Burst Process of Spherical Aerial Shells

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ABSTRACT

The burst process of spherical fireworks shells has been examined experimentally and presented as a simplified physical model. The pressure in a shell was measured with a strain-type pressure transducer, which was inserted into the center of the shell. After the ignition of the bursting powder, pressure increased exponentially and the pressure also decreased exponentially, when the shell burst. The analysis of the pressure-versus-time curve indicated that the acting force on the stars in the shell was found to be dependent on various physical parameters: 1) the shape and material of the shell, 2) the characteristics of the bursting charge, and 3) the stars in the shell. The bursting process proposed in this study was confirmed by the observed ejection process of the stars in a Japanese-style, "warimono" spherical shaped shell.*

**A spherical shaped shell containing stars and bursting charge that produces a chrysanthemum-flower shaped display in sky.* [1]

Keywords: spherical aerial shell, burst process, pressure impulse, star acceleration

Introduction

The Japanese-style shells are known to be completely spherical in shape,[1] ranging from 70 to 900 mm in diameter as shown in Figure 1. A typical example of the biggest shell, 900 mm in diameter, is also shown in Figure 2. The shell is made of a relatively thick paper that consists of several pasted layers. The thickness of the shell wall is dependent both on the spherical size of the shell and the mass of the bursting charge. In general, the thickness of the shell wall increases as the size of the shell increases and as

Figure 1. Examples of typical Japanese-style spherical shells.

Figure 2. One of the biggest spherical shells in Japan.

the mass of the bursting charge increases. Figure 3 shows a cut-away model of a typical Japanese-style spherical warimono. A number of stars are set inside of the shell wall and held in

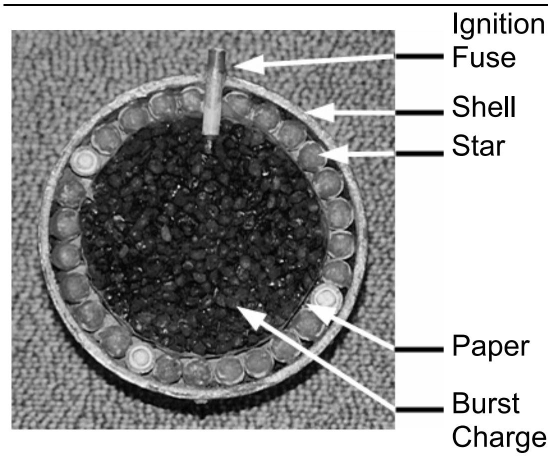

Figure 3. A typical cut-away model of a warimono (Japanese-style spherical display shell).

place with a spherical sheet of paper. A bursting charge is stuffed inside of the spherical sheet of paper. The ignition fuse is inserted into the center of the shell from the outside of the shell wall.

The design of the warimono shells is based on the long-term experience and skill of the technicians. Theoretical analysis and experimental data related to shell design have not been previously reported. In this study, experimental measurements on the process of bursting shells have been conducted to evaluate the force acting on the stars and the initial velocity of the stars ejected from the bursting shell.

Experimental

To measure the force acting on the stars, which are placed inside of the spherical shell, the internal pressure generated by ignition of the bursting charge was measured using a pressure transducer. A warimono shell containing no stars was used as shown in Figure 4. The pressure was measured using a small stainless tube that was placed at the center of the shell. The tube was 8 mm in diameter, and the pressure transducer was mounted on the stainless tube outside the casing. The pressure measurement setup is shown in Figure 5. The time response of the transducer was approximately 4 µs. That was considered short enough to measure the burning process of the bursting charge and the pressure decay process of the shell burst.

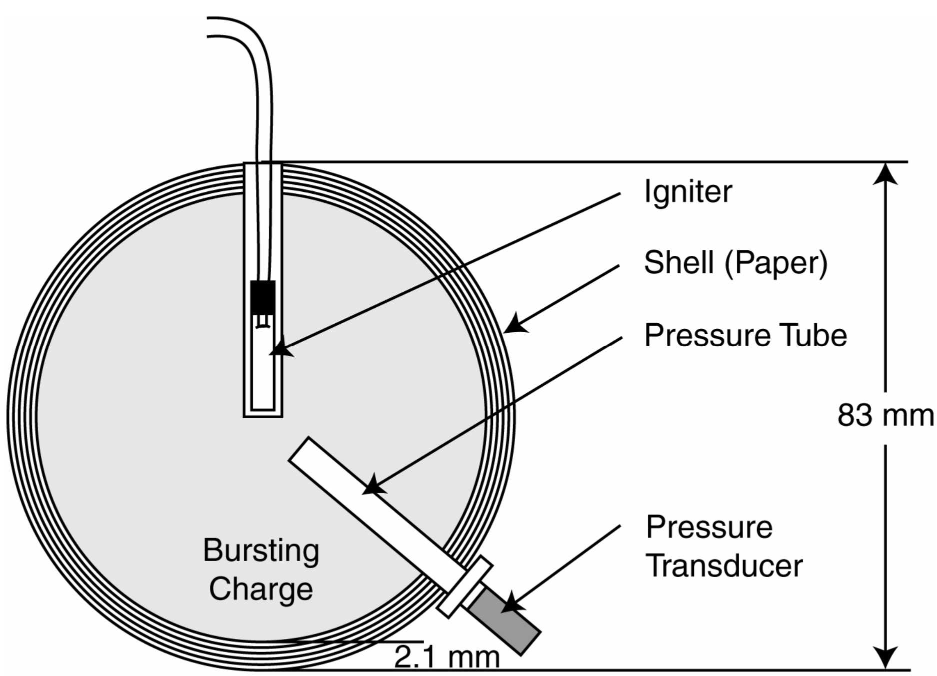

Figure 4. The warimono used for the measurements of pressure and shell fragments.

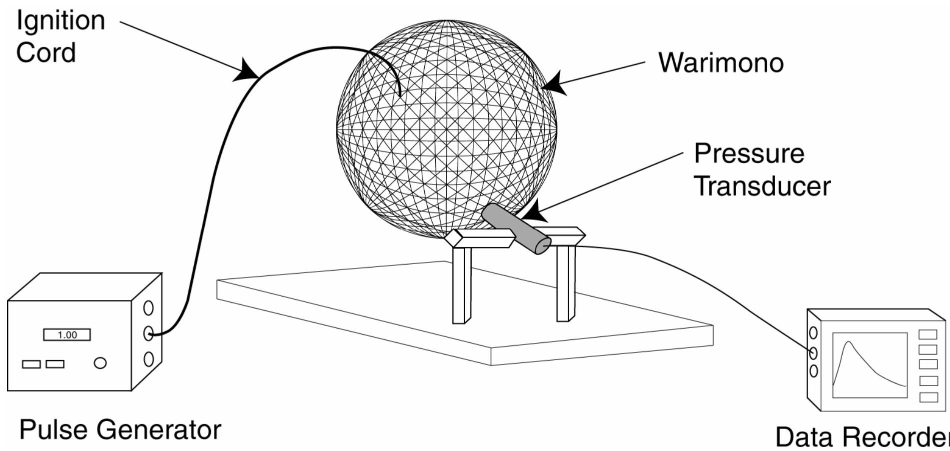

Figure 5. The experimental setup used for the measurements of pressure and shell fragments.

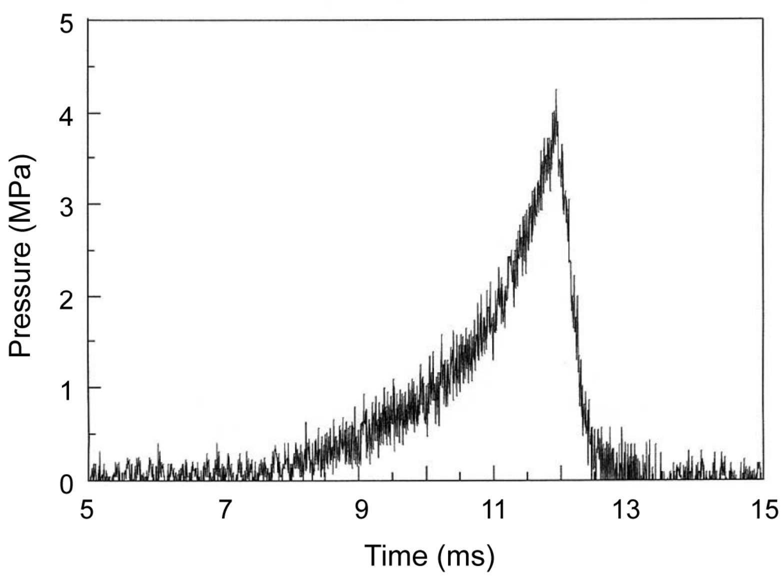

Figure 6. A typical pressure-versus-time curve during the process of a bursting warimono shell.

The bursting charge used was 100 g of potassium nitrate-based powder. The charge was ignited electrically through an ignition charge (0.3 g) of B/KNO_3 powder. The ignition signal and pressure were recorded by a DL708 Digital Scope. The chemical composition of the bursting charge is shown in Table 1.

Table 1. Chemical Composition of the Bursting Charge Used in this study.

Chemical Composition	% (mass)
Potassium nitrate	70
Sulfur	9
Hemp charcoal	14
Cooked rice powder	4
Chaff	3

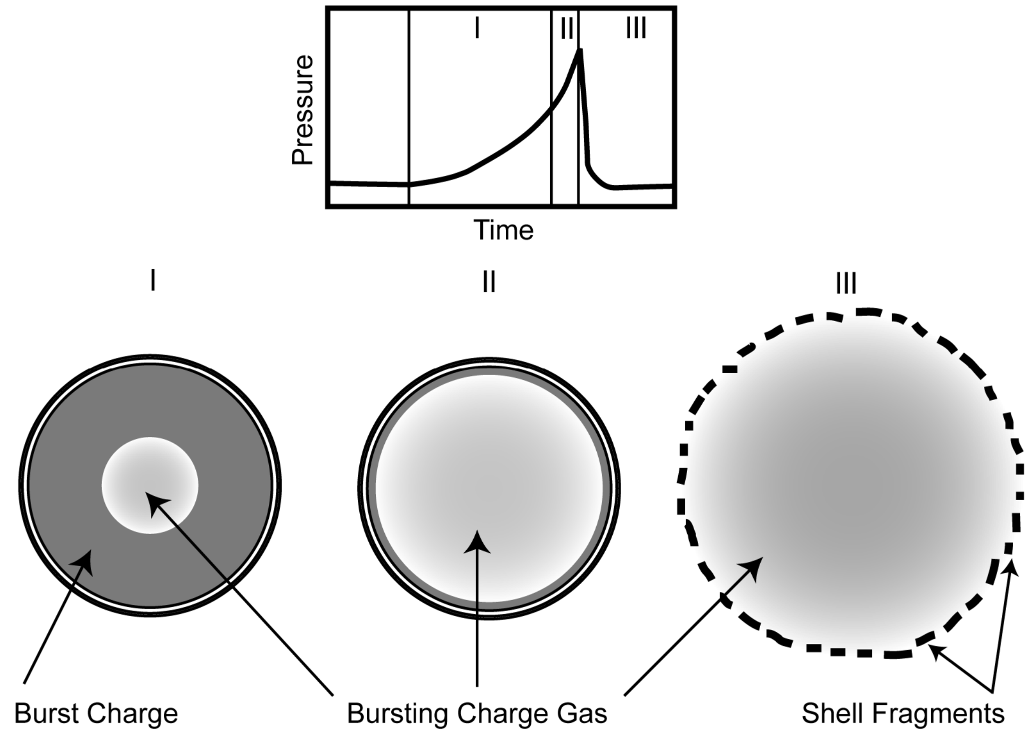

Figure 7. The bursting model of a warimono shell proposed in this study.

Results and Discussion

Figure 6 shows a typical example of the pressure-versus-time curve. No pressure rise was seen until 7 ms after the ignition signal. The pressure started to increase relatively smoothly at 10 ms then increased rapidly and reached its maximum of 4.4 MPa at 11.9 ms. The pressure decreased rapidly after reaching the maximum and returned to the initial atmospheric pressure within 0.5 ms.

The combustion gas generated in the shell, due to the rapid burning of the bursting charge, raises the pressure in the shell. Since the initial pressure wave, generated at the center of the shell, propagates at the speed of sound of the burned gas (approximately 600 m/s), it passes before the pressure rises uniformly in the shell

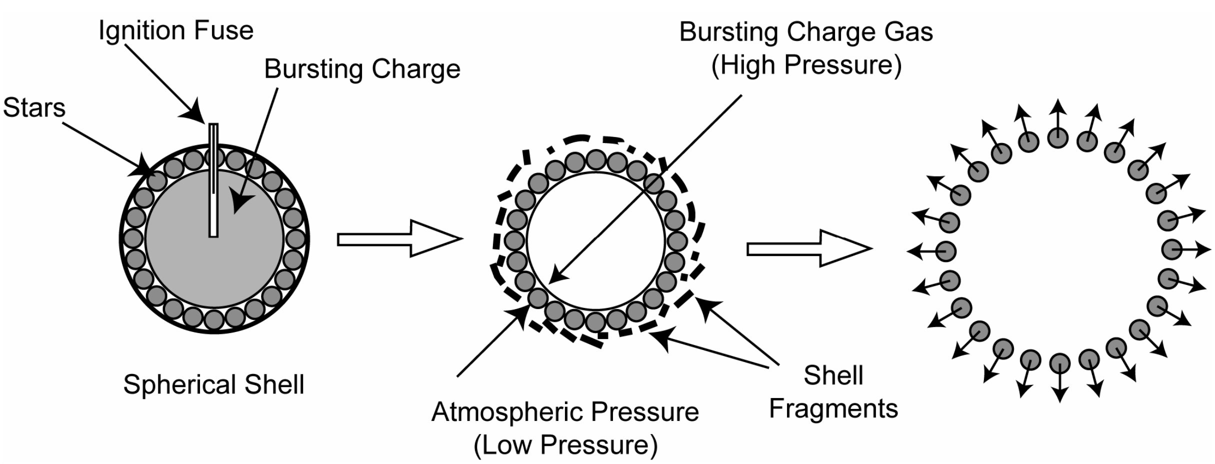

Figure 8. The ejection process of stars from a burst shell.

during the burning of the bursting charge. The pressure reaches its maximum when the shell bursts. The pressure is released, and the burned gas is ejected radially (i.e., to the atmosphere). This process is illustrated in Figure 7. No significant change in the shape of the shell is seen in Zones I and II during pressure build up. A large number of tiny fragments of the burst shell casing are created in Zone III, which are also ejected radially, and the pressure in the shell rapidly decreases. This process is illustrated in Figure 8. Figure 9 is a photograph of typical fragments of a burst shell. The tiny fragments are the result of the brittle fracture nature of the paper shell casing.

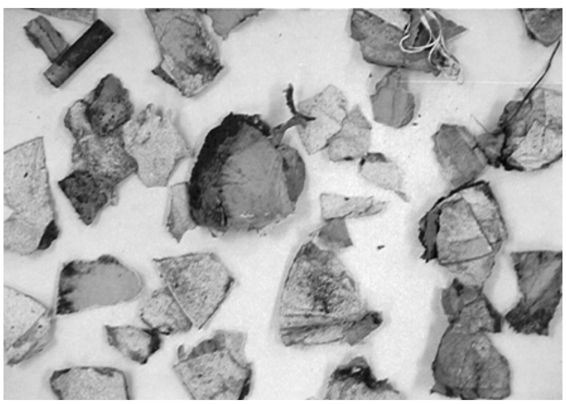

Figure 9. A photograph of the typical fragments of a burst shell.

Since the pressure difference between the gas generated by the burning bursting charge and the atmosphere is large where the shell bursts, a pressure difference is created between the inner surface and the outer surface of each star.

It is evident that the pressure difference generated at the shell surface acts to force the stars outward in a radial direction when the shell bursts. If one assumes that the pressure difference between the inner surface and the outer surface of a star in the shell is p_s, and the surface area of the shell is a_s, the acting force on the star, F_s (illustrated in Figure 10), is given by

$$F_s = \int p_s \, da_s \tag{1}$$

The impulse acting on the star caused by the pressure difference, I_s, is given by

$$I_s = \int F_s \, dt \tag{2}$$

Substituting equation 1 into equation 2, one gets

$$I_s = \iint p_s da_s dt \tag{3}$$

Since the pressure acting on the star surface is dependent on the pressure decay process when the shell is burst, the force acting on the star is also dependent on the pressure decay process. It is also assumed that the pressure created in the shell acts on the inner-hemisphere of the shell and the atmospheric pressure acts on the outer-hemisphere of the shell. The effective pressure surface area of the star A_s is given by

$$A_s = \tfrac{1}{4}\pi d_s^2 \tag{4}$$

where d_s is the diameter of the star. Thus, the impulse is given by

$$I_s = (\tfrac{1}{4}\pi d_s^2) \int p_s dt \tag{5}$$

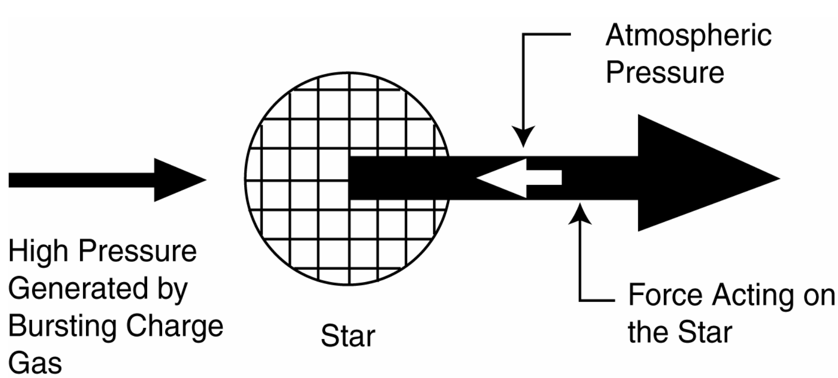

Figure 10. The impulse acting on a star surface due to the high pressure generated by the bursting charge.

This impulse is converted to the momentum change of the star as

$$I_s = m_s\, v_s \tag{6}$$

where m_s is the mass of the star and v_s is the initial velocity of star toward the outward radial direction. Using equations 5 and 6, v_s is represented by

$$v_s = \left(\frac{\frac{1}{4}\pi d_s^2}{m_s}\right)\int p_s \mathrm{d}t \tag{7}$$

Since the real star ejection velocity v_s is considered to be reduced by aerodynamic and mechanical losses caused by gas movement and shell fragment formation process, the pressure efficiency η_b is defined as

$$v_s = \eta_b \left(\frac{\frac{1}{4}\pi d_s^2}{m_s}\right)\int p_s \mathrm{d}t \tag{8}$$

The ejection model indicates that the pressure decay process occurring at the shell burst is an important parameter for the determination of the star ejection velocity.

In order to evaluate the validity of the star ejection model represented by equation 8, a model calculation was done at the following condition:

$d_s = 11$ mm

$m_s = 1.0 \times 10^{-3}$ kg

Using the pressure curve $p_s(t)$ shown in Figure 6, the ejection velocity was determined to be $v_s = 95$ m/s in case of $\eta_b = 1.0$.

The experimental results obtained by photographic observation[2] showed that the star ejection velocity ranged from 34 to 95 m/s. Using equation 8 and the observed results, the pressure efficiency was determined to be $\eta_b = 0.36$ to 1.0. Though the experimental values are scattered in the data and the star ejection model is a simplified one, the ejection process of stars from spherical aerial shells can be understood.

Conclusions

The experiments conducted in this study revealed the ejection process of the stars in a spherical shell. The shell wall is burst by the pressure created by the burning of the bursting charge. The pressure difference between the inner-side and the outer-side surfaces of each star in the shell is converted to the impulse given to each star. The impulse gives the ejection velocity of each star toward the outward radial direction.

It is important to note that a large number of fragments are created when the shell wall is made of paper. This indicates that the spherical shell bursts uniformly along the shell surface, and the impulse acts on each star in a radial direction. The ejection velocity of each star is dependent on the maximum burst pressure created by the bursting charge and the inner spherical diameter, and the mass of each star.

References

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