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RESEARCH REPORT

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ABSTRACT

The University of Newcastle (UoN) conducted field trials in July 2014 to measure the peak incident pressure (P_i), impulse (I_i) and time of positive phase duration (t_d) following the detonation of different masses of the Plastic Explosive No #4 (PE4). A novel aspect of these field trials was the repeatability of tests.

A variety of spherical masses of PE4 were detonated (in free air) with the following variables:

- Explosive mass (M) of PE4 ranged between 0.02 kg and 1.8 kg. There were fifteen different masses in total.
- There were four blasts of each similar mass; thus, 60 blasts were fired in total.
- The distance (R) between each explosive's centre and any blast-gauge was constant, such that R = 0.882 m.
- The variety of Mass (M) and Range (R) resulted in different Scaled Distances (Z), from 0.65 m/kg$^{1/3}$ to 3.07 m/kg$^{1/3}$. There were fifteen different scaled distances, for both pressure and impulse.

Eight pressure gauges collected data during each blast, and at each scaled distance. Consequently, this repeatability of testing allowed the mean and variance of blast load parameters to be quantified, with a view to better characterise the variability of a blast itself, and other parameters, such as model error variability.

This report describes the conduct of, and data obtained from, the University of Newcastle's July 2014 explosive field trials.

1. BACKGROUND

To properly assess the safety and reliability of structures subject to an explosive blast-load there is a need to first understand and quantify the variability of blast loads. Whilst many highly regarded physics-based models do presume to predict answers with high accuracy, e.g. those that use Finite Element Methods (FEM) or Computational Fluid Dynamics (CFD) such as Air3D (2001), ProSAir (2016), LS-DYNA (2016) and AUTODYN (2016), they are still deterministic blast-load models. In that, they do not take into account the actual variability and uncertainty associated with the:

- Predictive model itself (i.e. model error),
- Input parameters used within the model (i.e. explosive mass, stand-off distance), and
- Inherent – or aleatory – variability, which relates to the natural (intrinsic, irreducible or fundamental) random uncertainty of a situation (Stewart & Melchers 1997).

The current weaponeering techniques used by the Australian Defence Force, the U.S. Department of Defense and many other armed forces consider the variability of weapon-platform integration, weapon-launch and a weapon's delivery to a desired point of impact. No consideration is given to the variability of post-detonation blast-loads and/or the variability of damage to people and/or structures given such loads. Other risk-based calculations proposed by the U.S. Department of Defense Explosive Safety Board (DDESB 2007) – particularly in terms of explosive safety distances – are the basis of the Safety Assessment for Explosives Risk (SAFER 2015) software. However, whilst the DDESB (2007) methodology is formulated on the basis of expectancy, at the core of their effects-analysis they calculate blast-load parameters deterministically. This means that problems associated with calculating deterministic estimates remain. The U.S. Department of Defense manual UFC 3-340-01 (DoD 2002), which superseded TM5-855-1 (DoD 1997), describes the benefits of reliability-based design, which help "*understand airblast uncertainty, intelligently select design loads, and conduct cost-survivability tradeoff studies*". DoD (2002) developed reliability-based load factors to be applied to nominal pressures to give 5^{th} to 99^{th} percentiles of loads, for general purpose (GP) bomb detonations. However, the statistics of pressure variability were obtained from only one detonation of a GP 500 lb bomb, and three detonations of GP 1,000 lb bombs.

A number of studies have reported on the observed variability of explosive blast loads. Twisdale *et al*. (1994) conducted a statistical analysis of blasts from 325 Mark-83 GP conventional bombs, which found a COV of 0.30 for peak pressure and 0.25 for impulse. Low & Hao (2002) found a similar variability of peak reflected pressure (COV=0.32) at various scaled distances in their review of available data. Bogosian *et al.* (2002) reported a COV of 0.23 for peak reflected pressure results of 190 blast tests involving TNT, C-4 and ANFO explosives. However, these statistics are based on data obtained from tests aggregated from various scaled distances. Hence, the observed statistics represent the variability of scaled distance (range, explosive mass) as well as of the blast itself.

Stewart *et al.* (2006), Netherton & Stewart (2010), Netherton (2012), and Stewart & Netherton (2014) desegregated these sources of variability and developed a probabilistic blast load model called P-Blast that predicts the variability of the blast load itself. This new probabilistic blast load model considered variability of explosive mass (W), Net equivalent quantity (NEQ), range (R), angle of Incidence (AOI), air temperature (Ta) & pressure (Pa), and model error (measure of accuracy of the predictive model). The probabilistic blast loading model predicts blast-load values via the polynomials of Kingery & Bulmash (1984), which are the basis of the blast-load models ConWep (1991) and UFC-3-340-02 (DoD 2008), which superseded TM5-1300 (DoD 1990). The mean and variability of peak incident pressure (P_i), incident impulse (I_i) and the time of a blast-waves first positive phase duration (t_d) are all outcomes of P-Blast.

The characterisations of a blast-load's physical parameters are only possible from actual tests. Indeed, whilst many explosive field trials have been conducted over the decades, the majority of programs (and the data from them) are classified. In the few occasions where field trial data is available (e.g. the trials conducted by Hoffman & Mills (1956), and Kingery & Coulter (1983)), all of the experiments have been organised to meet an agenda different to that associated with probabilistic modelling. Consequently, the University of Newcastle (UoN) commenced explosive field trials in 2012, with a view to capture blast-load data that is better suited in terms of characterising model error and blast-load variability. Information from tests such as these is then available for a variety of structural engineering applications, such as: calculating reliability-based design load factors for explosive blast loading (Stewart & Netherton 2014), or, determining partial factors for the major wavefront parameters of reflected shock wavefronts (Campidelli *et al*. 2015).

2. EXPERIMENTAL FIELD TRIALS

Proof of concept field trial

The very first field trial was a "proof-of-concept" blast trial, conducted at RAAF Base Williamtown, NSW, between 12-20 April 2012.

- The intent of this trial was to confirm UoN's ability to capture suitable pressure-time histories, given a detonation of an explosive charge in an open-air arena.
- The trial was a success, with observed pressure/impulse values matching those predicted via Kingery & Bulmash (1984).
- Data from this trial has not been published.

First blast trial (June 2012)

The next field trial was the first of the UoN's actual experimental programme, conducted at RAAF Base Williamtown, NSW, between 4-8 June 2012.

The intent of this experiment was to detonate similar masses of explosives, but at a variety of ranges such that scaled distances (Z) were within the Z-domain described by Kingery & Bulmash (1984), as well as meeting the physical limits of the test arena.

This trial is described, in full, by Netherton *et al.* (2014), a summary of which is:

- Explosive = PE4;
  - Manufactured to an Australian Defence Force Standard, DEF (AUST) 4061, by Thales Australia Limited (AM 2016)
- Explosive mass (M) = 0.250 kg per charge;
- There were four distances (R) between the centre of the explosive mass and the centre of each pressure measurement gauge, where R = 0.670, 1.000, 1.340 and 2.000 m;
- There were thus four scaled distances (Z), where $Z \approx 1.1$, 1.6, 2.1 and 3.2 m/kg$^{1/3}$;
- There were 7 blasts at $Z \approx 1.6$ and 3.2 m/kg$^{1/3}$, plus 8 blasts at $Z \approx 1.1$ and 2.1 m/kg$^{1/3}$,
  - thus, a total of 30 blasts in all.

- Further, the following UoN undergraduate student projects describe the field trial's equipment, test set-up, results, and in much greater detail than Netherton *et al*. (2014):
  - Test equipment for blast loads tests: Papp (2012),
  - The conduct of explosive blast tests: Blandford (2012).
  - Characterisation of blast wave variability: Lyons (2012), and
  - Instrument error: Pleasance (2012).

Second blast trial (July 2014)

The next experimental blast trial was conducted at RAAF Base Williamtown, NSW, between 14-31 July 2014. The purpose of this trial was to detonate:

- different masses of explosives, and
- at the same range between the charge and the blast measurement gauge.
  - As distinct from the earlier June 2012 trial, which used the same mass of explosives but at a variety of ranges.

The intent of the second blast trial was that scaled distances (Z) would: (1) complement the scaled distances from the earlier (June 2012) trial, (2) be within the Z-domain described by Kingery & Bulmash (1984), and (3) be within the physical limits of the test arena.

A summary of the second blast trial is:

- Explosive = PE4.
  - Manufactured to an Australian Defence Force Standard, DEF (AUST) 4061, by Thales Australia Limited (AM 2016)
- Explosive mass (M) of PE4 ranged between 0.02 kg and 1.8 kg.
  - There were fifteen different masses in total.
- There were four blasts of each similar mass; thus, 60 blasts were fired in total.
- The distance (R) between each explosive's centre and any blast-gauge, R = 0.882 m.
- The variety of Mass (M) and Range (R) resulted in fifteen different scaled distances (Z) between 0.65 m/kg$^{1/3}$ and 3.07 m/kg$^{1/3}$, for both pressure and impulse.

Experimental intent of these field trials

The principle deliverable for the explosive trial program was the capture of appropriate pressure/time data (and with sufficient fidelity) to enable the statistical characterisation of the desired blast-wave parameters. Further, the field trials focussed on capturing incident pressure values only, and not reflected pressure values. The motivation behind this experimental series was the calculation of a blast wave's variability, not necessarily capturing what may be the greatest peak load. Consequently, only incident pressures were captured, with a plan to record reflected values in the future. A supplementary consideration for capturing only incident pressures was the relatively low-cost, ease and simplicity of recording only side-on pressures. Moreover, structural damage criteria is often based on values of incident pressure (ie: FEMA 2003, ASCE 2010). Finally, a key assumption herein is that the variability of an incident pressure wave will describe the variability of that same wave when reflected. Future tests will capture the variability of reflected pressures; however, at present, it is assumed that the variability of incident waves will have a strong positive correlation to their variability post-reflection.

3. LOCATION OF BLAST TRIAL

Understandably, explosive field trials can only be undertaken in dedicated areas specifically designed for such activities. The UoN was granted access to an explosives range owned by the Australian Defence Force (ADF), which is a purpose-built open-air explosives bunker at the Royal Australian Air Force (RAAF) Base at Williamtown, NSW, see Figure 1.

Figure 1. The explosives range at RAAF Base Williamtown.

4. EXPLOSIVES

Choice of explosive (PE4)

The license limit for the bunker shown in Figure 1 is 2.5 kg of the explosive Trinitrotoluene (TNT). Ordinarily, the preferred explosive for this trial would have been TNT, as this is the universally accepted explosive of reference. However, the license requirements for this particular range dictated that the explosive "PE4" had to be used.

PE4 is a conventional plastic explosive used extensively by military forces worldwide. Its principle energetic component is Cyclotrimethylenetrinitramine, or, more simply known as RDX. The British coined this acronym as an abbreviation to their Research Department Explosive (EB 2016). RDX – and thus PE4 – is more powerful, relative to a similar mass of TNT.

PE4 is considered by Weckert & Anderson (2006) to have the same explosive equivalency as the (regularly substituted) alternative plastic explosive compound C-4, albeit with a slight reduction in the percentage of RDX; further, they list the TNT equivalence of PE4 as NEQ = 1.37 (in terms of pressure) and NEQ = 1.19 (in terms of impulse), when considered as an air burst.

Scaled distance limits

The P-Blast model discussed earlier (in the Background) incorporates the Kingery & Bulmash (1984) blast-load polynomials, which have scaled-distance limits between 0.59 $m/kg^{1/3}$ and 40.0 $m/kg^{1/3}$. These Z-limits, along with other constraints for the RAAF's range, dictated lower and upper PE-4 mass-limits of 0.0042 kg and 0.660 kg, respectively. A key area of variability identified by Netherton & Stewart (2010) and Netherton (2012), particularly with respect to elements of model-error variability, is between the scaled distances of 0.7 $m/kg^{1/3}$ and 4.0 $m/kg^{1/3}$. As such, and whilst cognisant of the four scaled distances used in the first (June 2012) blast-trial, and the physical limits of the RAAF Range, fifteen scaled-distances (for both pressure and impulse) were selected for the second (July 2014) blast-trial, as described below in Table 1. Of note is that scaled distances (Z) were calculated via Eqn. 1.

$$Scaled\ Distance_{(p/i)} = Range^{1/3} / (Mass \times NEQ_{(p/i)}) \quad (1)$$

Where:

Scaled Distance $_{(p)}$ =	Z	=	Scaled Distance appropriate for Pressure
Scaled Distance $_{(i)}$ =	Z	=	Scaled Distance appropriate for Impulse
Range =	R	=	The distance (in metres) between the centre of the explosive mass and the centre of each blast
Mass =	M	=	The mass (in kg) of each explosive sphere
NEQ $_{(p)}$ =	1.37		(Appropriate NEQ for Pressure, for PE4)
NEQ $_{(i)}$ =	1.19		(Appropriate NEQ for Impulse, for PE4)

Repeatability of explosive mass

A key aspect of the field trials was the repeatability of tests, as this is critical to the characterisation of parameter variability. Care was taken with respect to the repeatability of: explosive mass, detonator location and the distance between the explosive and instruments. That said, there will, of course, be some variability of these parameters. So, whilst the nominal mass values (as listed in Table 1) were desired, the actual mass values used were within a tolerance of Nominal Mass (g) ± 0.6%. The listed tolerance of the scales used to measure mass was ± 0.001 g. An unexpected challenge related to the scales, in that, wind and or/other air movement affected the reading. Consequently, explosive charges were assembled – and weighed – within a tent, see Figure 2. Full details of each explosive mass, as assembled and detonated, are listed in Annex A.

Table 1. Nominal Explosive Mass, Range, Scaled Distance and lot details from the second (July 2014) blast trial.

Nominal explosive mass (M) of PE4 (g)	Nominal range, R (m)	Nominal Scaled Distance, Z ($m/kg^{1/3}$)	
		Z_p	Z_i
Detonator only	0.882	N/A	N/A
20	0.882	2.93	3.07
30	0.882	2.56	2.68
40	0.882	2.32	2.43
50	0.882	2.16	2.26
100	0.882	1.71	1.79
300	0.882	1.19	1.24
500	0.882	1.00	1.05
700	0.882	0.89	0.94
850	0.882	0.84	0.88
1000	0.882	0.79	0.83
1200	0.882	0.75	0.78
1400	0.882	0.71	0.74
1600	0.882	0.68	0.71
1800	0.882	0.65	0.68
Explosive lot details:	Charge Demolition PE4-MC 230g; Lot: 0431; MEM 0313 Thales Australia Limited, Bayly Street Mulwala, NSW 2647, Australia		

Figure 2. Measuring explosive mass within a tent at the RAAF Range.

Cartridges of PE4, as used

Each explosive blast used a spherical mass of PE4, with each sphere made from portions of standard-military-cartridges of PE-4. See Figure 3 for an image of cartridges of PE4.

Figure 3. Four cartridges of PE4 (nominal mass = 0.230 kg, each), as used in the trial.

Of supplementary interest was the measured mass of the as-supplied cartridges of PE4. In that, during the assembly of each sphere, each individual-cartridge was first weighed, thus permitting the characterisation of the mass-variability of an industrially-produced explosive compound. Full details of the mass of each PE4 cartridge (as-used) are provided in Annex A, with the statistical characterisation of explosive mass summarised in Table 2.

Table 2. Statistical characterisation of the variability of explosive mass (M), of the PE4 cartridges as-used in the trial.

Parameter:	**Value:**
Nominal mass of each cartridge (g)	230.000
Number of cartridges weighed (n)	139
Mean mass of all cartridges, μ, (g)	229.437
Standard Deviation, σ, (g)	4.802
Coefficient of Variation (COV = σ/μ)	0.021

Moulding PE4 into Spheres

Portions of PE4 cartridges were hand-shaped into spheres: using either a moulded-rubber form, or, via a stocking, see Figures 4, 5 & 6.

Figure 4. A sphere of PE4 (0.25 kg) hand-moulded via the rubber mould.

(a) (b)

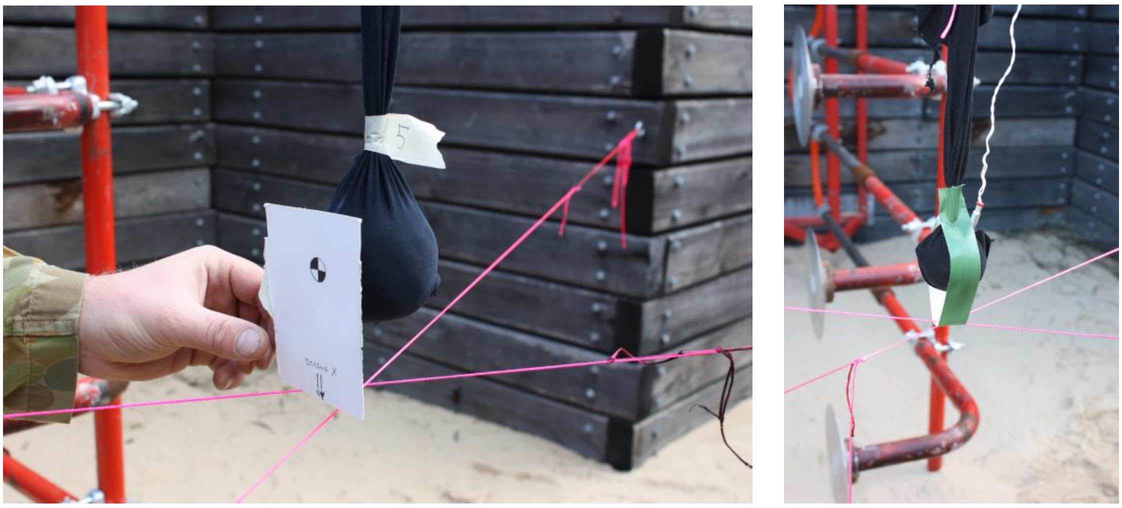
Figure 5. The production of a 1.2 kg charge of PE4: (a) A number of PE4 cartridges placed into a stocking, then, (b) hand-moulding the total mass of PE4 into a sphere.

Figure 6. The completed (1.2 kg) sphere of PE4, in location and ready for the detonator.

Location of explosive spheres

The placement of each explosive used a combination of: an over-head suspension cable, cross-strings, a "centering" card and a steel rod (cut to a specific length), such that the explosive's centre-of-mass was the same distance – or range (R) – from the eight "*in-plane*" blast gauges that surrounded the charge, see the three images within Figure 7.

(a)



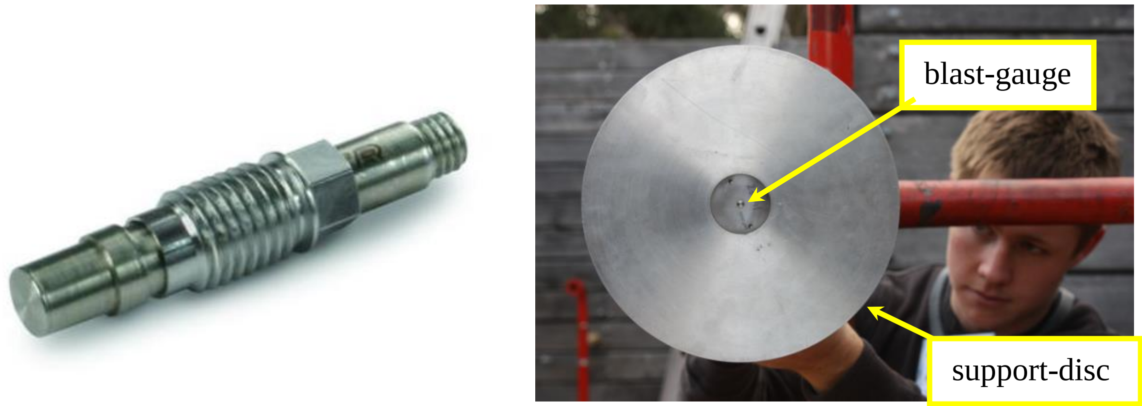
(b) (c)

Figure 7. (a) Using a plumb line from the overhead steel cables, plus a specific length of steel rod, (b) a "centering" card, relative to 2 string-lines and, finally, (c) sticking-tape, to hold each explosive's mass at the same distance from each of the eight blast gauges.

5. MATERIALS AND EQUIPMENT

Blast wave parameters are relatively difficult to capture, particularly as blast testing places great demands on instrumentation systems, in that they have to record data that is extremely transient and often within severe loading environments. In consultation with the Australian Defence Science and Technology Group (DST Group), the UoN developed a bespoke blast data recording system. This included:

- A sensor sub-system: Piezoelectric gauges (PCB: Model 113B) held within gauge support discs (DST Group design), and instrumentation support frames (UoN design), see Figure 8.
- A data collection sub-system: An integrated electronic piezoelectric excitation power supply unit (UoN design), and a 2 MHz, 24 channel, signal acquisition and data storage unit (UoN design), see Figure 9.
- For further information on all equipment used, and the connection of test equipment see Papp (2012) and Blandford (2012), respectively.



(a) (b)

Figure 8. (a) A blast-gauge, as-used in the trial (image from PCB 2016), and (b), the blast-gauge in the centre of the much larger support-disc.

(a) (b)

Figure 9. Components of the integrated electronic piezoelectric excitation power supply unit; (a) shows the cable-input panel from each blast-gauge, and (b) shows the internal power distribution circuitry. All items designed and built by Mr. Ross Gibson, UoN.

6. EXPERIMENTAL SET-UP

The experiment used eight sensors, arranged so they were all in-plane with the explosive's centre of mass and all equidistant from the point of detonation.

Each explosive sphere was placed inside a stocking, which was then hung from overhead steel cables and securely located (underneath) via a set of cross-strings. The intent was that the centre of the explosive was always at the same point in 3-Dimensional space for each detonation, see Figure 8.

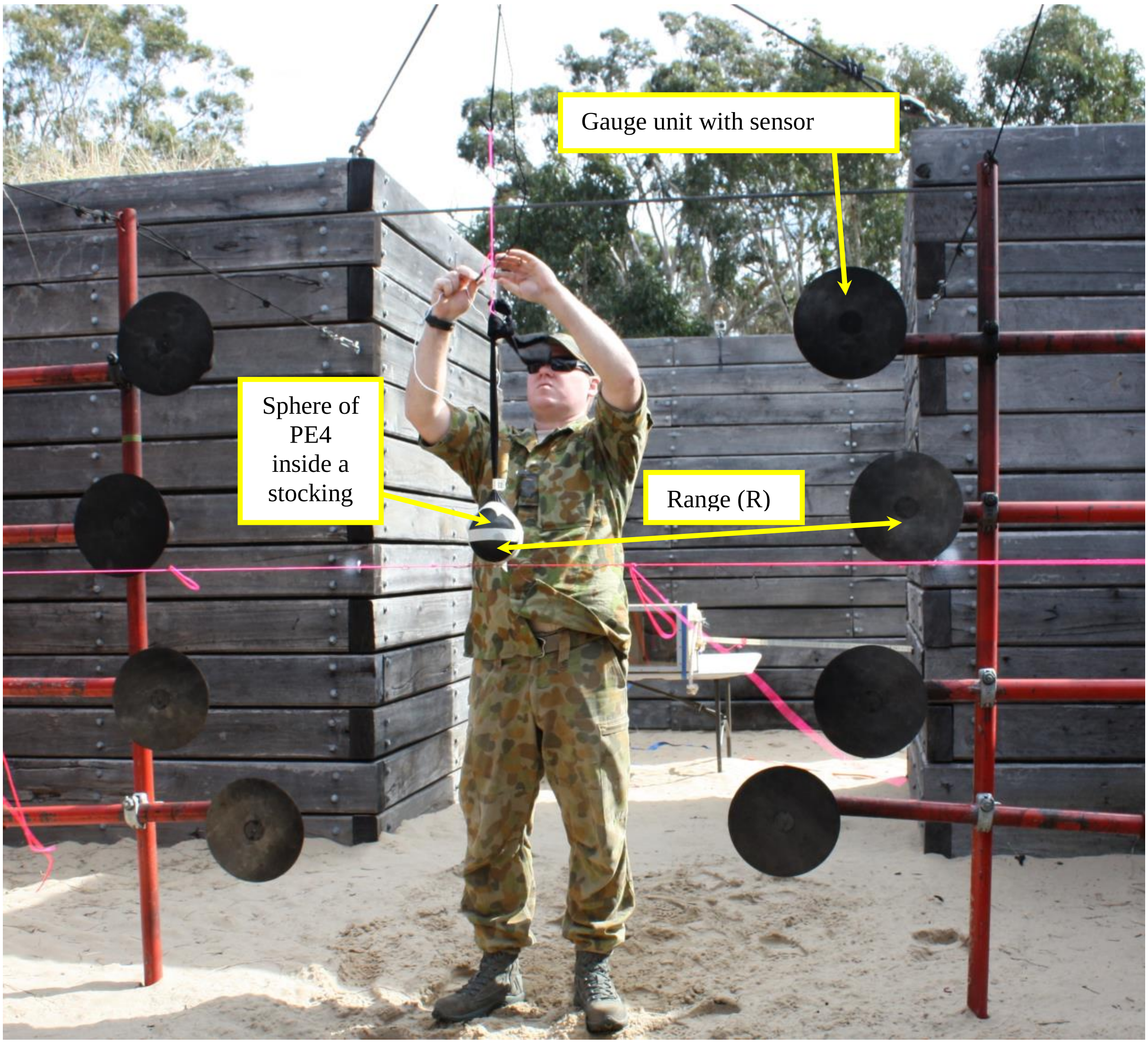


Figure 8. Experimental set-up showing: (i) a stocking holding a 1.2 kg sphere of PE4, where the charge is suspended, centred and placed, relative to the cross-strings, and (ii) eight blast-gauges connected to a support framework, such that each instrument is located the same distance – or range (R) – from the centre of the explosive.

Electric detonators were introduced into the top of each sphere (and inserted to a depth) such that the tip of the detonator was located in the middle of each sphere. The intent was that each explosive was centre-detonated. Detonator details are provided in Table 3. See Figure 9 for the placement of a detonator into a 0.1 kg charge of PE4.

Table 3. Details of the detonators used in all explosive charges.

Parameter:	Value:
Detonator name:	Detonator Electric Demolition F2
NSN:	1375-66-145-9398
Specification:	Thales Australia Tech Spec TS-277
NEQ:	1.5 g
Batch number:	0025 ADI 06

Figure 9. Experimental set-up, showing: a stocking holding a 0.1 kg sphere of PE4, where the charge is suspended, centred and placed, relative to the locating-cross-strings, and the detonator pushed into the top of the PE4, with the detonator's tip located right at the middle of the sphere.

Detonation

Once the detonator is electrically-initiated, a high-order detonation of the PE4 sphere ensues, as shown in Figure 10.

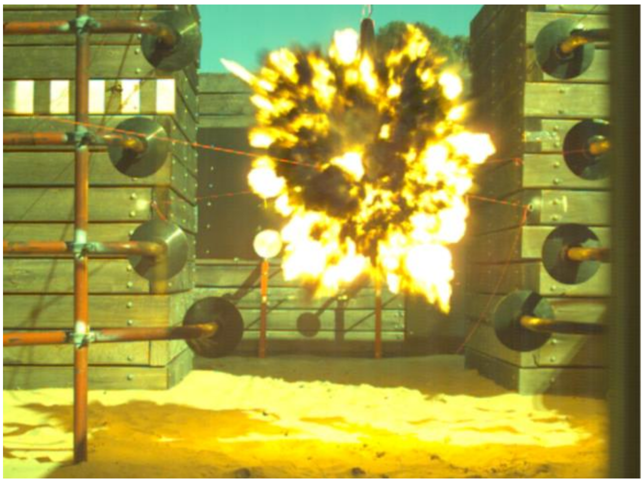


Figure 10. The detonation of a 0.050 kg sphere of PE4
(still-image taken from high-speed video, via a Phantom V311 camera).

7. DATA

The data captured consisted of voltage-time histories from each of the eight blast gauges, and from each of the 60 blasts fired; for a total of 480 individual data records.

Relevant information for each record is:

- The voltage-time history was converted into a pressure-time history using the voltage/pressure calibration data appropriate for each particular gauge.
- The raw pressure-time data was "smoothed" using 100,000 curve-fit points within the program: "KaleidaGraph". An example of raw and smoothed plots are shown together in Figure 11.
- The incident pressure value (P_i) was taken from the raw pressure-time history.
- The time of arrival of the blast-wave (t_a) was determined from the smoothed pressure-time history, and was taken as that time when pressure values first passed through the x-axis, and continued trending upward toward the maximum value.
- The time at the end of the blast-wave's first positive phase (t_e) was taken as that time when the smoothed curve first passed below the x-axis, post P_i.
- The time of duration of the blast-wave's first positive phase (t_d) was calculated as $t_d = t_e - t_a$.
- The blast-wave's incident impulse (I_i) was calculated via trapezoidal integration between all data points of the raw pressure-time history, between values of t_a and t_e.
- Blast-wave values for all 480 data records are provided at Annex B, whilst Mean and COV values, for each blast, are summarised in Table 4.
- The summary of blast-load values (across nominal mass groups) are shown in Table 5.

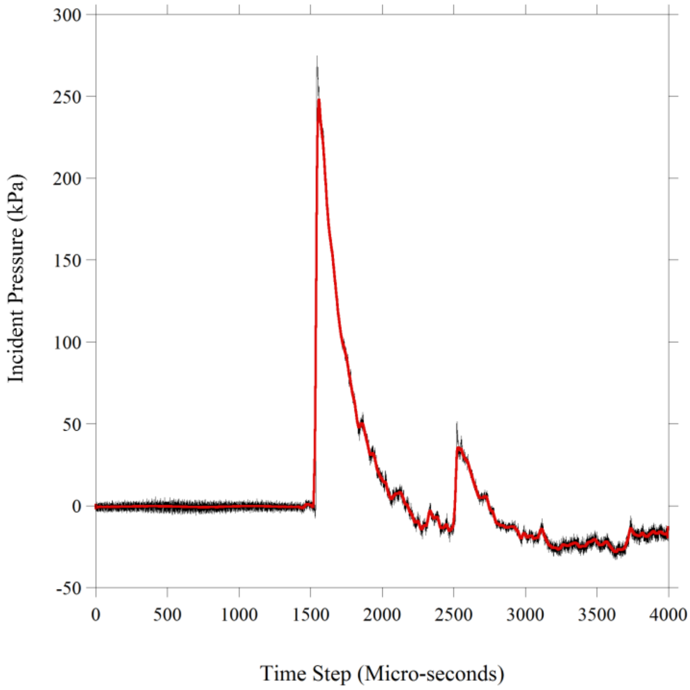


Figure 11. The pressure-time history from a blast of 0.1 kg PE-4, recorded at a distance of 0.882 m (for: Serial #1, Blast #01, Gauge #06). The black line is the raw data, whilst the red line shows the smoothed data line. Note: the time of the blast-wave's arrival (t_a) at approximately 1.5 milli-seconds, the end of the first positive phase (t_e) at approximately 2.0 milli-seconds, plus a reflected blast-wave recorded at approximately 2.5 milli-seconds.

Table 4. Summarised values of blast-wave pressure, impulse and duration, for each blast. NOTE: full details of each blast-wave value (for each blast-gauge) are given in Annex B, N/D = No Data

Blast Number #	Mass of PE4 (kg)	Incident Pressure P_i (kPa)		Incident Impulse I_i (kPa-msec)		Duration t_d (msec)	
		Mean	COV	Mean	COV	Mean	COV
1	0.100123	258.71	0.14	46.75	0.11	0.66	0.14
2	0.100033	256.45	0.09	47.26	0.09	0.66	0.07
3	0.100027	250.82	0.13	46.93	0.14	0.66	0.18
4	0.100093	267.38	0.06	47.46	0.09	0.65	0.08
5	0.300060	644.07	0.15	89.34	0.24	0.67	0.16
6	0.300070	629.78	0.15	93.13	0.20	0.73	0.25
7	0.300060	631.53	0.17	92.00	0.19	0.72	0.24
8	0.300040	629.05	0.24	86.31	0.25	0.67	0.19
9	1.800000	2540.4	0.12	262.50	0.23	0.59	0.23
10	1.800000	1955.6	0.50	314.61	0.35	1.00	0.53
11	1.800000	2399.2	0.09	282.86	0.10	0.84	0.27
12	1.800000	2757.6	0.28	302.08	0.20	0.69	0.19
13	0.500017	924.59	0.16	130.16	0.21	0.76	0.12
14	0.500040	895.09	0.11	117.98	0.12	0.70	0.16
15	0.500027	986.49	0.09	130.42	0.09	0.68	0.14
16	0.500240	1009.4	0.16	132.12	0.11	0.72	0.13
17	0.700041	1313.4	0.11	161.41	0.14	0.70	0.11
18	0.700066	1344.0	0.16	170.42	0.21	0.78	0.13
19	0.699995	1199.8	0.08	173.23	0.25	0.79	0.19
20	0.700094	1275.9	0.13	174.55	0.20	0.80	0.12
21	0.850020	1517.6	0.12	223.69	0.14	1.20	0.38
22	0.850020	1449.7	0.13	196.79	0.12	0.85	0.15
23	0.850040	1469.4	0.12	202.76	0.22	0.94	0.21
24	0.850030	1610.9	0.08	216.36	0.13	1.11	0.14
25	1.000090	1602.6	0.16	195.54	0.16	0.74	0.26
26	1.000040	1655.8	0.10	209.29	0.17	0.74	0.27
27	1.000090	1725.2	0.12	190.31	0.09	0.82	0.17
28	1.000020	1751.3	0.11	204.82	0.11	0.87	0.20

Table 4. Continued....

Blast Number #	Mass of PE4 (kg)	Incident Pressure P_i (kPa)		Incident Impulse I_i (kPa-msec)		Duration t_d (msec)	
		Mean	COV	Mean	COV	Mean	COV
29	1.200070	1893.3	0.20	200.90	0.02	0.65	0.14
30	1.200020	1852.5	0.15	223.73	0.12	0.75	0.23
31	1.200070	1958.0	0.15	228.58	0.19	0.74	0.26
32	1.200000	1886.8	0.13	245.62	0.25	0.95	0.24
33	1.400070	2054.3	0.16	252.43	0.31	0.86	0.60
34	1.400060	2131.7	0.13	240.31	0.11	0.75	0.34
35	1.400030	2207.9	0.09	249.07	0.12	0.88	0.33
36	1.400080	2400.4	0.21	260.16	0.09	0.85	0.25
37	1.600090	2374.6	0.08	288.55	0.04	1.40	0.15
38	1.600000	2016.9	0.19	253.04	0.10	0.94	0.39
39	1.600080	2344.2	0.06	239.47	0.05	0.83	0.17
40	1.600060	2441.6	0.11	240.57	0.18	0.63	0.22
41	0.009545	22.66	0.16	3.16	0.20	0.38	0.07
42	0.009561	20.81	0.17	2.55	0.21	0.38	0.09
43	0.009687	21.14	0.12	2.71	0.18	0.40	0.08
44	0.009567	21.94	0.16	2.82	0.16	0.43	0.12
45	0.020019	92.12	0.12	18.45	0.08	0.60	0.05
46	0.020045	87.24	0.13	18.00	0.09	0.58	0.05
47	0.020035	88.14	0.12	18.08	0.11	0.60	0.04
48	0.020400	92.18	0.10	18.93	0.08	0.61	0.05
49	0.030650	117.80	0.15	22.67	0.09	0.63	0.07
50	0.030650	104.03	0.13	23.54	0.13	0.66	0.07
51	0.030400	111.69	0.12	22.52	0.10	0.60	0.10
52	0.030029	116.07	0.08	25.07	0.08	0.66	0.09
53	0.040039	145.03	0.11	27.45	0.08	0.62	0.10
54	0.040055	142.48	0.15	26.37	0.11	0.59	0.05
55	0.040019	137.94	0.09	27.15	0.10	0.66	0.07
56	0.040043	134.80	0.13	27.26	0.10	0.61	0.10
57	0.050071	157.39	0.11	32.71	0.10	0.65	0.10
58	0.050071	157.59	0.19	29.09	0.08	0.58	0.12
59	0.050600	160.96	0.11	30.32	0.07	0.61	0.11
60	0.050050	156.62	0.09	31.52	0.11	0.66	0.11

Table 5. Summarised values of blast-wave pressure, impulse and duration, for each explosive's Nominal Mass group.

Nominal Explosive mass group (kg)	**Range (m)**	**Blast-wave parameter**	**Mean**	**Sdev**	**COV**
Detonator only	0.882	P_i (Pa)	21.64	3.27	0.15
		I_i (Pa-sec)	2.81	0.55	0.20
		t_d (milli-sec)	0.40	0.04	0.10
0.020	0.882	P_i (Pa)	89.92	10.25	0.11
		I_i (Pa-sec)	18.36	1.63	0.09
		t_d (milli-sec)	0.59	0.03	0.05
0.030	0.882	P_i (Pa)	112.40	14.25	0.13
		I_i (Pa-sec)	23.45	2.45	0.10
		t_d (milli-sec)	0.64	0.06	0.09
0.040	0.882	P_i (Pa)	139.98	16.42	0.12
		I_i (Pa-sec)	27.08	2.54	0.09
		t_d (milli-sec)	0.62	0.06	0.09
0.050	0.882	P_i (Pa)	158.14	19.65	0.12
		I_i (Pa-sec)	30.91	3.02	0.10
		t_d (milli-sec)	0.62	0.07	0.12
0.100	0.882	P_i (Pa)	258.34	27.68	0.11
		I_i (Pa-sec)	47.10	4.95	0.11
		t_d (milli-sec)	0.66	0.08	0.12
0.300	0.882	P_i (Pa)	633.67	109.23	0.17
		I_i (Pa-sec)	90.14	19.01	0.21
		t_d (milli-sec)	0.69	0.15	0.21
0.500	0.882	P_i (Pa)	954.02	127.65	0.13
		I_i (Pa-sec)	127.87	18.01	0.14
		t_d (milli-sec)	0.72	0.10	0.14
0.700	0.882	P_i (Pa)	1278.08	157.16	0.12
		I_i (Pa-sec)	170.16	33.55	0.20
		t_d (milli-sec)	0.77	0.11	0.15

Table 5. Continued...

Nominal Explosive mass group (kg)	Range (m)	Blast-wave parameter	Mean	Standard Deviation	COV
0.850	0.882	P_i (Pa)	1514.26	175.42	0.12
		I_i (Pa-sec)	210.39	32.90	0.16
		t_d (milli-sec)	1.03	0.29	0.28
1.000	0.882	P_i (Pa)	1674.68	206.75	0.12
		I_i (Pa-sec)	200.40	27.70	0.14
		t_d (milli-sec)	0.79	0.18	0.23
1.200	0.882	P_i (Pa)	1897.17	282.93	0.15
		I_i (Pa-sec)	225.70	42.26	0.19
		t_d (milli-sec)	0.78	0.21	0.26
1.400	0.882	P_i (Pa)	2187.98	325.97	0.15
		I_i (Pa-sec)	249.98	42.99	0.17
		t_d (milli-sec)	0.83	0.32	0.38
1.600	0.882	P_i (Pa)	2319.56	258.04	0.11
		I_i (Pa-sec)	255.62	31.06	0.12
		t_d (milli-sec)	0.95	0.35	0.37
1.800	0.882	P_i (Pa)	2413.22	669.81	0.28
		I_i (Pa-sec)	290.51	67.53	0.23
		t_d (milli-sec)	0.78	0.32	0.41

8. DISCUSSION OF RESULTS

The data in this report is presented "*as-is*". That said, the only data records included were those associated with blast-waves that were unaffected; in that, the wave had to pass a "*visual inspection*" where rate of decay of the first positive wave was examined. If a wave had (clearly) been affected by something – such that the "*as-recorded*" decay rate was not "*smooth*" – then the data associated with that particular wave, from that particular gauge, was not included in this report's tabled data. In such a situation, the record was annotated as "*No Data*", or simply as: "N/D". This situation occurred 279 times out of the possible 480 data records. For example, Figure 12 shows the raw pressure-time history for Serial 03, Blast 09, Channel 04 (which was the blast-record for 1.8 kg of PE4 detonated at a range of 0.882 m). This figure shows an interruption to the "*normal*" decay profile of a blast wave's pressure time history; in that, at approximately 1.4 milli-seconds after the wave's arrival, the pressure jumps up again, and stays elevated, albeit with some slight decay over time.

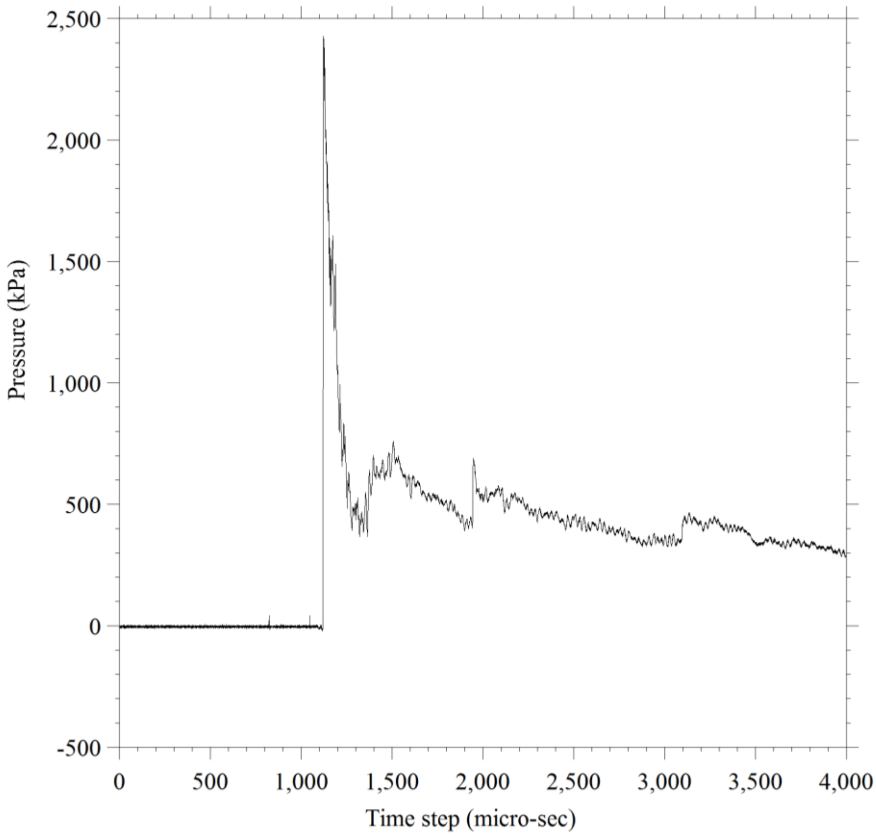


Figure 12. The raw pressure-time history from 1.8 kg of PE4, range = 0.882 m.
(Serial 03, Blast 09, Channel 09)

Another challenge was the determination of t_d, as it was (often) not easily identified. Previously, Figure 11 showed a "smoothed" pressure-time history, thus permitting a reasonable estimate of t_d. However, in some instances, the wave's profile seems to take a relatively long time to pass from positive pressure to negative, as shown in Figure 13.

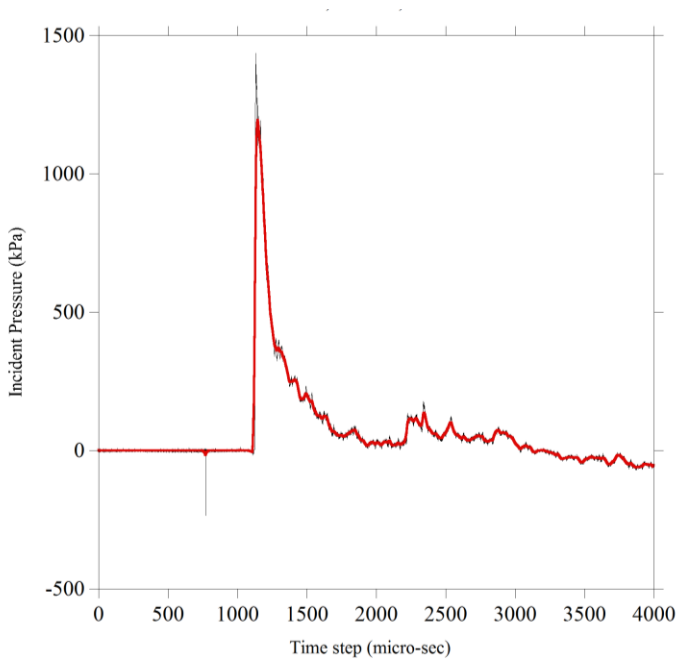


Figure 13. The raw pressure-time history from 0.85 kg of PE4, range = 0.882 m.
(Serial 06, Blast 22, Channel 04)

In this instance, the (red/smoothed) pressure-time history does not pass below the x-axis when expected, at approximately 1.8 milli-seconds; rather, the pressure seems to "hang-on" until approximately 2.2 milli-seconds. This 0.4 milli-second, or 22%, increase in t_d will cause significant differences in consequential calculations, such as t_d's model error.

There are a number of possible reasons for these situations, such as reflection of the wave from the ground, following which the incident and reflected waves coalesce; or, there could be a general increase in gas pressure around the base of the bunker, such that rapid "*clearing*" of the blast-wave does not occur. Notwithstanding, it is not the scope of this report to desegregate and/or identify the various reasons for a wave's disruption. Rather, the intent is to simply present the raw data, as best able, and to defer detailed review/analysis to another time and publication.

9. CONCLUSIONS AND RECOMMENDATIONS

An explosive blast trial was conducted with the following intent:

- To repeatedly detonate spheres of PE4, where all ranges are the same, such that an appropriate "spread" of scaled distances were observed, thus facilitating
- The capture of associated pressure time-histories from each blast, leading to
- The determination of three key blast wave parameters (P_i, I_i and t_d), destined for use in future probabilistic considerations.

The trial was considered a success, given the capture of more than 200 separate pressure-time histories, across 15 different explosive mass values.

The next trial will include additional (smaller) mass values, which should significantly reduce the number of "No-Data" situations.

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Figure 12. Professor Mark G. STEWART (Chief Investigator for the Project) inside the RAAF Base Williamtown blast test arena.

Figure 13. Inside the RAAF Base Williamtown blast test arena; from left to right:

- Ross GIBSON, Ian JEANS & Mick GOODWIN (UoN Civil Eng. Lab Technicians)
- Bryn ROGERS, Sam BUTTENSHAW & Kaitlyn READY (UoN Civil Eng. Students)
- Michael NETHERTON (UoN Project Supervisor)

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Annex A

The values of mass for the 60 different explosive charges are shown below in Table A1.

Table A1: Nominal and actual explosive masses, plus the relative difference between each.

Nominal mass (g)	Measured mass (g)	Relative difference (%)
20	20.019	0.095%
	20.045	0.225%
	20.035	0.175%
	20.040	0.200%
30	30.065	0.217%
	30.065	0.217%
	30.040	0.133%
	30.029	0.097%
40	40.039	0.098%
	40.055	0.137%
	40.019	0.047%
	40.043	0.107%
50	50.071	0.142%
	50.071	0.142%
	50.060	0.120%
	50.005	0.010%
100	100.123	0.123%
	100.033	0.033%
	100.027	0.027%
	100.093	0.093%
300	300.060	0.020%
	300.070	0.023%
	300.060	0.020%
	300.040	0.013%
500	500.017	0.003%
	500.040	0.008%
	500.027	0.005%
	500.024	0.005%

Nominal mass (g)	Measured mass (g)	Relative difference (%)
700	700.041	0.006%
	700.066	0.009%
	699.995	-0.001%
	700.094	0.013%
850	850.020	0.002%
	850.020	0.002%
	850.040	0.005%
	850.030	0.004%
1000	1000.090	0.009%
	1000.040	0.004%
	1000.090	0.009%
	1000.020	0.002%
1200	1200.070	0.006%
	1200.020	0.002%
	1200.070	0.006%
	1200.000	0.000%
1400	1400.070	0.005%
	1400.060	0.004%
	1400.030	0.002%
	1400.080	0.006%
1600	1600.090	0.006%
	1600.000	0.000%
	1600.080	0.005%
	1600.060	0.004%
1800	1801.522	0.085%
	1800.000	0.000%
	1800.013	0.001%
	1810.000	0.556%

The measured values of mass for the 139 different cartridges of PE4 as-used in the experiment, and the calculated statistics, are shown below in Tables A2 and A3, respectively.

Table A2: Measured explosive mass values (in grams) of the as-used PE4 cartridges.

226.340	224.280	235.120	230.760	220.570	234.570	229.352
226.316	233.665	223.327	220.282	231.971	233.014	224.010
230.497	225.757	232.428	230.832	242.828	232.277	225.383
241.118	226.902	226.239	227.820	229.528	235.739	236.829
228.573	223.198	230.770	223.460	223.420	227.748	227.578
225.775	235.056	228.323	243.164	226.734	223.206	230.529
221.744	226.800	231.006	226.896	229.181	213.224	231.873
227.696	231.502	227.898	230.412	222.454	229.960	229.071
225.245	237.827	223.857	221.806	230.516	236.556	229.384
236.539	230.244	227.987	230.975	227.326	228.248	236.034
229.823	222.839	223.823	224.762	229.259	235.601	228.494
235.348	224.751	232.896	230.911	221.313	227.030	224.282
227.659	220.638	227.485	232.384	227.893	234.022	231.454
228.466	234.021	233.375	228.844	234.487	224.636	223.990
222.424	235.005	227.071	236.208	233.479	228.797	234.237
233.097	230.357	234.145	231.611	228.509	236.039	228.464
233.473	230.137	227.778	227.262	235.912	233.811	230.032
226.642	232.828	225.312	226.634	223.530	229.444	231.385
226.724	234.714	228.487	235.559	235.410	229.531	223.251
233.326	230.523	233.871	234.359	228.436	225.843	

Table A3: Statistical information on the as-used PE4 cartridges:

Parameter:	**Value:**
Number of cartridges weighed (n)	139
Nominal mass of each cartridge (g)	230.000
Mean measured mass, μ (g)	229.437
Standard Deviation, σ (g)	4.802
Coefficient of Variation (COV = σ/μ)	0.021
Maximum mass (g)	243.164
Minimum mass (g)	213.224

Annex B.

Table B1. All Blast-wave information, for the 15 different explosive mass values, and for each of the 60 different blasts. NOTE: N/D = "*No Data*", as described in Section 8.

Serial #	**Blast #**	**Mass (kg)**	**Range (m)**	**Blast-Wave Value**	**Ch 1**	**Ch 2**	**Ch 3**	**Ch 4**	**Ch 5**	**Ch 6**	**Ch 7**	**Ch 8**
1	**1**	0.100123	0.882	P_i (Pa):	218.54	N/D	240.03	214.69	254.74	274.85	307.98	300.11
				I_i (Pa-sec):	41.51	N/D	43.13	41.91	46.54	47.71	49.88	56.59
				t_d (millisec):	0.617	N/D	0.706	0.641	0.607	0.641	0.575	0.851
	2	0.100033	0.882	P_i (Pa):	218.75	N/D	247.88	257.96	260.46	262.85	247.59	299.69
				I_i (Pa-sec):	42.94	N/D	45.56	45.72	46.19	48.82	45.93	55.64
				t_d (millisec):	0.697	N/D	0.701	0.659	0.607	0.653	0.604	0.726
	3	0.100027	0.882	P_i (Pa):	219.17	N/D	243	248.81	225.13	236.27	267.57	315.81
				I_i (Pa-sec):	40.77	N/D	42.83	44.39	45.79	46.04	47.5	61.2
				t_d (millisec):	0.508	N/D	0.693	0.641	0.647	0.666	0.571	0.893
	4	0.100093	0.882	P_i (Pa):	255.16	N/D	261.89	265.04	267.44	269.07	253.39	299.69
				I_i (Pa-sec):	45.26	N/D	43.56	45.97	46.92	45.52	47.78	57.23
				t_d (millisec):	0.665	N/D	0.687	0.576	0.607	0.657	0.614	0.731
2	**5**	0.30006	0.882	P_i (Pa):	556.97	579.1	636.72	753.53	571.44	588.45	647.31	819.03
				I_i (Pa-sec):	73.01	74.56	82.2	102.52	72.63	83.13	91.46	135.19
				t_d (millisec):	0.619	0.631	0.693	0.653	0.534	0.697	0.607	0.907
	6	0.30007	0.882	P_i (Pa):	514.67	494.77	575.8	663.24	666.64	694.13	648.39	780.61
				I_i (Pa-sec):	74.71	75.62	89.72	91.76	85.76	95.53	98.64	133.28
				t_d (millisec):	0.78	0.656	0.77	0.656	0.602	0.62	0.602	1.14
	7	0.30006	0.882	P_i (Pa):	464.79	641.97	657.94	591.25	610.36	N/D	818.38	636
				I_i (Pa-sec):	71.49	83.46	89.3	97.49	74.96	N/D	105.41	121.9
				t_d (millisec):	0.616	0.734	0.753	0.748	0.543	N/D	0.57	1.056
	8	0.30004	0.882	P_i (Pa):	583.91	476.68	583.02	592.08	569.96	531.86	963.87	731.02
				I_i (Pa-sec):	75.03	67.83	78.8	79.6	76.14	74.55	108.16	130.37
				t_d (millisec):	0.668	0.561	0.706	0.767	0.552	0.572	0.597	0.925
3	**9**	1.8	0.882	P_i (Pa):	2492.4	2359.9	2406.7	N/D	3058	N/D	2385.1	N/D
				I_i (Pa-sec):	258.16	213.37	208.65	N/D	273.66	N/D	358.65	N/D
				t_d (millisec):	0.667	0.345	0.629	N/D	0.648	N/D	0.65	N/D
	10	1.8	0.882	P_i (Pa):	2231	2530	2348.3	2457	211.7	N/D	N/D	N/D
				I_i (Pa-sec):	218.62	294.33	297.69	500.51	261.91	N/D	N/D	N/D
				t_d (millisec):	0.469	1.238	0.745	1.801	0.752	N/D	N/D	N/D
	11	1.8	0.882	P_i (Pa):	2324.7	2734	2214.6	N/D	2263	2459.7	N/D	N/D
				I_i (Pa-sec):	321.53	269.26	297	N/D	274.58	251.92	N/D	N/D
				t_d (millisec):	1.221	0.768	0.653	N/D	0.715	0.827	N/D	N/D

Table B1. Continued... (part 2 of 6)

Serial #	Blast #	Mass (kg)	Range (m)	Blast-Wave Value	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
3	**12**	1.8	0.882	P_i (Pa):	1967.5	N/D	N/D	3992	2287.3	2945.9	N/D	2595.6
				I_i (Pa-sec):	204.26	N/D	N/D	364.98	308.85	311.95	N/D	320.35
				t_d (millisec):	0.505	N/D	N/D	0.861	0.665	0.666	N/D	0.769
4	**13**	0.500017	0.882	P_i (Pa):	823.84	819.88	859.58	960.74	808.38	1223.4	976.34	N/D
				I_i (Pa-sec):	113.11	109.37	124.25	135.94	101.4	144.72	182.34	N/D
				t_d (millisec):	0.779	0.774	0.833	0.805	0.571	0.833	0.731	N/D
	14	0.50004	0.882	P_i (Pa):	799.43	822.19	849.18	856.72	N/D	1006.7	1036.3	N/D
				I_i (Pa-sec):	104.71	109.45	111.6	124.69	N/D	113.35	144.06	N/D
				t_d (millisec):	0.8	0.79	0.805	0.556	N/D	0.615	0.612	N/D
	15	0.500027	0.882	P_i (Pa):	1088.8	858.79	991.6	1032.3	902.52	1068.2	963.23	N/D
				I_i (Pa-sec):	140.63	122.48	131.22	138.58	115.34	120.38	144.29	N/D
				t_d (millisec):	0.776	0.682	0.809	0.572	0.737	0.623	0.581	N/D
	16	0.50024	0.882	P_i (Pa):	1039.1	720.62	1194.3	972.39	N/D	1026.8	1103.3	N/D
				I_i (Pa-sec):	117.44	129.59	134.09	130.82	N/D	122.69	158.09	N/D
				t_d (millisec):	0.65	0.776	0.849	0.64	N/D	0.774	0.617	N/D
5	**17**	0.700041	0.882	P_i (Pa):	1290	1482.3	1254.4	1097.6	1211.6	1451.4	1406.6	N/D
				I_i (Pa-sec):	141.14	173.93	144.77	155.61	139.5	177.72	197.18	N/D
				t_d (millisec):	0.809	0.71	0.679	0.634	0.591	0.782	0.673	N/D
	18	0.700066	0.882	P_i (Pa):	1243.5	1130.1	1299.8	N/D	1212.4	1456.4	1721.9	N/D
				I_i (Pa-sec):	152.86	150.82	170.5	N/D	138.06	171.92	238.34	N/D
				t_d (millisec):	0.811	0.806	0.862	N/D	0.606	0.867	0.739	N/D
	19	0.699995	0.882	P_i (Pa):	1112.2	1276.2	1172	1058.1	1105.4	1247.8	1310.7	1316.1
				I_i (Pa-sec):	140.75	149.63	158.62	191.97	139.54	149.59	187.26	268.44
				t_d (millisec):	0.789	0.881	1.009	0.772	0.665	0.594	0.681	0.962
	20	0.700094	0.882	P_i (Pa):	1140.8	1420.1	1011.3	1109.7	1352.3	1447.1	1337	1389.6
				I_i (Pa-sec):	138.88	165.12	144.32	174.86	158.39	163.21	210.85	240.75
				t_d (millisec):	0.806	0.814	0.819	0.889	0.701	0.66	0.788	0.955

Table B1. Continued... (part 3 of 6)

Serial #	Blast #	Mass (kg)	Range (m)	Blast-Wave Value	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
6	21	0.85002	0.882	P_i (Pa):	1391	1313.7	1388.5	1436.3	1567.2	1703.3	1823.5	N/D
				I_i (Pa-sec):	184.34	224.05	214.64	277.34	221.75	197.59	246.11	N/D
				t_d (millisec):	0.884	1.516	1.31	2.002	0.708	1.148	0.814	N/D
	22	0.85002	0.882	P_i (Pa):	1280.3	1525.8	1328.6	1460.5	1306.2	1797.2	N/D	N/D
				I_i (Pa-sec):	200.24	169.77	190.04	241.69	182.74	196.25	N/D	N/D
				t_d (millisec):	0.824	0.678	0.961	0.996	0.724	0.896	N/D	N/D
	23	0.85004	0.882	P_i (Pa):	1171.5	1377.8	1450.1	1510.4	1594.9	1432.8	1748.7	N/D
				I_i (Pa-sec):	161.69	166.56	197.62	274.32	197.36	169.16	252.63	N/D
				t_d (millisec):	0.993	0.842	1.157	1.034	1.157	0.649	0.776	N/D
	24	0.85003	0.882	P_i (Pa):	1460.7	1625.7	1441.1	1651.5	1603	1681.2	1813.4	N/D
				I_i (Pa-sec):	180.84	189.65	205.99	244.86	208.33	229.58	255.27	N/D
				t_d (millisec):	1.017	1.208	1.069	1.005	1.261	1.307	0.899	N/D
7	25	1.00009	0.882	P_i (Pa):	1265	1418	1572.3	1751.3	1609.7	1524.3	2078	N/D
				I_i (Pa-sec):	167.44	179.92	197.74	226.26	177.82	172.32	247.29	N/D
				t_d (millisec):	0.66	0.895	1.071	0.791	0.563	0.498	0.736	N/D
	26	1.00004	0.882	P_i (Pa):	1343.3	1548.1	1616.2	1809.6	1714	1773.2	1786.8	N/D
				I_i (Pa-sec):	140.91	221.66	201.11	245.47	201.14	209.86	244.89	N/D
				t_d (millisec):	0.439	0.697	1.024	0.961	0.775	0.644	0.646	N/D
	27	1.00009	0.882	P_i (Pa):	1522.2	1469.7	1834.4	N/D	1944.6	1855.1	N/D	N/D
				I_i (Pa-sec):	163.29	186	190.05	N/D	209.17	203.04	N/D	N/D
				t_d (millisec):	0.845	0.828	1.037	N/D	0.724	0.681	N/D	N/D
	28	1.00002	0.882	P_i (Pa):	1562.2	1659.6	1693.5	N/D	2065.4	1775.8	N/D	N/D
				I_i (Pa-sec):	179.67	190.58	203.48	N/D	238.26	212.12	N/D	N/D
				t_d (millisec):	0.978	0.712	1.056	N/D	0.967	0.655	N/D	N/D
8	29	1.20007	0.882	P_i (Pa):	1986.9	2498.9	1666.5	N/D	1479.2	1835.1	N/D	N/D
				I_i (Pa-sec):	196.37	202.9	198.12	N/D	207.8	199.32	N/D	N/D
				t_d (millisec):	0.804	0.669	0.585	N/D	0.577	0.612	N/D	N/D
	30	1.20002	0.882	P_i (Pa):	2258.8	1928.3	N/D	1637.7	1546.5	1891.5	N/D	N/D
				I_i (Pa-sec):	197.25	200.53	N/D	260.18	218.64	242.03	N/D	N/D
				t_d (millisec):	0.845	0.698	N/D	1.008	0.586	0.626	N/D	N/D
	31	1.20007	0.882	P_i (Pa):	1583.2	1861	1837.2	N/D	2245.2	2263.8	N/D	N/D
				I_i (Pa-sec):	167.72	219.71	233.45	N/D	290.57	231.43	N/D	N/D
				t_d (millisec):	0.491	0.744	0.699	N/D	0.72	1.033	N/D	N/D

Table B1. Continued... (part 4 of 6)

Serial #	Blast #	Mass (kg)	Range (m)	Blast-Wave Value	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
8	32	1.2	0.882	P_i (Pa):	1577.7	1711.1	1831.5	N/D	2152.8	1824.4	N/D	2223.3
				I_i (Pa-sec):	197.84	214.2	261.36	N/D	241.38	196.69	N/D	362.24
				t_d (millisec):	0.968	0.828	1.259	N/D	1.161	0.635	N/D	0.862
9	33	1.40007	0.882	P_i (Pa):	1629.9	2159	2262.5	N/D	2403.3	1817.1	N/D	N/D
				I_i (Pa-sec):	167.39	274.85	371.2	N/D	246.67	202.04	N/D	N/D
				t_d (millisec):	0.463	1.249	1.543	N/D	0.653	0.381	N/D	N/D
	34	1.40006	0.882	P_i (Pa):	1809	2008.7	1987.3	N/D	2363.9	2489.8	N/D	N/D
				I_i (Pa-sec):	196.91	261.45	254.21	N/D	255.65	233.33	N/D	N/D
				t_d (millisec):	0.489	1.173	0.76	N/D	0.628	0.71	N/D	N/D
	35	1.40003	0.882	P_i (Pa):	2338.1	2100.6	2374.6	N/D	2309.6	1916.6	N/D	N/D
				I_i (Pa-sec):	238.19	250.9	268.8	N/D	281.37	206.08	N/D	N/D
				t_d (millisec):	1.157	1.235	0.694	N/D	0.684	0.628	N/D	N/D
	36	1.40008	0.882	P_i (Pa):	1694.1	2426.1	N/D	N/D	2802.3	2679.2	N/D	N/D
				I_i (Pa-sec):	225.84	263.79	N/D	N/D	269.53	281.47	N/D	N/D
				t_d (millisec):	1.153	0.858	N/D	N/D	0.682	0.71	N/D	N/D
10	37	1.60009	0.882	P_i (Pa):	2241.1	2282.5	N/D	N/D	2600.2	N/D	N/D	N/D
				I_i (Pa-sec):	276.44	294.02	N/D	N/D	295.2	N/D	N/D	N/D
				t_d (millisec):	1.632	1.309	N/D	N/D	1.247	N/D	N/D	N/D
	38	1.6	0.882	P_i (Pa):	N/D	1740.8	N/D	N/D	2293.1	N/D	N/D	N/D
				I_i (Pa-sec):	N/D	235.35	N/D	N/D	270.73	N/D	N/D	N/D
				t_d (millisec):	N/D	0.686	N/D	N/D	1.202	N/D	N/D	N/D
	39	1.60008	0.882	P_i (Pa):	2373.9	2479.3	N/D	N/D	2179.4	N/D	N/D	N/D
				I_i (Pa-sec):	252.16	238.27	N/D	N/D	227.97	N/D	N/D	N/D
				t_d (millisec):	0.984	0.708	N/D	N/D	0.787	N/D	N/D	N/D
	40	1.60006	0.882	P_i (Pa):	2137.1	N/D	N/D	N/D	2516.5	2671.3	N/D	N/D
				I_i (Pa-sec):	198.28	N/D	N/D	N/D	285.08	238.36	N/D	N/D
				t_d (millisec):	0.487	N/D	N/D	N/D	0.763	0.632	N/D	N/D
11	41	0.009545	0.882	P_i (Pa):	22.81	18.67	19.5	25.37	26.06	19.13	21.08	28.66
				I_i (Pa-sec):	3.87	2.07	2.86	3.22	4.07	3.06	2.88	3.26
				t_d (millisec):	0.387	0.349	0.404	0.4	0.35	0.387	0.355	0.416
	42	0.009561	0.882	P_i (Pa):	20.92	18.67	17.17	25.78	22.88	15.27	21.29	24.53
				I_i (Pa-sec):	2.63	2.07	2.67	3.12	2.93	2.04	1.74	3.17
				t_d (millisec):	0.388	0.35	0.393	0.388	0.406	0.359	0.317	0.425

Table B1. Continued... (part 5 of 6)

Serial #	Blast #	Mass (kg)	Range (m)	Blast-Wave Value	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
11	43	0.009687	0.882	P_i (Pa):	21.13	17.82	22.05	22.45	21.83	17.42	21.08	25.36
				I_i (Pa-sec):	2.95	1.86	2.73	3.02	3.05	2.07	2.72	3.25
				t_d (millisec):	0.388	0.364	0.429	0.426	0.416	0.359	0.395	0.457
	44	0.009567	0.882	P_i (Pa):	21.34	16.77	21.2	22.45	22.46	18.7	24.73	27.84
				I_i (Pa-sec):	3.31	1.96	2.67	3.01	3.22	2.46	3.19	2.7
				t_d (millisec):	0.519	0.376	0.394	0.44	0.425	0.453	0.449	0.367
12	45	0.020019	0.882	P_i (Pa):	88.48	89.32	112.25	87.78	77.25	83.22	100.59	98.07
				I_i (Pa-sec):	17.07	17.08	19.09	18.45	16.91	17.68	20.27	21.01
				t_d (millisec):	0.572	0.616	0.568	0.573	0.65	0.631	0.565	0.598
	46	0.020045	0.882	P_i (Pa):	84.69	81.33	102.07	96.93	71.75	79.15	81.89	100.14
				I_i (Pa-sec):	17.52	17.15	19.8	20.19	16.06	16.11	18.36	18.81
				t_d (millisec):	0.612	0.547	0.577	0.587	0.596	0.531	0.596	0.563
	47	0.020035	0.882	P_i (Pa):	74.16	85.54	95.91	89.03	78.31	81.94	93.5	106.75
				I_i (Pa-sec):	16.05	15.74	18.72	19.04	16.46	17.41	19.81	21.41
				t_d (millisec):	0.579	0.598	0.604	0.608	0.642	0.569	0.617	0.582
	48	0.0204	0.882	P_i (Pa):	84.06	84.7	105.04	98.18	80.21	87.51	102.95	94.77
				I_i (Pa-sec):	17.25	17.55	19.05	19.16	17.95	18.35	21.58	20.54
				t_d (millisec):	0.607	0.61	0.585	0.606	0.664	0.562	0.613	0.605
13	49	0.03065	0.882	P_i (Pa):	101.1	104.67	127.96	121.07	90.16	120.73	136.05	140.63
				I_i (Pa-sec):	21.6	20.6	22.22	22.86	20.02	22.89	25.13	26.05
				t_d (millisec):	0.634	0.628	0.669	0.59	0.673	0.549	0.65	0.657
	50	0.03065	0.882	P_i (Pa):	81.53	95.84	111.19	113.58	93.75	97.37	117.78	121.21
				I_i (Pa-sec):	20.31	19.73	23.45	23.67	21.93	23.91	27.75	27.54
				t_d (millisec):	0.693	0.596	0.693	0.598	0.701	0.68	0.691	0.659
	51	0.0304	0.882	P_i (Pa):	98.58	121.71	126.69	121.07	93.75	96.73	116.28	118.73
				I_i (Pa-sec):	21.87	20.01	22.84	25.15	20.73	19.77	24.96	24.79
				t_d (millisec):	0.634	0.502	0.583	0.602	0.592	0.523	0.667	0.669
	52	0.030029	0.882	P_i (Pa):	111	112.25	134.11	122.31	112.37	103.16	122.08	111.29
				I_i (Pa-sec):	23.87	22	24.29	25.55	24.97	24.53	27.39	27.96
				t_d (millisec):	0.719	0.603	0.624	0.549	0.698	0.697	0.676	0.7
14	53	0.040039	0.882	P_i (Pa):	130.36	135.59	174.23	144.37	129.51	139.6	144.86	161.7
				I_i (Pa-sec):	25.05	25.03	27.78	28.33	25.24	27.12	30.43	30.64
				t_d (millisec):	0.567	0.566	0.557	0.587	0.646	0.606	0.673	0.738

Table B1. Continued... (part 6 of 6)

Serial #	Blast #	Mass (kg)	Range (m)	Blast-Wave Value	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7	Ch 8
14	54	0.040055	0.882	P_i (Pa):	116.47	135.8	142.18	143.54	120.62	170.03	N/D	168.72
				I_i (Pa-sec):	23.27	23.2	26.53	25.93	26.48	26.96	N/D	32.2
				t_d (millisec):	0.62	0.599	0.573	0.557	0.641	0.555	N/D	0.599
	55	0.040019	0.882	P_i (Pa):	134.99	124.65	164.89	132.72	145.37	143.03	125.95	131.95
				I_i (Pa-sec):	23.01	24.23	28.06	28.54	26.51	26.19	29.98	30.64
				t_d (millisec):	0.718	0.585	0.649	0.612	0.658	0.639	0.686	0.7
	56	0.040043	0.882	P_i (Pa):	137.09	129.07	164.04	153.52	112.79	119.66	136.48	125.75
				I_i (Pa-sec):	28.62	23.78	28.43	29.31	24.81	23.91	29.69	29.56
				t_d (millisec):	0.674	0.581	0.566	0.537	0.621	0.554	0.695	0.678
15	57	0.050071	0.882	P_i (Pa):	138.15	149.26	162.77	152.69	135.43	160.82	169.36	190.62
				I_i (Pa-sec):	29.98	29.1	31.75	29.59	32.37	34.85	36.54	37.51
				t_d (millisec):	0.677	0.582	0.7	0.586	0.563	0.674	0.7	0.716
	58	0.050071	0.882	P_i (Pa):	138.78	153.25	215.19	190.14	139.24	131.45	144.22	148.48
				I_i (Pa-sec):	27.66	27.15	32.28	31.15	26.89	26.72	30.11	30.73
				t_d (millisec):	0.637	0.513	0.536	0.513	0.546	0.562	0.672	0.683
	59	0.0506	0.882	P_i (Pa):	164.24	164.19	193.76	176.41	144.74	139.81	146.15	158.39
				I_i (Pa-sec):	29.34	27.65	30.92	33.55	29.25	29.63	29.02	33.18
				t_d (millisec):	0.619	0.496	0.545	0.543	0.647	0.65	0.672	0.674
	60	0.05005	0.882	P_i (Pa):	136.88	148.63	171.47	150.19	145.37	164.46	177.53	158.39
				I_i (Pa-sec):	31.42	26.1	29.53	30.42	29.8	32.06	36.95	35.86
				t_d (millisec):	0.658	0.587	0.572	0.671	0.648	0.666	0.678	0.802