Article

Numerical investigation of warhead design with HE

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A conventional warhead commonly employs case loaded high explosives (HE). The casing (shell and liner) of the warhead is accelerated and transformed by detonation energy of a HE into fragments, which destroy a target effectively. We should select the HE and design of the casing to destroy the target most effectively. To improve the performance of the warhead, we should consider not only the improvement of the HE and the shell, but also interaction between HE and the casing. Generally it may require a long time and high cost in the development of a new warhead. It is necessary to reduce the time and the cost, which are mainly originated from the experimental verifications in the development. Recently advancement in the computer technology and appearance of numerical analysis softwares enabled one to reduce time and cost for warhead design significantly. We tried to compare the experimental data with the calculated results obtained by using the hydrocode AUTODYN for warhead designs. The precision of the numerical values required for computer simulations has improved the accuracy of the calculated results for a warhead. Numerical methods for simulating different types of warheads are proposed in this paper.

1. Introduction

A warhead generally consists of a casing and a HE. It is classified into three major types; fragment-, HEAT (High Explosive Anti-Tank)- and EFP (Explosively Formed Penetrater)-warhead. A warhead requires the most suitable HE since size and structure of the warhead are restricted by a carrier such as missile and projectile. It is necessary to determine the optimal casing and HE in the development stage of the warhead by repetition of a series of process design, trial production, and testing. Thus great deal of time and cost should be spent in this process. In the past performance prediction of the warhead has been carried out by the empirical methods. Thus the predicted results were insufficient and the efficiency of HE was inestimable. However, at the present time, with a spread of high-performance personal computers and a progress in software, estimation of the interaction between the shell and HE and the simulation of a detonation in the HE have become possible. Accuracy of the simulation results also has increased to a practically usable level. It became possible to shorten the development period and to reduce the development cost. In this paper, the case studies of the computer simulation for warhead design in NIPPON KOKI Co. will be introduced.

2. The numerical analysis method

A PC (PENTIUM III: 1GHz, memory: 512MB) was used by using the following softwares.

2.1 KHT program ver.4.4

2.1.1 Calculation of detonation velocity, energy, and C-J (Chapman-Jouguet) pressure in loaded density of a HE

As for a HE, density and detonation velocity would be changed with the material lots, the composition ratio, and the loading conditions.

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Generally, a required performance will be realized, if the loading conditions are determined to satisfy a necessary density under the condition that the material lots and the composition are the same. If the actual measured values of the detonation velocity for the experimental HE were within 3% of the theoretical values calculated by using KHT (Kihara-Hikita-Tanaka) program, the HE is considered to satisfy a design level [1]. However, if dealing with a critical problem, the initial data of the KHT program should be corrected so the computed value to agree with the experiment value.

2.1.2 Calculation with the JWL E.O.S.

In order to use the JWL E.O.S. (Jones-Wilkins-Lee equation of state) applied to a HE in AUTODYN (Hydrocode) [2], it is necessary to determine the parameter of this equation [3][4]. Usually, these parameters of JWL E.O.S. have to be determined by experiments. However in this calculation, it could be determined numerically from the above-mentioned KHT program for the preservation of cost necessary for the experiments.

2.2 AUTODYN (Hydrocode)

2.2.1 Simulation by AUTODYN-2D

Simulations of a warhead by AUTODYN has been performed by inputting a set of data as follows; (1) geometric model of the warhead: (2) physical properties of the JWL E.O.S. for HE and Shock Hugoniot E.O.S. for a shell and liner: (3) physical properties of strength models for the structural materials: (4) boundary and initial conditions.

3. Example of an EFP warhead

3. 1 Experimental configuration

The performance confirmatory-test equipment of the EFP warhead is shown in Fig. 1. The EFP warhead (liner diameter: 90 mm) shown in Fig. 2 explodes by an electric detonator. The liner is accelerated and deformed by the energy of the HE. Then, the protection plate removed the fragments and only an EFP can pass through it. A mean EFP velocity was measured by using the foil targets and the shape of formed EFP had been taken as photographs with a flash X-ray equipment.

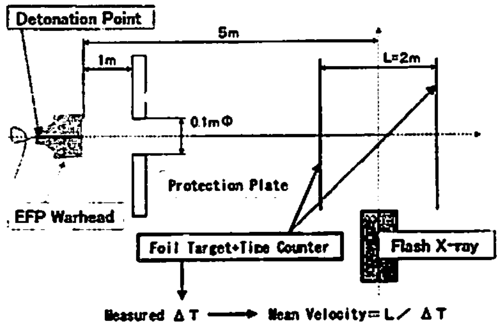


Fig. 1 Experimental set-up.

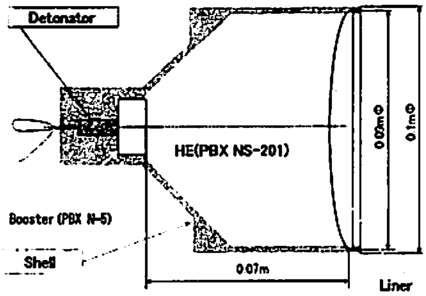


Fig. 2 EFP warhead.

3.2 Numerical calculations

3.2.1 Geometric model of the warhead

A geometric model is shown in Fig. 3. In order to save the computer time and the total cost, a two-dimensional axisymmetric model was used. An Eulerian processor for the HE and a Lagrangian processor for the shell and liner were applied.

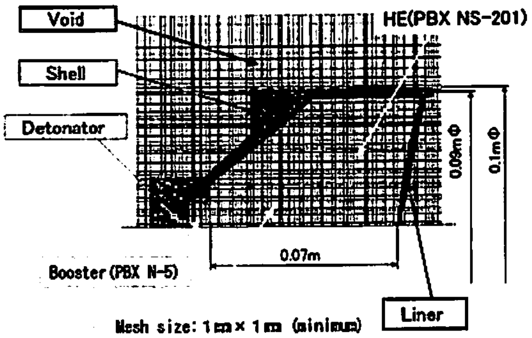


Fig. 3 Geometric model.

3.2.2 Physical-property model of the HE

PBX (PBX NS-201) made for an experiment in NIPPON KOKI Co. was used for the HE. PBX N-5 was used for the booster charge, and Tetryl for the detonator. The JWL parameters of these explosives are shown in Table 1.

Table 1 JWL parameters of explosives (the strength model is applied for Hydro model)

	Explosives name	PBX NS-201	PBX N-5	TETRYL
Combination component	Base material	HMX 90%	HMX 95%	TETRYL 99%
	Binder etc.	HTPB 10%	VITON A 5%	GRAPHITE 1%
Density (g/cm^3)		1.705	1.88	1.73
Detonation velocity (m/s)		8406	8816	7910
C-J Energy/Unit Vol. (kJ/mm^3)		9.381x10^{-3}	9.64x10^{-3}	8.20x10^{-3}
C-J Pressure (TPa)		3.095x10^{-2}	3.53x10^{-2}	2.85x10^{-2}
JWL parameters	A (TPa)	1.100	1.756	5.87x10^{-1}
	B (TPa)	2.862x10^{-2}	3.475x10^{-2}	1.07x10^{-2}
	R1	5.501	5.810	4.40
	R2	1.450	1.500	1.20
	ω	2.934x10^{-1}	3.21x10^{-1}	2.75x10^{-1}

3.2.3 Physical-property model of the casing

Two casing materials were used: (1) Steel for the shell, and (2) Tantalum for the liner. The E.O.S. was applied for the Shock Hugoniot and the strength model was applied for the Steinberg-Guinan.

3.2.4 Boundary and initial conditions

A boundary condition was applied for the Euler/Lagrange interaction. As the initial condition, the time detonation model* was used.

* (Detonation time of each HE cell) = (the distance from the initial detonating point to each HE cell) /(detonation velocity of the HE)

3.3 Results of the EFP warhead

The detonating simulation of the HE is shown in Fig. 4. The deforming simulation of the EFP and an outline of flash X-ray photographs are shown in Fig. 5.

When the simulation results and the experimental values were compared, the deformation of EFP, the path, length, and the velocity agreed well with the simulated values.

4. Example of the warhead controlling detonation waveform with an explosive lens

A HEAT warhead utilizes a technique to control the waveform of HE by either a wave shaper or multi-point detonator. In order to maximize this

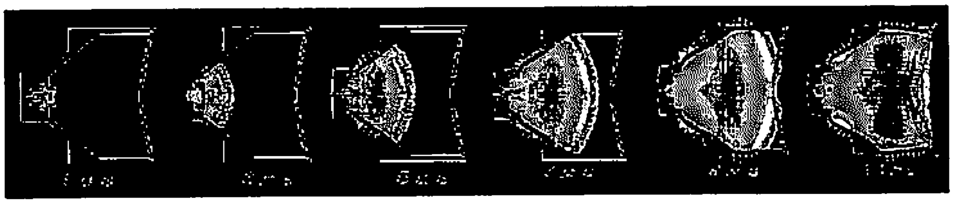


Fig. 4 Calculated results for detonation of the HE.

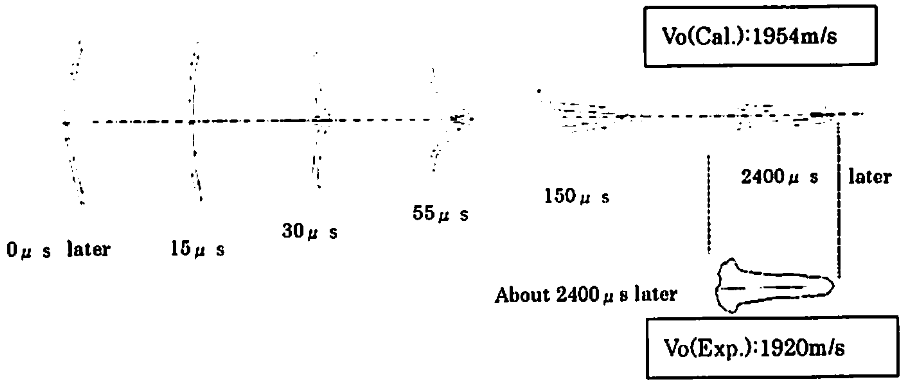


Fig. 5 Simulation of the EFP(upper) and an outline of flash X-ray photograph(under).

technique, we have to know the deformation efficiency of a liner and the performance of the metal jet.

A wave shaper is usually made of an inactive material. Fragment effect may decrease since the mass of the HE becomes lesser with increasing the mass of the wave shaper. A wave shaper is structurally simple but a multi-point detonation device has complicated shape and large size. The control technology of a detonation waveform is an effective means in order to use the energy of HE effectively. However development of a HEAT warhead employing a wave shaper costs much compared to a conventional HAET warhead because of structural complexity. If the simulation of an accurate explosives performance can be used in the design stage of a warhead, it will become reduction of development costs (trial production plus experiment). Therefore, a test warhead which using an explosive lens was made for obtaining necessary data for simulation.

4.1 Experimental configuration

The conventional warhead type without explosive lens is shown in Fig. 6. Two types of warheads controlling of detonation waveform with an explosive lens are shown in Fig. 7. An ion-gap probe was also set to others test warhead in the same manner as shown in Fig. 6.

4.2 Numerical method

4.2.1 Geometric model of the warhead

The geometric models of three warheads are shown in Fig. 8. In order to use the model of a two-dimensional axisymmetry, the Lagrangian processor was used to save the computer time and

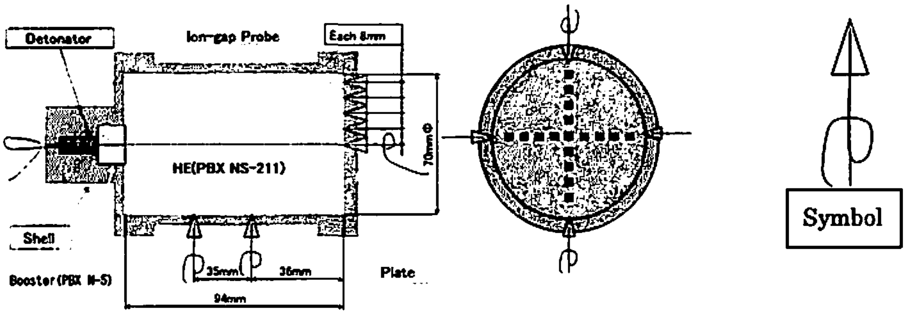
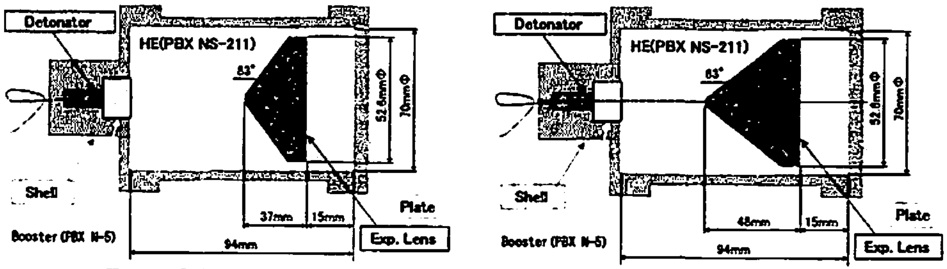
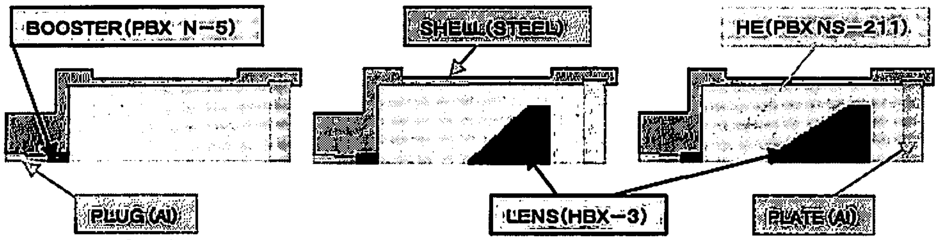


Fig. 6 Conventional warhead type (Type of no lens).
(The symbol of the right in the left figure indicates the ion-gap probe.)



Type of short length lens Type of long length lens.

Fig. 7 Two warheads with an explosive lens.



Type of no lens Type of short length lens Type of long length lens

Fig. 8 Geometric models of three warheads.

Table 2 JWL parameters of explosives (the strength model is applied for Vonmieses model)

	Explosives name	PBX NS-211	PBX N-5	HBX-3
Combination component	Base material	RDX 91%	HMX 95%	RDX 31% TNT 29%
	Binder etc.	HTPB 9%	VITON A 5%	Al etc. 40%
Density (g/cm^3)		1.650	1.88	1.80
Detonation velocity (m/s)		8184	8816	6849
C-J Energy/Unit Vol. (kJ/mm^3)		8.755x10^{-3}	9.64x10^{-3}	4.00x10^{-3}
C-J Pressure (TPa)		2.831x10^{-2}	3.53x10^{-2}	1.70x10^{-2}
JWL parameters	A (TPa)	1.027	1.756	2.254
	B (TPa)	2.608x10^{-2}	3.475x10^{-2}	1.587x10^{-2}
	R1	5.524	5.810	6.623
	R2	1.450	1.500	1.587
	ω	2.88x10^{-1}	3.21x10^{-1}	2.23x10^{-1}

Table 3 Typical parameters of the Lee-Tarver model

Explosives name		PBX NS-211	HBX-3
Ignition parameter	I(1/μs)	44	400
Growth parameter	G1	800	45000
Growth reaction ratio exp. C		0.222	0.222
Growth reaction ratio exp. D		0.667	0.667
Growth reaction ratio exp. Y		1.6	2.2

maintain the satisfactory resolution as structures. The target point was set to the same position as the ion-gap probe.

4.2.2 Physical property model of the HE

PBX (PBX NS-211) made as an experiment in NIPPON KOKI Co. was used for the HE. PBX N-5 was used for the booster charge, and HBX-3 for the explosive lens. The JWL parameters of these explosives are shown in Table 2.

4.2.3 Detonation condition of the HE (Lee-Tarver model)

Lee-Tarver model was described for ignition and growth model of explosive initiation. The results of calculation to apply the model on shock initiation of heterogeneous explosives such as PBX-9404, Comp.B were compared with published experimental data 5)6).

We thought that the Lee-Tarver model could be applied for explosion and the detonation model of the HE made in our company. Accordingly we tried to use it for the simulation of the warhead. Typical parameters of the Lee-Tarver model are summarized in Table 3.

4.2.4 Physical property model of the casings

The casings were used two materials: (1) Steel for the shell, and (2) Aluminum for the plate and plug. The shock Hugoniot E.O.S. was applied to both materials. The strength model of the Steinberg-Guinan was also applied to them.

4.3 Results of the warhead controlling detonation waveform with an explosive lens.

The detonating simulations of three warheads are shown in Fig. 9. The pressure curve figures on the target point of these warheads are shown in Fig.10.

From the comparison of the shape of detonation wave front (Fig.11), these look like flat in both warheads with an explosive lens. The attainment time lag of the detonation wave could be compared for calculation (left) and experiment (right) in Fig.12.

5. Consideration of the results

Although the form of a flare part is slightly different from calculation and experiment, as for the EFP warhead, the simulation became similar to the experimental results on the whole. On the

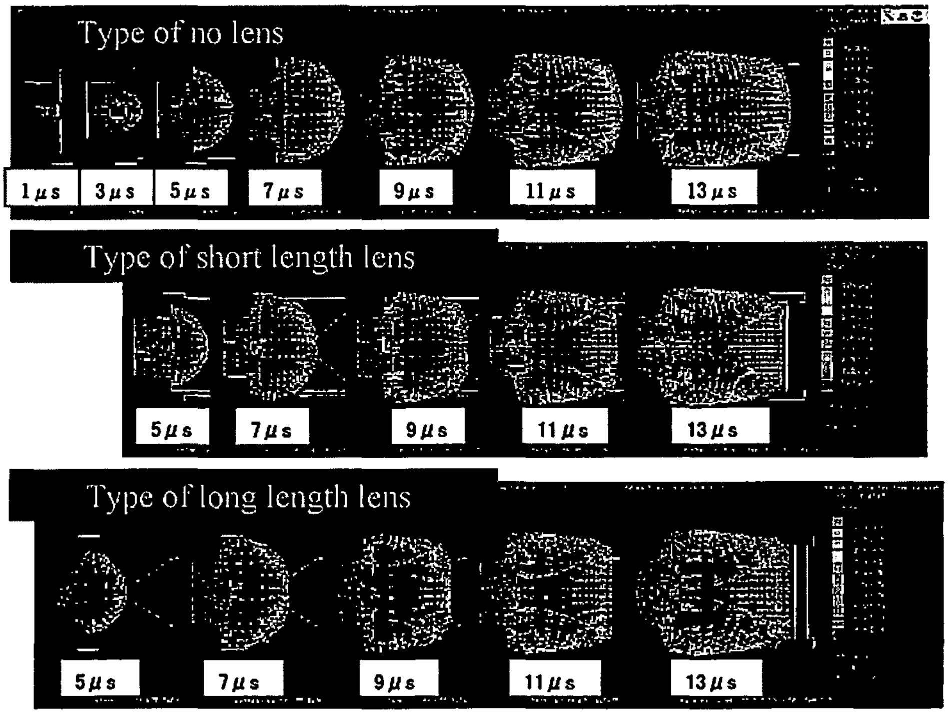
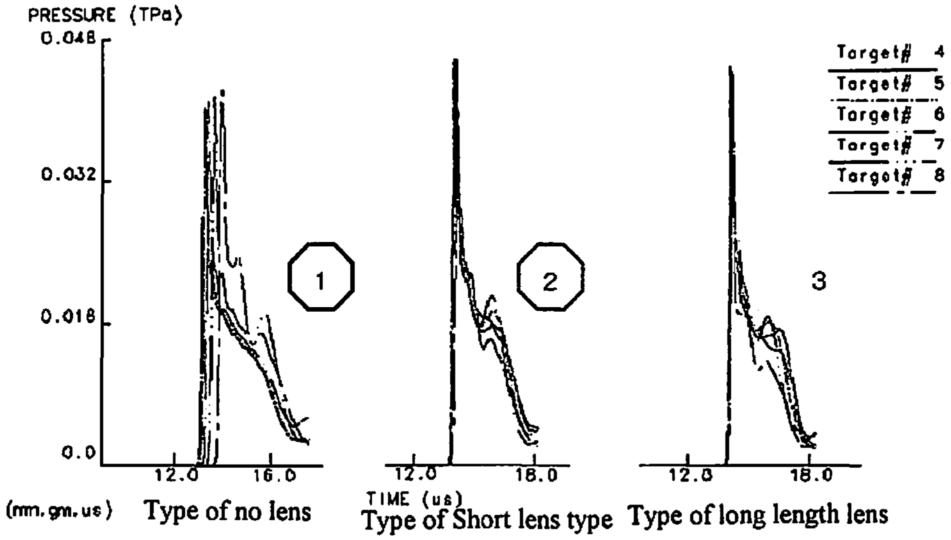


Fig. 9 Calculated results for detonation of three warheads.



Type of no lens Type of Short lens type Type of long length lens

Fig. 10 Pressure curve on the target point.

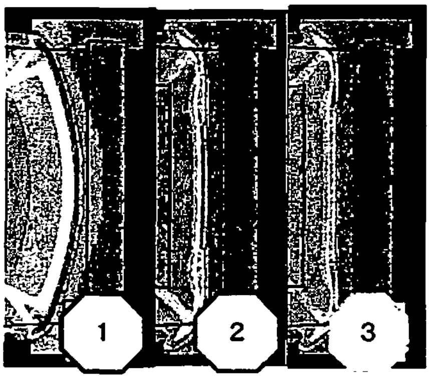


Fig. 11 Shape of detonation wave front in the warhead near the plate.

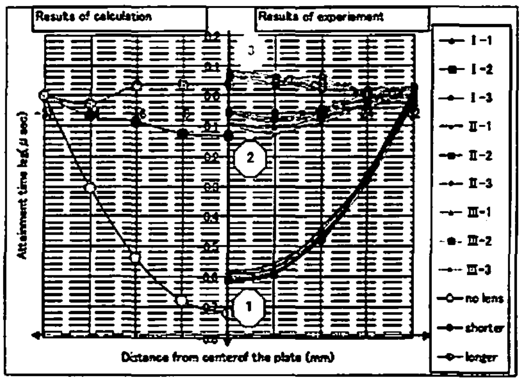


Fig. 12 Attainment time lag of the detonation wave to the ion-gap position on the plate in the warhead.

(The number inside the hexagon in these figures has the same meaning as the contents in Fig.10) other hand we think that the simulation of an explosion situation can express the detonation situation well although the tendency for the detonation velocity in the central part is quicker than that in circumference parts in the warhead from the comparison of the simulated results with those obtained experimentally. We consider that the velocity difference between the simulation and the experiment were caused by the accuracy of the Lee-Tarver modeling of HE based on the smaller scale test results.

6. Conclusions

As for this simulation, we have a final goal to calculate them less costly, more simply, and with higher speed. Since a mesh was coordinated more coarsely than the manual currently introduced to reference [7], the calculation of the EFP warhead took two hours for one case and the calculation of the warhead with the explosive lens took half an hour in one case.

Generally, since a calculation time is proportional to the number of mesh. The number of mesh is proportional to the calculation accuracy. Thus the number of mesh should be determined by trade-off of effects to expenses.

Since it is possible to verify the performance required for a design by coarse setup like this simulation, we believe that it is possible to use the simulation for the warhead design.

It is very important that a warhead designer's idea could be examined by using numerical simulation quickly. We will accumulate required data for these simulations further from now on. Accuracy of a warhead simulation would be much improved in near future.

References

1) K. Tanaka, Detonation Properties of Condensed Explosives Computed Using the Kihara-Hikita-Tanaka Equation of State, National Chemical Laboratory for Industry (1983).
2) Century Dynamics Inc., AUTODYN (Interactive Non-Linear Dynamic Analysis Software) Users Manual Revision 3.0 (1997).
3) M. Katayama, K. Tanaka, and T. Aizawa, Proc. Annual Symposium on Shock Wave, Tokyo (1992).
4) M. Katayama and K. Tanaka, J. Japan Explos. Soc., 62, 257-268 (2001).
5) Shiro Kubota, Hideki Simada, Kikuo Matsui, Yukio Kato, Katsuhiko Takahashi, Masatake Yoshida, Zhi-yue Liu, and Shigeru Itoh, Kayaku Gakkaishi, Vol.62, No.2 (2001).
6) E. L. Lee and C. M. Tarver, Phys. Fluids, 23, 2362 (1980).
7) Century Dynamics Inc., Explosive Initiation Users Manual (Lee-Tarver Ignition & Growth) Revision 4.1 (1999).