#### THE DEVELOPMENT OF TUBE TESTING FOR IM ASSESSMENT OF BOOSTER EXPLOSIVES

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#### 1 Background

As part of the "As Low As Reasonably Practicable" (ALARP) approach used by the UK MOD for assessing the predicted response from a weapon undergoing mechanical or thermal threat conditions, the results of sub-weapon or charge-scale trials are used to provide support to the information gained from conducting the full suite of Insensitive Munitions (IM) tests. This is because it is recognized that the data provided by the IM tests have limited statistical significance.

Charge scale tests come from the UK Energetic Materials Testing Assessment and Policy (EMTAP) manual and would, wherever possible, be performed during Material Qualification to STANAG 4170. They are likely to involve at least an ambient temperature explosiveness test, a thermal cook-off type of explosiveness test and a shock initiation test. The two explosiveness tests cover Deflagration to Detonation Transition (DDT) and violent Thermal Explosion, and involve tube testing. There are three methods of applying a thermal stimulus to filled tubes. The first uses an internal igniter with the tube and test explosive at ambient temperature. The second subjects the tube to a small fuel fire and the third applies a wide range of standard heating rates using electrical heating tape and thermal insulation. These are listed as UK EMTAP Tube Tests Nos.35 (internal ignition), 41 (fuel fire) and 42 (electrically heated).

The philosophy of tube testing is the application of an ignition stimulus to the explosive when it is retained under relatively high confinement. This technique has been effectively demonstrated for the assessment of main charge explosives over at least the last 9 years. There has been the occasional anomaly in the fast heating environment when one tube end has reacted benignly and the other end reacted relatively violently. This is an issue that is being addressed and modifications within the tubes to attempt to resolve the problem are being introduced during this Booster Tube Testing Programme.

This work programme is a two year collaborative exercise, the three participants being the Defence Ordnance Safety Group (DOSG), part of the Ministry of Defence in the UK, DynITEC in Germany and QinetiQ in the UK.

### 2 Introduction

The assessment of explosive response under realistic booster component environmental conditions is more complex. Although shock sensitive and usually of higher explosiveness than main charge explosives, boosters tend to be small and may benefit from lower confinement than main charge explosives. It is recognized that as the dimensions of boosters become smaller they are more likely to auto-ignite at or near their surface when undergoing even slow ramping cook-off stimuli and less explosive is available for reaction growth. Hence, violent thermal explosion responses are less likely to occur in small pellets than they are in large ones. Most weapon systems are designed so that in cook-off scenarios the main charge undergoes auto-

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ignition near its surface and near to a deliberately weakened region so as to effect confinement release. Booster explosives for the weapon system are normally chosen to have a higher ignition temperature than main charge explosives. A question that has been posed by MOD over the last few years is "How small does a booster have to be before the current suite of tube tests becomes a gross over-test?" This question is now being addressed by performing a range of modified tube testing, with reduced dimensions of explosive samples and reduced levels of confinement.

### 3 The Proposed Booster Tube Testing Approach

It is suggested that with the exception of the forces generated in very high acceleration environments such as gun launch, boosters are unlikely to encounter stimuli that will cause them to ignite without breaching their confinement. Thus a reduced scale internal ignition tube test has not been considered here. However it is recommended that wherever boosters are to be subjected to very high acceleration environments such a test should also be utilized.

Under thermal threat conditions all boosters are likely to be subjected to various heating rates until auto-ignition occurs. Therefore, it is proposed that wherever possible, reduced scale tube tests covering Fuel Fire and a range of Electrical Heating conditions should be applied to the explosives used in Booster Components. In order to generate a suitably wide range of reduced confinement, it was felt preferable to utilize two different tube materials, i.e. steel and aluminium alloy, rather than attempt to machine very uniform yet thin wall thicknesses from steel. The problem with the more readily available aluminium alloys is their significantly reduced strength at higher temperatures and because of that only the electrically heated version of the test is being performed on these tubes. It is clearly important to test booster explosives at the same density as that used in their intended application.

# 4 Selecting the Appropriate Booster Size and Confinement

While it is clearly possible to carry out a suite of tube tests tailored to a specific size of booster pellet in a specific application, the requirement in this exercise has been to attempt to generate a relatively small range of standard conditions from which the most appropriate configuration could be selected as a reasonably minimal over-test of a specific booster in a specific weapon application.

Calculated static bursting strengths of the range of tubes for this exercise are shown in Table 1. Rounded values of these strengths are used to demarcate the different confinement ranges shown in Table 2.

Tube material	Internal diameter (mm)	Wall (mm)	Static bursting pressure (MPa)
Steel	31.4	6.0	112.6
Steel	15.0	3.0	116.8
Steel	31.4	3.0	62.3
Aluminium	31.4	3.0	43.3
Aluminium	15.0	3.0	81.1

Table 1: - Calculated static bursting pressures for the different size / confinement options

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The range of standard test conditions selected for this study covers three values of major dimension, each sub-divided into up to three levels of confinement as shown in Table 2. Of the candidate booster pellet major dimensions, large has been defined as 50mm or more, medium has been defined as that where the major dimension is 15mm or greater but less than 50mm, whilst small is defined as less than 15mm.

Confinement level is not so simple to define but it can be considered as being the static pressure required to release the primary confinement from the booster. For any specific design this will have to be determined experimentally, calculated and / or computer simulated and the values of major dimension and confinement level fed into Table 2 to determine the appropriate test conditions to be applied.

Desigr	n data		Test conditions				
Major dimension (mm)	Confinement level (MPa)	Tube material	Internal diameter (mm)	Wall thickness (mm)	Test explosive length (mm)	Comments	
Large≥ 50	Any	Steel	31.4	6	Full	Same test as main charge explosives	
50 > Medium ≥ 15	High > 110	Steel	31.4	6	100	Two 50mm pellets	
50 > Medium ≥ 15	110 ≥ Medium ≥ 40	Steel	31.4	3	100	Two 50mm pellets	
50 > Medium ≥ 15	Low < 40	Aluminium	31.4	3	100	Two 50mm pellets	
Small< 15	High or medium > 80	Steel	15	3	30	Two 15mm pellets	
Small< 15	Low ≤ 80	Aluminium	15	3	30	Two 15mm pellets	

Table 2: - Booster pellet major dimension and confinement test configurations

### 5 Tube Design Modifications.

The steel used is the same as that in EMTAP test numbers 35, 41 and 42 to specification BS EN 10305-1, ES235 CFS4C or BS 6323 Part 4 Grade CF3 BK.

The aluminium alloy is to specification BS EN 755 6082 T6.

Steel end caps are used on all of the tubes because a) aluminium threads can bind and b) smaller end caps can then be used.

The length of standard Nichrome heating tape that is wound onto the tubes for EMTAP test No.42 will not fit onto the small diameter tubes and so a narrower heating tape of approximately the same resistance has been used for these trials. All reduced confinement electrically heated tubes will be tested at the same heating rates as are used in EMTAP test No.42, i.e.  $100^{\circ}$ C/min,  $10^{\circ}$ C/min,  $5^{\circ}$ C/min,  $1^{\circ}$ C/min and  $0.16^{\circ}$ C/min ( $10^{\circ}$ C/hr).

In order not to compromise tube bursting strengths or reduce significantly the volume of explosives under test, no internal thermocouples will be fitted to any tubes.

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It can be seen from Table 2 that the length of test booster explosive in the tubes is twice the length of the booster major dimension at the boundaries between Large and Medium and between Medium and Small. The factor of 2 is to attempt to ensure the test is an over-test but not a gross over-test. In order to achieve practical length-to-diameter ratios for pressed formulations two pellets have been used to make up each of the test charges.

An important consideration in the design of the tubes is the large thermal capacity of the end caps. Indeed it is suspected that it is this, combined with occasional increased variability in the distribution of thermal flux to tubes that has caused the few aforementioned anomalous results in the fuel fire version of the standard test. In order to ensure that end cap effects do not affect the results obtained from this work the design incorporates inert cylinders to fill the space at both ends of the test explosive. The material chosen for its suitable thermal and mechanical properties, is Macor<sup>™</sup>, a mica filled ceramic. The length of each Macor<sup>™</sup> cylinder is 77mm and while the length of the 31.4mm internal diameter tubes is the same as the EMTAP test tubes, the length of the 15mm internal diameter tubes has been reduced by 70mm, the difference between the two explosive charge lengths.

If the use of these Macor<sup>™</sup> inserts proves satisfactory QinetiQ shall suggest to EMTAP that the full size standard tube test Nos.41 and 42 are lengthened in order to accommodate similar inert material in the vicinity of the end caps. The size of the fuel fire tray will then also have to be increased.

### 6 Selection of Booster Tube Test Candidates

Two booster explosives have been selected for this study, both supplied by DynITEC. One is expected to give poor results in the standard tube tests. The other explosive has already demonstrated low levels of explosiveness response in the fuel fire version of the tube test and, with one exception, has demonstrated low levels of explosiveness response in the electrically heated version of the tube test.

The explosive that is expected to give poor results in the standard tube tests is PBXN-5 which comprises 95% HMX and 5% Viton. Since there is no baseline result from the standard tube tests for PBXN-5, this forms the initial part of the study. The second booster explosive is ITEX-07, used in the latest UK Artillery Fuze L166A1. ITEX-07 is similar to PBXN-7 (RDX 35%, TATB 60%, Viton A 5%) and to a UK booster explosive, Rowanex 3601.

To ensure that these booster explosives will be tested under realistic In-Service applications that are likely to exist in current weapon systems, the ITEX-07 boosters have been pressed to  $1.74 \pm 0.01$ g/cm<sup>3</sup> and PBXN-5 to  $1.75 \pm 0.01$ g/cm<sup>3</sup>.

## 7 Test Programme

The test programme is shown in Table 3. It is a two year programme, currently in year 1 and the schedule for year 1 is to fire the PBXN-5 baseline charges and the reduced confinement ITEX-07 charges. The results from this work should be given in Tables 4 to 9 below but they will not be available in time to meet the deadline for inclusion in the Conference Proceedings. They will therefore be given at the Symposium itself in the Presentation Session.

The reduced confinement PBXN-5 charge firing results will be reported in Financial Year 2011-2012.

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Figure 7-1 is a photograph showing the relative sizes of the tubes and end caps.

Figure 7-1: - From top to bottom, Standard tube (31.4mm ID, 6mm wall), 31.4mm ID 3mm wall and 15mm ID 3mm wall.

	Tests	No. of Trials	Tube Material	Tube Internal	Wall size	No. of Pellets	Dia. Pellet	Charge Length
				Dia. (mm)	(mm)		(mm)	(mm)
BASELINE			ŀ	-Y 2010 / 2	2011	I		
PBXN-5								
EMTAP Test	Fuel	10	Steel	31.4	6	60	31.3	253.2
N0.41	Fire (FF)							
EMTAP Test	Electrical	5, one	Steel	31.4	6	30	31.3	253.2
No.42	Heating	at each						
	(==)	rate						
					1	1		
REDUCED								
SIZE /	FY 2010 / 2011							
	I							
11EA-07								
Medium / High	FF	10	Steel	31.4	3	20	31.3	100
Ŭ	EH	5	Steel	31.4	3	10	31.3	100
Medium /	FF	10	Steel	31.4	3	20	31.3	100
Medium	EH	5	Steel	31.4	3	10	31.3	100
Medium / Low	FF	5	Al	31.4	3	10	31.3	100
Small /	FF	10	Steel	15.0	3	20	14.9	30
High or	EH	5	Steel	15.0	3	10	14.9	30
	FU	F	A 1	15	2	10	14.0	20
Small / Low	EH	5	AI	15	3	10	14.9	30
REDUCED SIZE / CONFINEMEN PBXN-5	т	. FY 2011 / 2012						
Modium / High		10	Stool	21 /	2	20	21.2	100
	FH	5	Steel	31.4	3	10	31.3	100
Medium/Mediu	m FF	10	Steel	31.4	3	20	31.3	100
	EH	5	Steel	31.4	3	10	31.3	100
Medium / Low	/ FF	5	AI	31.4	3	10	31.3	100
Small /	FF	10	Steel	15.0	3	20	14.9	30
High or Mediu	m EH	5	Steel	15.0	3	10	14.9	30
Small / Low	EH	5	AI	15	3	10	14.9	30

Table 3: - Booster Tube Testing Programme

# 8 <u>The Results for FY 2010 / 2011</u>

## 8.1 Baseline results, PBXN-5

Test	Time to Reaction	Type of Response	No. of Tube Fragments	Amount of Pellet Debris	Remarks
	(s)	•	0	(g)	
Fuel		El	MTAP Test No.	41	
Fire			1		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Electrically		EN	MTAP Test No.	42	
Heated					
100°C/min					
10°C/min					
5°C/min					
1°C/min					
10°C/hr					

Table 4: - Baseline tube test results for PBXN-5

8.2	Reduced Size and Confine	ement results
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Test	Time to Reaction (s)	Type of Response	No. of Tube Fragments	Amount of Pellet Debris	Remarks
Fuel Fire	100m	m charge lengt	h, 31.4mm dian	neter, 6mm stee	el wall
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Electrically Heated	100m	m charge lengt	h, 31.4mm dian	neter, 6mm stee	el wall
100°C/min					
10°C/min					
5°C/min					
1°C/min					
10°C/hr					

Table 5: - Medium pellet size high confinement test results for ITEX-07

Test	Time to	Type of	No. of Tube	Amount of	Remarks
	Reaction	Response	Fragments	Pellet Debris	
	(s)	•	-	(g)	
Fuel	100m	m charge lengt	h, 31.4mm dian	neter, 3mm stee	el wall
Fire					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Electrically	100m	m charge lengt	h, 31.4mm dian	neter, 3mm stee	el wall
Heated					
100°C/min					
10°C/min					
5°C/min					
1°C/min					
10°C/hr					

Table 6: - Medium pellet size medium confinement test results for ITEX-07

Test	Time to Reaction	Type of Response	No. of Tube Fragments	Amount of Pellet Debris	Remarks
	(s)	•	-	(g)	
Electrically Heated	100mm (	charge length, 3	31.4mm diamet	er, 3mm alumir	nium wall
100°C/min					
10°C/min					
5°C/min					
1°C/min					
10°C/hr					

Table 7: - Medium pellet size low confinement test results for ITEX-07

Test	Time to Reaction	Type of Response	No. of Tube Fragments	Amount of Pellet Debris	Remarks
	(s)			(g)	
Fuel	30m	m charge lengt	h, 15mm diame	eter, 3mm steel	wall
Fire					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Electrically	30m	im charge lengt	h, 15mm diame	eter, 3mm steel	wall
Heated					
100°C/min					
10°C/min					
5°C/min					
1°C/min					
10°C/hr					

Table 8: - Small pellet size high or medium confinement test results for ITEX-07

Test	Time to Reaction	Type of Response	No. of Tube Fragments	Amount of Pellet Debris	Remarks
	(s)		-	(g)	
Electrically	30mm	charge length,	15mm diameter	r, 3mm aluminiu	um wall
100°C/min					
10°C/min					
5°C/min					
1°C/min					
10°C/hr					

Table 9: - Small pellet size low confinement test results for ITEX-07