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ASSESSMENT OF SHAPED CHARGE JET MITIGATION, AND THE DEVELOPMENT OF A HYDROCODE, ANALYTICAL MODEL LINK

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Stored weapon systems including shaped charge warheads represent a threat above that of the explosive content alone. A fast cost-effective methodology is required to assess this threat in relation to the existing structures and proposed mitigant structures. A methodology linking an Eulerian hydrocode for the formation and analytical techniques for the target penetration was successfully pursued.
The demonstration of the approach on a conical shaped charge also allowed validation of the approach. The results indicated that such an approach was necessary as other indicators such as reduction of tip velocity were inaccurate and over estimated the reduction in penetrative capability offered by mitigant structures.

INTRODUCTION

Whole life weapon system safety cases are required to demonstrate due care of weapon stores. An understanding of the effects of an accidental initiation during the storage and handling phases of the weapon lifecycle is therefore required.

In particular a fast cost-effective methodology to assess the threat posed by shaped charge jets is needed, as they represent a threat above that of the explosive content alone. In addition this assessment capability is required to evaluate the ability of existing and proposed additional structures to mitigate such threats.

Eulerian hydrocodes, though capable of modelling the whole process, do not offer a fast solution, especially for long stand-offs. Analytical techniques are only available for a subset of shaped charge geometries, and may not adequately predict the mitigation ability of the intervening structures. However, they provide an ability to include degradation effects such as drift. The challenge was to identify which methodology to employ to best utilise the available modelling tools.

The solution adopted by DERA was to develop a methodology to encompass the strengths of both approaches, linking the Eulerian hydrocode cAst, to the analytical JET-SUITE [1–3]. Comparisons of the predicted penetration depths with those given by JET alone would validate the methodology. JET itself has been previously validated by experimental trials. Such methods have been implemented in the past linking with less appropriate Lagrange codes [4].

The initial location of concern in the weapon safety case addressed by DERA was storage in a magazine with concrete and soil traverses. Likely mitigation structures (without adding additional explosive mass into the store) include adjacent weapons and additional light, easily handled structures. The particular requirement for DERA to consider was to demonstrate this approach on a large truncated conical shaped charge warhead. In the study three sample mitigation structures were considered: a steel encased energetic material, representative of a adjacent rocket motor/warhead, and two steel rod designs aligned with the warhead.

ASSESSMENT METHODOLOGY

The purpose of this study was to assess cost-effectively the threat posed by shaped charge jets whilst in storage. Although the likelihood of such an event was considered extremely low it did represent the worst case consequence.

The methodology chosen linking the hydrocode and analytic methodologies utilised the strengths of each tool to characterise the performance of the mitigants relative to the baseline. The cAst Euler hydrocode was ideal to assess the jet formation process and interactions with mitigation structures. The analytic JETSUITE was ideal to assess quickly the relative penetration performance of different shaped charge designs. The challenge was to develop a validated, semi-automated link between the two tools; this link was to be called cAstJET.

A subset of the components of JETSUITE allows the prediction of the penetration ability of experimental shaped charge jets from two X-ray snapshots at a known time interval. It was this portion of the JETSUITE that was chosen to link cAst output into JET to predict the penetration. The cAst output had the benefit of including rate information within a single snapshot of the jet, removing the need for interpolation between 2 different times and reducing scope for inaccuracies.

Program JETPEN, treats each particle individually prior to and after break-up. The program models the off-axis motion of the jet particles, thereby achieving realistic penetration stand-off curves at stand-offs up to 20CD approximately. Work on improving the accuracy of the program at higher stand-offs is in progress [5]. A treatment of compressibility effects is incorporated in this code.

The new program cAstJET, reads selected jet characteristics data from a file generated by the cAst-Euler hydrocode. It builds a model of the extending jet by interpolation (along the jet) of this hydrocode data. A simple assumption about the strain rate in the jet is used to determine the time at which each jet element is formed. Then the program applies a modification of the break-up model used in JETBREAK [6] to create a break-up history of the jet in the appropriate format for JETPEN. The flow of data between the programs is illustrated in Figure 1.

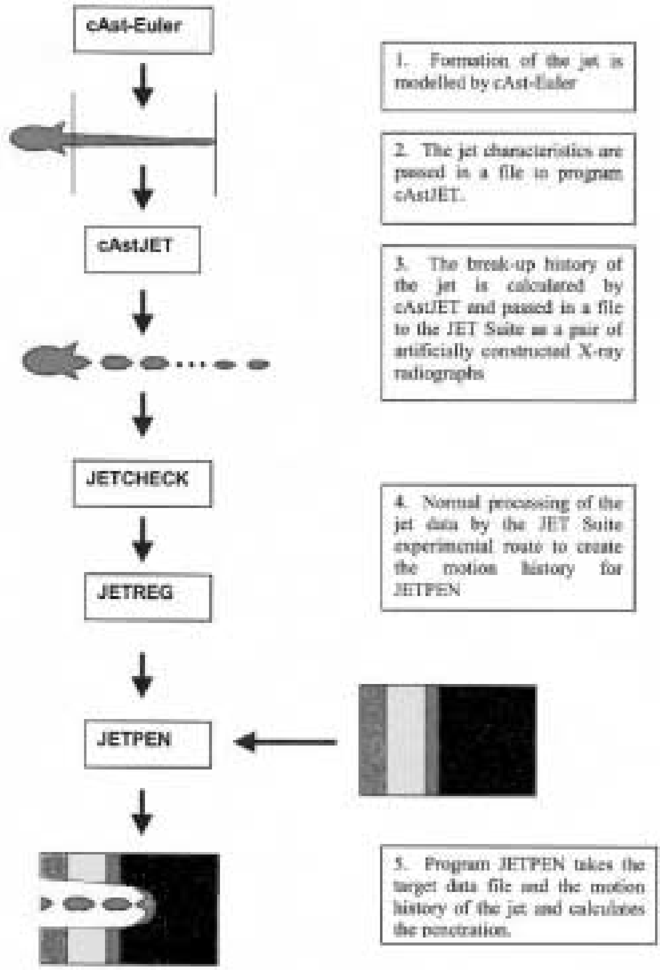

Figure 1. Data flow associated with the cAsjet link between the cAst-Euler hydrocone and the jet suite.

Validation was important to provide confidence in the predictions. Validation would be obtained by comparing the penetration prediction of a pure JETSUITE result with that obtained using cAst Euler, cAstJET then JETSUITE. Two conical shaped charge geometries were used in the validation process. The JETSUITE prediction was obtained using the following standard methodology; program JETFORM of the JET Suite was run to form a jet and program JETBREAK was then applied to determine the break-up history used in JETPEN. Extensive use of JETSUITE has indicated that this results in an accuracy within 5%. The results of the validation are shown in table 1. It shows that the differences in exit velocity through panels is very small, however the when considering penetration depth of thick targets these differences increase. Despite the relatively large differences they were well within the safety tolerances likely to be employed. Though indicating where development effort should be deployed, it was considered sufficiently accurate to continue the study.

Scenario	Difference
Large shaped charge Semi-infinite armour target. Penetration depth	7-14% Increases with stand-off
Large shaped charge Armour plate. Exit velocity	<1%
Large shaped charge Semi-infinite concrete target. Penetration depth	13% at 7CD
Small shaped charge Concrete panel. Exit velocity	<1%

Table 1 – Jet and linked methodology comparison

MITIGATION METHODOLOGY

The basis for the selection of mitigant devices was armour technology, though a considerable advantage was available, as the attack direction would be known. The mitigants would be constrained to axi-symmetric to maintain the cost-effectiveness of the assessment.

The mitigants selected for assessment were steel rods representative of thick plates aligned with the jet, and a cased energetic material (EM) representative of either Explosive Reactive Armour or cased propellant/explosive from an adjacent weapon system. Cased propellant had been observed to disrupt jets in propellant sensitivity trials.

The penetration assessment was of the jet was performed against two semi-infinte targets representative of typical storage facilities:

1) A good quality concrete of 40MPa compressive strength, and
2) A typical soil/sand of density 1.5 g/cc and 15% saturated (15% of the air-volume between soil particles is filled with water).

Storage facilities are often very limited in space hence the mitigants were placed at close stand-offs equivalent to about 1.1CD. The penetration assessment was performed at a stand-off of 7CD. The length of the nose cones, and likely distances to magazine walls drove these criteria.

RESULTS OF cAst EULER SIMULATIONS

Figure 2 shows the baseline shaped charge at 60 µs, showing variation of velocity along the jet's length.

The mitigation devices were chosen to be 0.7CD in length, driven by the perceived space available within magazines. This meant that the devices were physically small and were not expected to be hugely destructive to the jet.

Figure 2 – Velocity contours along jet.

The mitigant devices are illustrated in Figure 3. In addition to the baseline axi-symmetric rod a modification to include a funnel on the front end was also included. It was thought that the funnel could have potentially acted in two ways, to restrain the lateral motion of the jet debris and/or cause shock focusing to disrupt the jet. The funnel might also have had a practical purpose, to reliably locate the rod on the nose cone aligned with the jet axis. The encased EM was assumed to be initiated by a prompt shock mechanism caused by the impact of the jet.

Figure 4 shows the resultant jet penetrating the 3 devices. An initial assessment of the effectiveness of each of the devices was expected to be obtained from the degradation of the tip velocity, Table 1. This showed that both the steel devices reduced the tip velocity by 48%, the EM device reduced it by 21%.

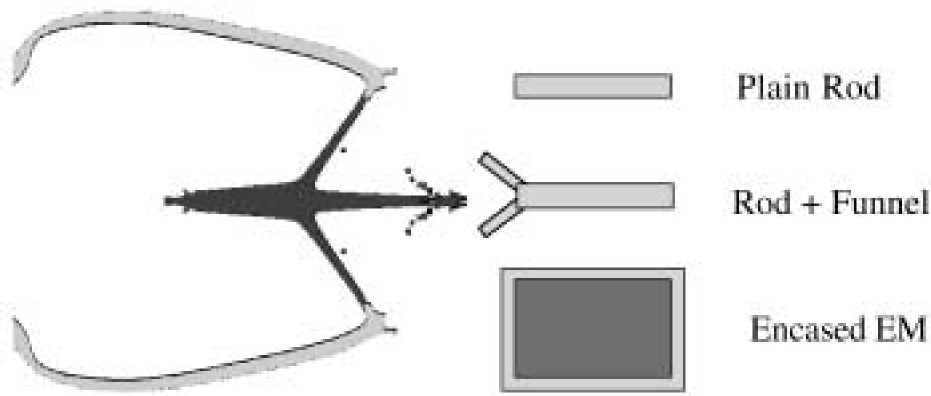

Figure 3 – Illustration of example mitigants.

Home
Table of Contents

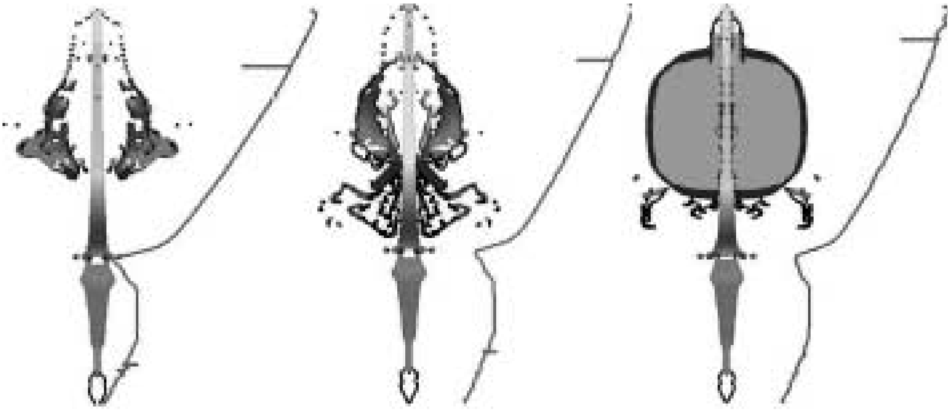

Figure 4 – Jet post penetration of example mitigants, plain rod (left), rod & funnel (centre) and encased EM (right), input into cAstJET.

RESULTS OF MITIGATION

Each of the resultant jets was then loaded into cAstJET and on into JETPEN to predict the degradation of penetration performance. It was assumed that there would be no change to the expected lateral drift velocities due to the mitigant devices from those expected (and validated against experimental data) in the baseline (unfettered) scenario.

The relative performances of the mitigation devices are shown in Table 2 for the conical shaped charge. It was immediately apparent that the degradation of penetration performance was much less than that predicted by the reduction in tip velocity. Here the standard steel rod device was observed to be most effective reducing the penetration distance by 15% in soil, whereas the EM device only reduced the penetration distance by 5%.

Suppressant	Relative tip velocity	Relative Soil penetration	Relative Concrete penetration
None	100%	100%	100%
Steel encased EM	79%	95%	92%
Steel rod	52%	85%	82%
Steel funnel	52%	91%	88%

Table 2 – Mitigation performance of selected devices for a large conical shaped charge

DISCUSSION

The fundamental problem with the application of mitigant devices in confined environments such as a magazine is that the shaped charge jet was designed to attack and defeat substantial targets. The best chance of successfully mitigating a shaped charge would probably be to place a device within the formation zone in order to disrupt the natural formation. Failing that an alternative approach would be to introduce significant lateral drift. This was beyond the scope of the present study.

The EM device performed particularly poorly. The expected advantage of EM solutions (in this geometry) was that the high-pressures from detonation would erode the jet. However at this stand-off and with this tip velocity the pressure was not high enough compared with the jet impact pressure. With shaped charges with lower tip velocities this method will more effective. EM solutions may also be more effective in introducing lateral velocities (not assessed here) than the inert solutions. Some research has suggested that EM geometry can be important, with 'thick' EM offering increased performance [7].

The axi-symmetric constraint of these simulations would tend to lead to the under estimation of the performance of the devices, particularly those containing explosive. Three dimensional effects could be expected to introduce significant lateral velocities.

CONCLUSIONS AND RECOMMENDATIONS

The development of an automated link between the hydrocode and the analytical tool provides a powerful methodology to assess quickly the performance of mitigation devices for all shaped charge designs across a broad spectrum of targets.

Physically small mitigant devices were not very effective at reducing penetration performance. The steel rod was the most effective device reducing penetration ability by 15–18%.

Without the linking cAstJET software the designer may have relied on the reduction in tip speed to assess the relative performance of the devices. The results indicate that, whilst this can (crudely) predict trends, it is a poor measure of absolute performance.

This approach now demonstrated can now be utilised on warheads with other shaped charge geometry.

Selected predicted scenarios should now be validated though experimental trials.

ACKNOWLEDGEMENTS

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