tests of this flare are required to generate further evidence for modelling purposes.

Typical Inputs

4. The current inputs into the Dstl-generated safety trace takes account for aircraft parameters, flare parameters and atmospherics, to include the following:

  a. Aircraft Parameters:

    i. Airspeed inc hover

    ii. lookup angle (from camera to aircraft)

iii. aircraft track

iv. Ejection position (radial and range from trials location)

v. Dispenser angle (not position as this is not deemed to be significant)

b. Flare parameters:

i. Size

ii. Mass (including nose weight)

iii. Ejection Velocity

iv. Drag coefficient

v. Flare type.

c. Atmospherics:

i. Wind – 30 kts applied, either tailwind or crosswind (this can be increased/adjusted as required),

ii. $g = 9.81 m/s^2$

iii. International Standard Atmosphere

d. Assumptions:

i. For a given height, the aircraft was assumed to be +/- 100m of track

ii. Release was assumed to never be early, but up to 1s late (button press)

iii. Option to fly either: track +/- 5 planned track (allowing crabbing)
or HDG +/- 5 degrees of planned track (allowing drift).

iv. Aircraft to be straight and level

Other Factors

An updated flare safety trace needs to take account of the updated factors discussed above, Furthermore, a 3rd party assessment should be carried out on any future flare safety traces required for trial work.

P S Sanders

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Aircraft Countermeasures (Flares) Digital Twin Development Exercise

Strand 2 – Environmental Testing – Statement of Requirements

Introduction

5. This task is to develop and verify a model / tool that can predict the life of a countermeasure against specific environmental conditions, defined by the countermeasure's MTDS[1]. Environmental testing / accelerated aging is at present the "best estimate" for simulating the real world and providing results in a reduced amount of time.

6. The aim of the model is to accurately predict the life of countermeasure for a given environment, this can then be used to reduce over-testing from qualification activities. The tool could also be used to manage complex life restraints and possibly afford cross platform use.

Background

7. Following the traditional approach to Ordnance, Munitions and Explosives (OME) qualification as defined within AOP-15[2], the User will define their requirements within a URD[3] describing in broad terms the capability which they require. The URD is delivered to the DE&S Delivery Team who then develop an SRD[4], which defines the system level requirements. As part of the requirements setting process, the DT in conjunction with the User, will develop a Manufacture to Target or Disposal Sequence (MTDS) which defines the environments the OME will be exposed to throughout it's service life. This MTDS will align with the URD and encompasses the complete logistics, storage, and operational environmental envelope.

8. An ITEAP[5] is produced which defines how the OME will demonstrate the SR's have been met, and in turn this demonstrates how the UR's are satisfied. The ability of the OME to withstand the environmental conditions specified within the SRD are verified through a bespoke qualification programme conducted as part of the ITEAP.

9. This qualification programme tests the OME to the extremes of climatic and mechanical environments as defined by the MTDS, and is typically considered to be an over test due to the derivation of mechanical and climatic testing regimes which condense the testing time to a reasonable length. The most stressing environment typically comes from installing the OME to a specific platform, in the case of a countermeasure, it is when it is fitted to a helicopter or aeroplane.

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[1] Manufacture to Target/Disposal Sequence.

[2] Allied Ordnance Publication 15, Ed 3. Guidance on The Assessment of The Safety And Suitability For Service Of Non-Nuclear Munitions For NATO Armed Forces.

[3] User Requirement Document.

[4] System Requirement Document.

[5] Integrated Test, Evaluation and Acceptance Plan.

10. The evidence generated by this qualification programme is used to demonstrate the OME will remain Safe and Suitable for Service (S3) throughout its service life in support of the Safety Case Report, and to define appropriate limitations which typically align with the tests which have been carried out. E.g., platform specific vibration testing may be carried out for a total of 1 hour in each axis, which is representative of 100 Air Carriage Hours (ACH).

11. The DA provides a test house report summarising the qualification activity, which includes environmentally testing the countermeasure but also includes breaking down the nature into its constituent parts, this provides visual checks on the condition of the components to assess against common failure modes. The final stage is to conduct proof firings, these investigates its functionality, safety features and performance metrics.

Issue

12. Following completion of environmental testing, OME is subjected to Breakdown, Testing and Critical Analysis (BTCA) and performance testing to ensure they remain S3 following the environmental testing. The failure modes for countermeasures are fairly well understood; most commonly the pressed pellet will powder, but can crack, which is considered to be a safety issue.

13. Due to the numerous environments and the complexities of test specifications it can take 12-18 months to qualify a single countermeasure against the requirements. Therefore, understanding when the pellet is likely to begin to lose its structural integrity is key to obtaining better defined qualification strategies, ultimately, reducing the number of tests and time spent on the test bed.

14. Countermeasures withdrawn from the operational stockpile which have reached their ACH limit have been subjected to routine In Service Surveillance (ISS) and found to be like-new, suggesting that the limitations applied following the qualification programme are overly pessimistic, or that any life limiting failure modes are not being replicated during service use.

15. Modelling considerations:

  a. Each countermeasure differs slightly not only in energetic material but in size and components used.

  b. Countermeasures are defined by their format and effect but are usually a single pressed pellet. New countermeasures have more internal components which appear to be less robust against simulated aging (vibration + shock). Modelling would need to take into account varying compositions and materials.

  c. To better understand mix platform usage. Currently a countermeasure's life is bound by the platform it was cleared on which can be numerous, however when deployed it will be assigned to a single platform and cannot be used on others. This stems from the qualification approach and test specifications used. A countermeasure undergoes standalone platform tests in order to obtain Air Carriage Hours.

d. The model should be able to determine with accuracy when the countermeasure will sustain failure modes for any given environment, which could include platform vibration + shock, as well as temperature variations. Any modelling tool will need to be proven using empirical evidence. This may require an in-depth study on existing qualification data or may use future ISS activities to provide validation.

A H Pickerill

WESCOE - Pyrotechnics

Aircraft Countermeasures (Flares) Digital Twin Development Exercise

Strand 3 – Statistical approach to Experimental Design

Introduction

1. The future pyrotechnic countermeasure solutions team is responsible for the development of new air countermeasures. This task is to advise or develop a model / tool that can reduce the number of test variables required during the design process by applying a statistical approach to the analysis of test results. A commonly used methodology is the Taguchi system, a tool could be developed around this but there may be other approaches that would be better suited to development of new countermeasure flares.

Design of experiment.

2. The future pyrotechnic countermeasures team would like a better understanding of how a statistical approach to the design of experiments can help to reduce the number of variables that are required during the development of new designs. This approach is traditionally used to identify and reduce the occurrence of defects and failures. This type of experimental design will identify factors that influence variability through statistical analysis, which factors have the greatest influence and whether they are controllable or uncontrollable.
3. This system reduces variables by taking a number of parameters that may be effecting performance and creating a matrix. If for example, 6 parameters needed testing a great many experiments would be required to compare each variable against all the other variables. However the Taguchi methodology designs the experiment to reduce the number of tests required, then applies statistical analysis to the results to show which factors have the greatest and least influence. This then leads the developer to towards the most likely solution.

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Future Pyrotechnic Countermeasures Solutions

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Aircraft Countermeasures (Flares) Digital Twin Development Exercise

Strand 4a – MTV Combustion model

Introduction

1. The future pyrotechnic countermeasure solutions team is responsible for the development of new air countermeasures. This task is to develop and verify a model / tool that can predict the radiant intensity of an MTV (Magnesium, Teflon, Viton) pellet from a series of parameters input to a model / tool.

Design of experiment.

2. The purpose of the task will be to assess existing countermeasure data, and perform additional burn tests of pyrotechnic pellets where necessary, to produce a sample range of typical radiant intensity levels.
3. An agreed form of testing would need to be established so that all measurements are carried out in the same way i.e. static, dynamic, absolute or apparent. Once a series of outputs are established these data can be used to validate a predictive model based on the basic principles of chemical reaction and the formation of combustion products.
4. The input parameters required to predict radiant intensity of materials like MTV should include:-
    a. The surface area - taking account of any inhibited surfaces,
    b. The change in surface area over time,
    c. The size and shape of the proposed pellet,
    d. The mass of composition consumed as a function of time,
    e. The burn rate of the composition
    f. Other factors such as temperature and atmospheric pressure.

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Strand 4B – Dynamics of Mixing – Statement of Requirements

Introduction

16. This task is to investigate and develop a robust model for simulating the mixing of pyrotechnic materials, and other highly solid-loaded systems, to enable rapid experimentation and optimisation of proposed manufacturing methods throughout the development lifecycle and scale-up into mass manufacture. The aim is to enhance understanding of the process and to enable more rapid mixing optimisation and scale-up in a manufacturing environment to achieve consistent and high-quality resultant product. The focus will be on characterising flow dynamics, interfacial interactions and rheological properties involved in the mixing process. It is important for the user to be able to enter data for their substances in order to assist in formulation and process design. This activity may wish to consider typical technologies, such as orbital planetary mixing, as well as disruptive technologies, such as double-action centrifugal mixing (e.g. Speemixer by Hauschild) and resonant acoustic mixing (Resodyn mixer technologies). Some exploratory works were presented at the Royal Society of Chemistry Formulation Science & Technology Group conference ‘Modelling and Simulation in Formulations’ in July 2022 (Formulation Science & Technology Group - Modelling and Simulation in Formulations 2022)

Disruptive Technologies

17. Another factor to be considered is the use of disruptive technologies, such as resonant acoustic mixing by Resodyn, USA, and dual-action centrifugal mixing, such as Speedmixer technologies by Hauschild. Resonant Acoustic Mixing (RAM) mixes materials by vertical displacement at high acceleration. This is achieved by placing the mixing vessel on a vibrating plate which creates small displacements of the mixing vessel at up to 100 G acceleration. This type of mixer requires materials to have a density gradient or dissimilar densities between them. Dual-action centrifugal mixing (Speedmixer) is a blade-less mixing technology which uses a mix vessel which is counter rotated against the movement of the centrifuge. This produces the necessary movement in the mixing vessel to intimately mix the component ingredients. It is likely a model of these systems would need additional validation studies as these are not typical systems in the sector.

Anticipated Inputs

18. No current capability exists within defence to model how materials mix together, however mixing technologies are well-understood, and it is foreseen that the following input data would be required for a useful model:

- a. Material Parameters:
  - i. Particle Size
  - ii. Material Density
  - iii. Viscosity (for Liquids)
  - iv. Mass of component materials
  - v. Shear Stress and Shear rate (rheology) of materials
- b. Equipment parameters:

i. Mixer speed (typically as revolutions per minute)

ii. Mixer Vessel size (diameter/volume)

iii. Mixer shear force

iv. Mixer paddle geometry

c. Atmospherics:

i. $g = 9.81 m/s^2$

ii. International Standard Atmosphere (1 atm, 298 K)

d. Assumptions:

i. Temperature of mixing does not cause autoignition

ii. Materials can be assumed to be spheres of equivalent mass and volume

iii. Order of addition of material is assumed to have no effect / materials are assumed to be added to mix vessel together

iv. No material is lost through the mixing operation / all material is incorporated.

Other Factors

Mixing of pyrotechnics brings unique challenges in terms of the need to balance safety of operations with optimisation and performance of the products of mixing. The factors which can influence unintended ignition include, frictional force, force of impact, temperature and electrostatic discharge. It may be desirable to introduce user-defined limitations for some or all of these factors, where practical.

Third party validation will almost certainly be required, and this will necessarily involve the manufacturer of these materials in the UK.

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Aircraft Countermeasures (Flares) Digital Twin Development Exercise

Strand 5 – Asset Management – Statement of Requirements

Introduction

1. This task is to explore whether improvements in tracking of assets can be identified and implemented to allow greater visibility of the life cycle of an air countermeasure (ACM). This greater visibility will allow improved data capture which would in turn help reduce waste and improve evidence gathering for safety/performance research. ACM life is dictated by a series of lifing categories which determine when the ACM is no longer able to be stored/used and is to be disposed of.

2. ACM contain pyrotechnics and are designed to defeat threats to platforms and different platforms carry different combinations of ACM. The ACM have to be both safe and be able to perform as designed in order to be effective. The lifing constraints give boundaries to ensure the ACM remain safe and suitable for service.

Typical Lifing Constraints

3. Air Countermeasures (CMs) are subject to a series of lifing categories that impact their storage, use and disposal. All Air CMs have the following lifing categories:

a. Shelf Life Expiry Date the normal life of a CM (e.g. storage in an appropriately defined UK munitions storage area). Measured in years.
b. Operational Packed – a reduced life for stores still in sealed manufacturers packaging but not in a storage area as per item a above. Measured in months.
c. Operational Unpacked – a further reduced life for stores that are no longer in sealed manufacturers packaging (items a and b). Measured in months.
d. Installed life – a further reduced life for stores that have been installed into magazines and held ready to fly or fitted to aircraft but not flown before being held back in store/prep area. Measured in days.
e. Aircraft Carriage Hours (ACH) – a further reduced life which limits the number of hours a CM can be flown. Measured in hours.

4. The below table show a few hypothetical scenarios for ACM fitting (assuming Op Packed and Op Unpacked are 12 and 6 months respectively in each example):

Platform	ACM Type	Installed	ACH (Magazine 1)	ACH (Magazine 2)
A	Flare 1	90 days	100 hrs	50 hrs
B	Flare 1	90 days	120 hrs	120 hrs
A	Flare 2	20 days	50 hrs	50 hrs
B	Flare 2	90 days	100 hrs	100 hrs
C	Flare 1	20 days	50 hrs	75 hrs
C	Flare 2	40 days	125 hrs	75 hrs
C	Flare 3	100 days	175 hrs	175 hrs

5. MOD relies heavily on manual processes to manage Installed Life and ACH effectively and ensure that CM fitted to a platform have enough life for the expected duration of the mission - whilst noting that a magazine may contain several different CM types which may have different limitations and may have flown different hours already.

6. A countermeasures “life” ends when whichever of the above is reached first and the above lifing categories are established through design/testing and often additional testing activity following a period of service. Each CM’s limitations are recorded on the Certificate of Design issued by the design authority and are reflected in safety and operational documents.

7. In addition to 3 a to e above, all countermeasures also have an air transportation life measured in hours depending on which platform is used to transport the items. This can vary between 20 and 100 hrs and limits the number of hours the CM can be transported in a transport aircraft. It means that MOD cannot keep transporting CMs by air indefinitely.

Requirement

8. A means, that is compatible with current and future inventory systems i.e. BMFS (Business Modernisation for Support), to track and record all limitations that affect its service life as ACM’s journey from depot to the front line and it is used and/or disposed of.

S M SEARLES

DGM

DE&S