

# Experimental validation study of equivalent bare charge calculation model for two shelled warheads

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**Abstract.** After the explosion of the warhead shell fragments will consume a portion of the charge release energy, a method of calculating the shockwave overpressure value of the explosion of the warhead is to calculate the shockwave overpressure value by firstly converting the actual charge  $C$  of the warhead into the charge  $C_{EB}$  of the bare charge, and then converting  $C_{EB}$  into TNT equivalent. Experimental results were used to compare the calculation error size of the two models for calculating the equivalent bare charge of the warhead, and the results show that the calculation results of Chi Jiachun's modified model are in better conformity with the experimental results; by analyzing the influence of the empirical constant in Chi Jiachun's modified model on the calculation results, the value of the empirical constant is given as a suggestion.

**Keywords:** Equivalent charge, warhead, bare charge, shockwave overpressure.

## 1. Introduction

Due to the fact that the warheads are equipped with housings, after the explosion of the charge to release part of the energy consumed in the fragmentation, another part of the consumption of the expansion of the blast products and the formation of air shock waves, therefore, compared with the same amount of bare charge, the warhead of the explosion of the formation of air shock wave overpressure and the specific impulse will be reduced. When calculating the shock wave overpressure value formed after warhead explosion, it is necessary to first equivalent the actual charge amount  $C$  of warhead to the charge amount  $C_{EB}$  of bare charge, and then convert  $C_{EB}$  to TNT equivalent to calculate the shock wave overpressure value [1].

There are some models for calculating the equivalent bare charge of the warhead, such as the early Fano model, Modified Fano model, Warren model, Fisher model, Modified Fisher model[2]. In recent years, Hutchinson[3] derived a new model based on the momentum step-by-step case between the detonation products and the shell during the explosion process, which takes into account the effects of shell material properties and explosive properties. Literature [1] provides a model for calculating the equivalent bare charge of the warhead, which is derived based on the conservation of energy in the explosion process of the warhead, although the calculation results of the model are in good conformity with the experimental results, Chi Jiachun[4] believes that the model ignores the change of the product density with the expansion of the volume when deriving the internal energy of the detonation products, and Chi is considering this change and under the assumption of the existing uniform distribution of the product density under the condition of this change and under the assumption of uniform distribution of product density, Chi re-deduced the model according to the same idea in the literature [1], and obtained the modified model.

In this paper, the experimental results in literature [3] and literature [4] are used to compare the error sizes of the computational results of the model in literature [1] and Chi Jiachun's modified model, and the computational results show that the computational results of Chi Jiachun's modified model conform better to the experimental results compared with the model in literature [1]. In addition, by

analyzing the influence of the empirical constant in the modified model of Chi Jiachun on the calculation results, a suggestion for the value of this empirical constant is given.

## 2. Equivalent Bare Charge Calculation Model for warhead

### 2.1 Modeling in the literature [1]

Because the warhead are with the shell, the warhead after the explosion of the release of energy consumed in part in the shell of the deformation, fragmentation and fragmentation of the dispersion, the other part of the consumption in the expansion of the explosion products and the formation of air shock waves. Shell deformation and fragmentation of the energy consumed about 1%~3% of the total energy, the approximate estimate is negligible, according to the law of conservation of energy, the weight of the explosive  $C$  of the total energy released should be used for the increase in the internal and kinetic energy of the explosion products, as well as fragmentation of the kinetic energy of the fly-away:

$$CQ_V = E_1 + E_2 + E_p \quad (1)$$

Where  $Q_V$  is the explosive heat of detonation,  $E_1$  is the internal energy of the bombardment product,  $E_2$  is the kinetic energy of the bombardment product,  $E_p$  is the kinetic energy of the fragmentation.  $E_1 + E_2$  can be considered to be the combat part of the explosion left to the energy equivalent of the bombardment product, if :

$$C_{EB}Q_V = E_1 + E_2 = CQ_V - E_p \quad (2)$$

The  $C_{EB}$  can be taken as the equivalent of the combatant charge considering the effect of the shell as the charge of the bare charge, and the expression for calculating the  $C_{EB}$  is obtained by derivation as:

$$C_{EB} = C \left[ \frac{\alpha}{a+1-a\alpha} + \frac{(a+1)(1-\alpha)}{a+1-a\alpha} \left( \frac{r_0}{r_m} \right)^{b(\gamma-1)} \right] \quad (3)$$

For an axisymmetric cylindrical warhead,  $a = 1$ ,  $b = 2$

$$C_{EB} = C \left[ \frac{\alpha}{2-\alpha} + \frac{2(1-\alpha)}{2-\alpha} \left( \frac{r_0}{r_m} \right)^{2(\gamma-1)} \right] \quad (4)$$

For spherical shell warheads,  $a = 2/3$ ,  $b = 3$

$$C_{EB} = C \left[ \frac{3\alpha}{5-2\alpha} + \frac{5(1-\alpha)}{5-2\alpha} \left( \frac{r_0}{r_m} \right)^{3(\gamma-1)} \right] \quad (5)$$

Where  $C$  is the actual charge for the warhead;  $C_{EB}$  is the equivalent bare charge for the warhead charge;  $\alpha$  for the warhead charge coefficient,  $\alpha=C/(C+M)$ ,  $M$  is the weight of the warhead shell;  $r_0$  for the radius of the warhead charge, that is, the inner radius of the shell before the explosion of the warhead;  $r_m$  for the shell is completely shattered inner radius, assuming that at this time the broken piece to reach the maximum speed;  $\gamma$  for the explosives multi-faceted index.

The experimental study shows that  $r_m/r$  can be approximated as  $r_m/r_0 \approx 1.5$  for steel shells and  $r_m/r_0 \approx 2.24$  for copper shells, and the value of  $r_m/r_0$  should be smaller when the shells are brittle materials or prefabricated fragments.

## 2.2 Modified model of Chi Jiachun

Chi Jiachun believes that the model in the literature [1] ignores the change in product density with volume expansion when deriving the internal energy of the detonation product, and he considers this change and under the existing assumption of a uniform distribution of product density, Chi Jiachun took  $\rho = M_e/V$  ( $\rho$  is the density of the detonation product,  $M_e$  is the mass of the charge, and  $V$  is the volume of the detonation product) and rederived it along the same lines as in the literature [1], resulting in the modified model [4].

For an axisymmetric cylindrical warhead:

$$C_{EB} = C \left[ \alpha + (1 - \alpha) \left( \frac{r_0}{r_m} \right)^{2(\gamma-1)} \right] \quad (6)$$

For spherical shell warheads:

$$C_{EB} = C \left[ \frac{3\alpha}{2 + \alpha} + \frac{2(1 - \alpha)}{1 + \alpha} \left( \frac{r_0}{r_m} \right)^{3(\gamma-1)} \right] \quad (7)$$

## 3. Experimental data

### 3.1 Modified model of Chi Jiachun

Chi Jiachun has conducted a set of experiments to study the effect of the shell on shockwave overpressure, and the schematic diagram of the charge structure used in the experiments is shown in Fig 1.

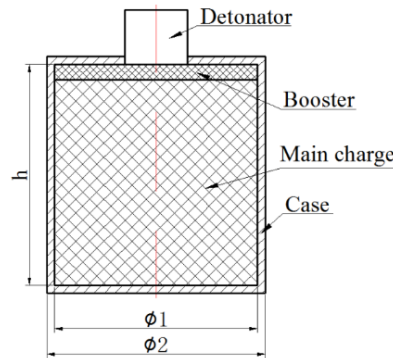


Fig. 1 Structural drawing for cased charge

This set of experiments included two warhead scenarios, which are shown in Table 1 for dimensions and charge mass.

Table 1 Structural dimension and charge's mass for cased charge

Program	Booster mass	Main charge mass (g)	φ1 (mm)	φ2 (mm)	h (mm)
NO.1	34	336	65	70	71
NO.2	34	516	66	71	95

The transmitting explosive charge was AIX-I(95%RDX, 5%mix-Wax) the main charge was AIX-II(76%RDX, 4%mix-Wax, 20%Al), and the shell material was steel. The calculated total charge for option I was 0.37kg and the mass of the shell was 0.446kg, and the total charge for option II was 0.55kg and the mass of the shell was 0.556kg.

Experimentally measured from the center of the explosion at different distances from the shockwave overpressure, through these data can be deduced by inverse calculation to obtain the corresponding TNT equivalent value, and then use the TNT equivalent coefficient of AIX-II explosives 1.521 calculated to obtain the corresponding equivalent AIX-II explosives charge, the results of the calculations are shown in Table 2.

Table 2 TNT equivalent values and AIX-II explosive mass calculated from experimental data

Program No.	C(kg)	M(kg)	TNT equivalent value	Mass of explosives for AIX-
NO.1	0.37	0.446	0.297±0.015	0.1953
NO.2	0.55	0.556	0.472±0.022	0.3103

### 3.2 BAE Systems experimental data[3]

BAE Systems carried out a series of experiments to study the effect of the warhead shell on the shockwave, and literature [3] used a set of experimental data from one of these experiments to validate its computational model. The set of experiments included four scenarios, in which the charge structure and material were the same, all cylindrical charge, the charge length-to-diameter ratio was 2:1, the charge was 1kg, the shell was an equal-wall-thickness steel shell, and the mass of the shells for the four scenarios was 0.5kg, 2kg, 5kg, and 10kg, respectively. The explosives used were ROWANEX 1100 (88% RDX, 12% plasticiser) and the casing material was EN 24 steel. For a detailed description of the experiments see literature [2].

Table 3 BAE Systems experimental data

C(kg)	M(kg)	CEB(kg)
1.0	0.5	0.783
1.0	2.0	0.487
1.0	5.0	0.365
1.0	10.0	0.330

## 4. Calculation result

### 4.1 Bursting parameter

According to the dimensions of the charge structure can be calculated to obtain the Chi Jiachun experiments in Scheme I charge density of  $1.57\text{g/cm}^3$ , Scheme II charge density of  $1.693\text{g/cm}^3$ , according to [5] in the method calculated to obtain the corresponding bursting speed  $D$ , bursting pressure of  $P_{CJ}$  and multi-faceted index  $\gamma$ , as shown in Table 4.

Table 4 Parameters of explosives used in Chi Jiachun's experiments

Program No.	$\rho(\text{g/cm}^3)$	$D(\text{m/s})$	$PCJ(\text{GPa})$	$\gamma$
NO.1	1.57	7244	19.54	3.217
NO.2	1.693	7589	22.57	3.32

The charge density, burst velocity and bombardment pressure of ROWANEX 1100 explosives are  $1.61\text{g/cm}^3$ ,  $8073\text{m/s}$  and  $25.07\text{GPa}$ <sup>[3]</sup>, and the multipartite index  $\gamma$  is calculated as 3.013 by the method in literature [5].

### 4.2 Comparison of the error in the calculation results of the two models

There is an empirical constant  $r_m/r_0$  in both models, which has a great influence on the calculation results, while the structure of the warhead, the shell material properties and the explosive properties have an influence on the  $r_m/r_0$  value, in order to accurately calculate the value of shockwave overpressure generated by the explosion of the warhead, it is usually necessary to test to obtain a

more appropriate  $r_m/r_0$  value. When there is no similar warhead test data, for steel shells,  $r_m/r_0$  can be approximated between 1.5 and 2.1 [6].

In order to examine the reliability of the calculation results of these two models, Eq. 4 and Eq. 6 were used to calculate the experimental programs of Chi Jiachun and BAE Systems, respectively, and to compare the magnitude of the error between the calculation results of the two models and the experimental results. The calculation results are shown in Fig. 2.

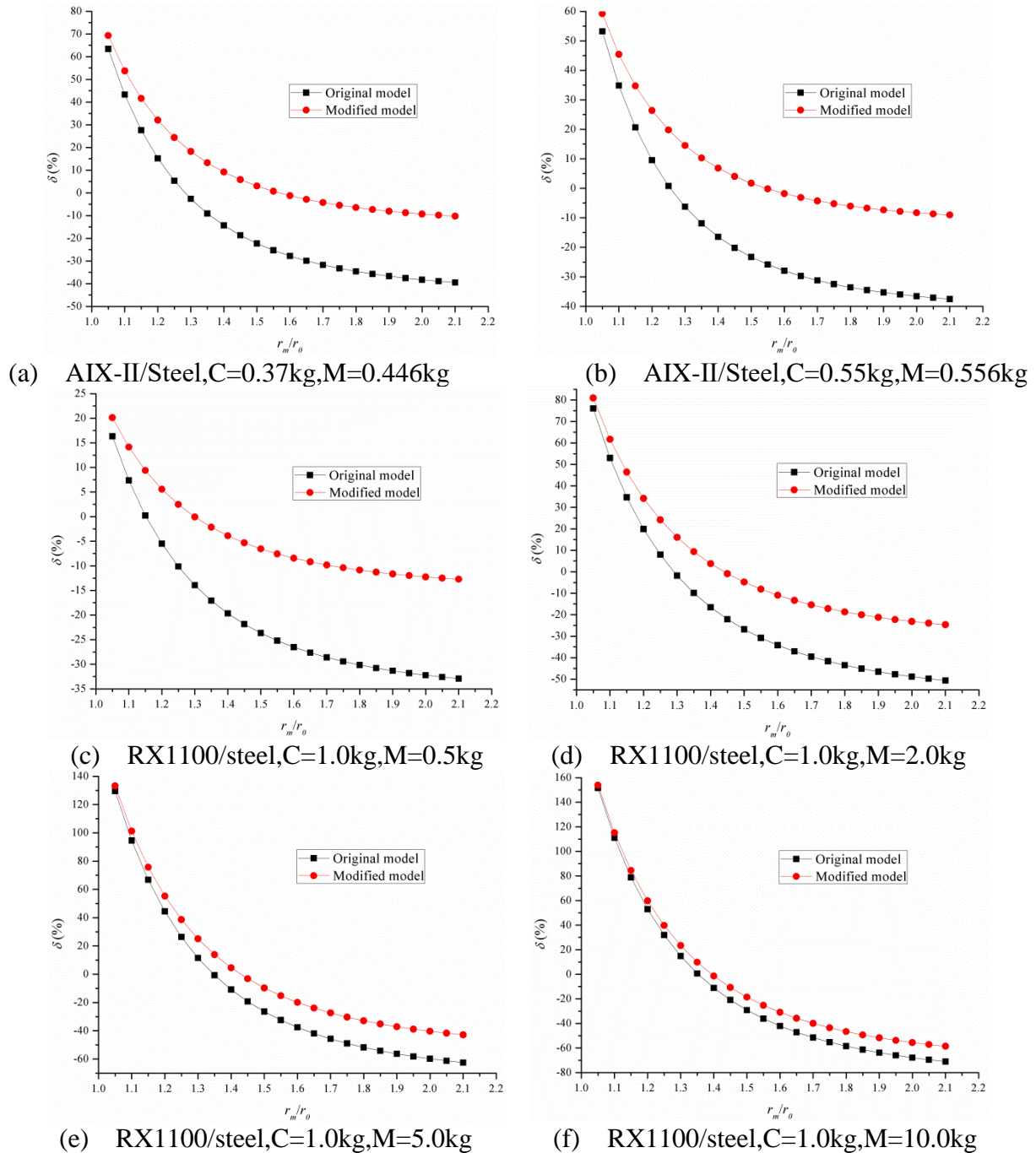


Fig. 2 Comparison of the errors in the calculation results of the two models

Table 5 Calculation results of Chi's modified model

rm/r0	AIX-II/Steel			RX1100/Steel		
	C=0.37kg	C=0.55kg	C=1.0kg	C=1.0kg	C=1.0kg	C=1.0kg
1.05	69.3	59.2	20.1	80.9	133.3	153.9
1.10	53.8	45.4	14.1	61.7	101.2	115.2
1.15	41.6	34.7	9.4	46.4	75.7	84.5

1.20	32.0	26.4	5.6	34.2	55.2	59.8
1.25	24.4	19.8	2.5	24.2	38.6	39.7
1.30	18.3	14.5	-0.1	16.1	25.1	23.3
1.35	13.3	10.3	-2.1	9.3	13.9	9.8
1.40	9.2	6.8	-3.9	3.8	4.6	-1.4
1.45	5.8	4.0	-5.3	-0.9	-3.2	-10.7
1.50	3.1	1.7	-6.5	-4.8	-9.7	-18.6
1.55	0.7	-0.2	-7.6	-8.1	-15.2	-25.3
1.60	-1.2	-1.8	-8.4	-10.9	-19.9	-30.9
1.65	-2.9	-3.1	-9.2	-13.3	-23.9	-35.8
1.70	-4.2	-4.3	-9.8	-15.4	-27.4	-39.9
1.75	-5.4	-5.2	-10.4	-17.2	-30.3	-43.5
1.80	-6.5	-6.0	-10.9	-18.7	-32.9	-46.6
1.85	-7.3	-6.7	-11.3	-20.1	-35.2	-49.3
1.90	-8.1	-7.3	-11.6	-21.2	-37.1	-51.7
1.95	-8.7	-7.8	-12.0	-22.2	-38.8	-53.7
2.00	-9.3	-8.3	-12.2	-23.2	-40.3	-55.5
2.05	-9.8	-8.7	-12.5	-23.9	-41.6	-57.1
2.10	-10.2	-9.0	-12.7	-24.6	-42.8	-58.6

### 4.3 Suggested values for empirical constants $r_m/r_0$

The results of the calculations for the above six experimental programs using the Chi Jiachun correction model are shown in Table 5.

As can be seen from the table, for the steel shell,  $r_m/r_0$  in the range of 1.4 ~ 1.5 range of values when the calculation results do not exceed 10% error (except  $\alpha=0.0909$  program, in practice, the warhead loading coefficient will not be so small), is acceptable. Therefore, when calculating the value of explosion shockwave overpressure with a steel shell warhead, it is recommended that the empirical constant  $r_m/r_0$  in the range of 1.4 ~ 1.5 value.

## 5. Conclusions

Compared with the original model for calculating the equivalent bare charge of the warhead in the literature [1], the error of the equivalent bare charge of the warhead calculated by Chi Jiachun's improved model is smaller, therefore, the value of shockwave overpressure formed by the explosion of the warhead using Chi Jiachun's modified model can get closer to the actual calculation results, and the empirical constants  $r_m/r_0$  in the model take the value of the range of 1.4 to 1.5.

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