History of Rocketry and Astronautics

Proceedings of the Forty-Third History Symposium of the International Academy of Astronautics

Daejeon, Republic of Korea, 2009

Christophe Rothmund, Volume Editor

Rick W. Sturdevant, Series Editor

AAS History Series, Volume 40

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 28

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 2013

ISSN 0730-3564

ISBN 978-0-87703-599-2 (Hard Cover)
ISBN 978-0-87703-600-5 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: http://www.univelt.com

Printed and Bound in the U.S.A.

Chapter 14

Study on the 15th-Century Korean Rocket, Dae-Sin-Gi-Jeon*

Hwanil Huh,† Yong Wu Lee‡ and Yeon Seok Chae§

Abstract

Based on the old Korean documents, *Kuk Cho Ore Sorye* (*Firearms Illustration*), written in the 15th century, we restored and tested the Dae-Sin-Gi-Jeon, the 15th Century Korean rocket and gunpowder weapons that were developed in 1448. The propellant case is made of Korean traditional paper, length 695 mm, thickness 17.8 mm, internal diameter 63.1 mm, the diameter in the bottom hole is 37.5 mm. The shaft is made of a bamboo stick, 5.31 m long. The tail fins are made of feathers, 31.28 mm wide, 843.48 mm long. The length from the end of the bamboo stick to the fins is 843.48 mm. The propellant case was charged with black powder. To restore Dae-Sin-Gi-Jeon (large-magical-machine-arrow), we performed experiments including but not limited to the following; (1) Tensile strength tests—analysis of strength and structure of Korean traditional paper (2) Internal pressure tests of the propellant case—analysis of strength and quality of propellant case Yak-Tong, (3) Ground firing test and thrust measurements, (4) Flight tests. Average thrust is 242.94 Newtons, total impulse is 925.60 Newton-sec during the boosting 4 seconds after ignition. Flight distance of the Dae-Sin-Gi-Jeon is approximately 900–1,000 meters.

---

* Presented at the Forty-Third History Symposium of the International Academy of Astronautics, 12–16 October 2009, Daejeon, South Korea, 2009. Paper IAC-09-E4.3.01.

† Professor, Chungnam National University, South Korea.

‡ Graduate Student, Chungnam National University, South Korea.

§ Research Fellow, Korea Aerospace Research Institute, South Korea.

Introduction

Five-hundred and sixty one (561) years ago, in 1488, Koreans had big rockets, called Dae-Sin-Gi-Jeon, meaning large-magical-machine-arrow. Four kinds of the magical-machine-arrow (Sin-Gi-Jeon) were constructed: small (so), medium (chung), large (dae), and multiple-bomblets-magical-machine arrow (sanhwa-sin-gi-jeon).[1]

The Great King of Se Jong, who was very concerned about firearms development, was the fourth king of the Yi Dynasty (1392–1910). According to Yeon Seok Chae,[2] many types of new Korean firearms were developed during the reign of Se Jong (1418–1450). Development of firearms in the region of Se Jong is notable as a turning point in the art of making firearms. The Yi Dynasty had stopped imitating the Chinese models and had created a distinctive Korean style. During the Great King of Se Jong's reign, Korean territory had been expanded and reached the current national border, which separates North Korea from China.

Chae[2] translated an old Korean document, "Firearms Illustration" in the *Guk Cho Ore Sorye*,[1] which described the design of Dae-Sin-Gi-Jeon,

> The propellant case is made of paper, length 695 mm, external circumference 299.9 mm, thickness 17.8 mm, internal diameter 63.1 mm, the length from the end of the propellant case to the attachment twine is 48.42 mm, the diameter of the hole in the bottom is 37.5 mm. The shaft is made of bamboo stick 5.31 m long, the upper circumference is 31.28 mm, lower circumference is 93.72 mm. The tail fins are made of feathers, 31.28 mm wide, 843.48 mm long. The length from the end of the bamboo stick to the fins is 843.48 mm.

The detailed internal structure of the large-magical-machine-arrow's propellant case and warhead was as follows (Figure 14–2). The propellant case was charged with black powder and the top of it was sealed with paper several times. On top of it, a large-magical-machine-arrow explosive-tube (dae-sin-gi-jeon-balhwa-tong) was attached, and the fuse connected the powder of the propellant case to the large-magical-machine-arrow explosive tube. The magical-machine-arrow explosive tube used a cylindrical paper tube, filled with black powder with both ends capped.[2]

According to the "Firearms Illustration," the large-magical-machine-arrow explosive tube was as follows: "The large-magical-machine-arrow-explosive tube is 228.1 mm long, 234.3 mm in circumference, 23.1 mm thick, 31.24 mm in internal diameter and is made of paper. Length from the end of the cylindrical case to the attachment twine is 15.62 mm. It has a bottom hole 3.12 mm in diameter, into which a fuse was inserted."[3]

In this study, the authors tried to restore the Dae-Sin-Gi-Jeon as exactly as possible according to the illustrations in the *Guk Cho Ore Sorye*,[1] and adopted the drawings of Chae.[2]

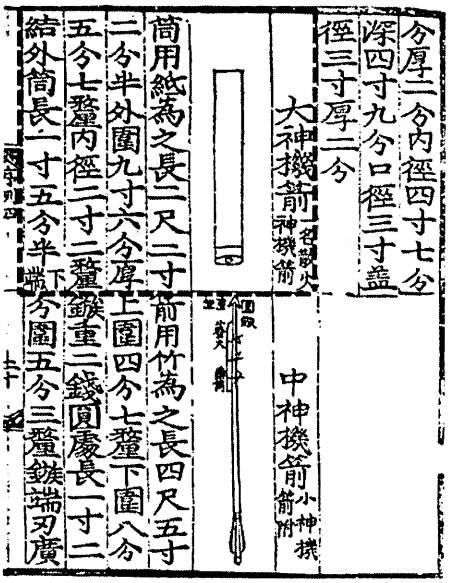


Figure 14–1: Firearms illustrations in the *Guk Cho Ore Sorye* (1474, 國朝五禮儀序例).[1]

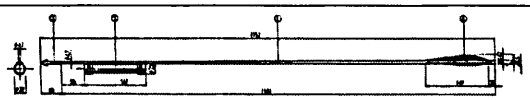
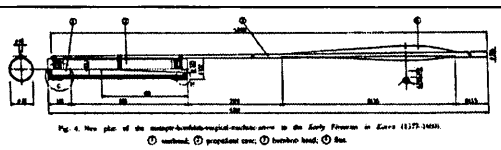
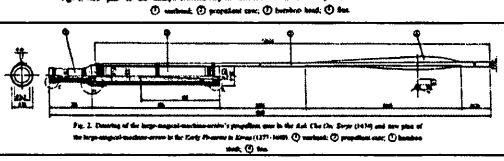
Name of Sin-Gi-Jeon	Drawing	Length (mm)	Remarks
Small		1,152	Launched at multiple launch pads. Manufactured in 1488.
Medium		1,455	Launched at multiple launch pads. Manufactured in 1488.
Multiple bomblets		5,310.8	Multiple bomblets
Large		5,588	

Table 14–1: Types of Sin-Gi-Jeon.[2]

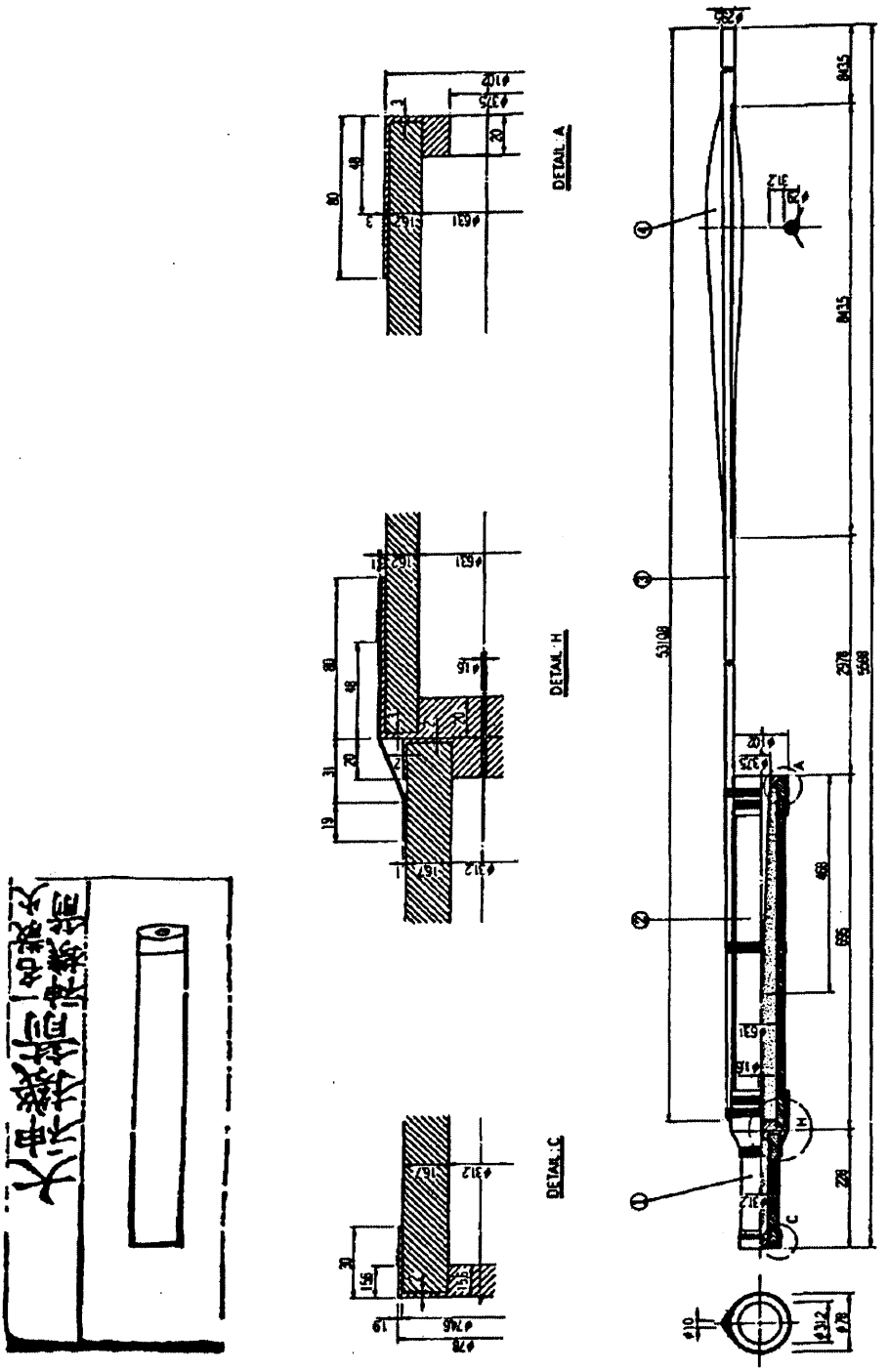


Figure 14–2: Drawing of the Dae-Sin-Gi-Jeon's propellant case in the *Guk Cho Ore Sorye* and in the *Early Firearms in Korea* (1377–1600). 1—warhead, 2—propellant case, 3—bamboo shaft, 4—fins.[1,2]

Manufacture of the Propellant Case

The propellant case is made of Korean traditional paper. There are three kinds of Korean traditional paper: hot-ji (single paper), e-hap-ji (double paper), and samhap-ji (triple paper). The authors tested these three types of paper in order to choose the best paper for the propellant case. Table 14–2 shows the test results of maximum stress for each thickness. After careful examination, hot-ji (single paper) was chosen, because it was easy to handle and showed good maximum stress.

Figure 14–3 shows tools to make a propellant case and Figure 14–4 is a manufactured yak-tong (propellant case). The average weight of yak-tongs is approximately 1.26 kg.

Traditional Korean Paper					**Improved Korean Paper**
		Single	Double	Triple	
1-fold	t	0.100	0.167	0.300	0.125
	σ	1.839	1.558	3.631	1.028
2-fold	t	0.167	0.450	0.667	0.317
	σ	3.529	1.903	4.651	1.754
3-fold	t	0.283	0.592	0.900	0.417
	σ	4.557	2.125	4.658	2.172
4-fold	t	0.333	0.800	1.233	0.567
	σ	5.284	2.399	5.410	2.139
5-fold	t	0.450	0.983	1.600	0.667
	σ	4.528	2.109	4.193	2.237

Table 14–2: Maximum Stress at Each Thickness.
(t = thickness—mm, σ = maximum stress—Kgf/mm^2)

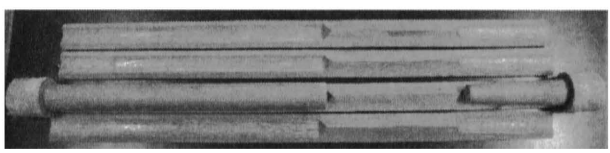


Figure 14–3: Tools to make propellant cases.

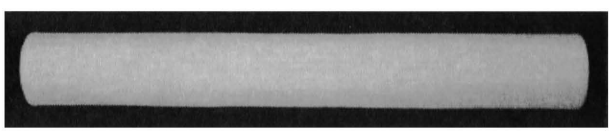


Figure 14–4: Yak-tong (propellant case).

Charged Propellant Cases

The Manufacturing Method of the Rocket's Propellant Charge:[2,4]

A long cone-shaped awl was inserted through the hole in the bottom of the propellant case, then a small quantity of powder was spread and hardened with empty cylindrical iron stick. This process was repeated until the case was filled up to a desired level. Then the long awl was taken out leaving the cone-shaped central cavity in the charged propellant case, then it received a fuse. The external diameter of the cylindrical iron stick was equal to the internal diameter of the propellant case. The internal diameter of the cylindrical iron stick was equal to the diameter of the hole in the propellant case's bottom.

Figure 14–5 illustrates the tools to charge black powder in propellant cases. During the charging process, 200 g of black powder was spread into the propellant case and hardened with an empty cylindrical iron stick, and this process was repeated until the case was filled to a desired level. Then the long cone-shaped awl was taken out, leaving the cone-shaped central cavity in the charged propellant case. This cone-shaped central cavity in the bottom of the propellant case acted as a nozzle.

Figure 14–6 shows two types of charged propellant case: nozzle type and nozzleless type. The authors tested numerous cases of different quantity of black powders with several cavity lengths. Figure 14–7 shows failure case of burning test of charged propellant case.

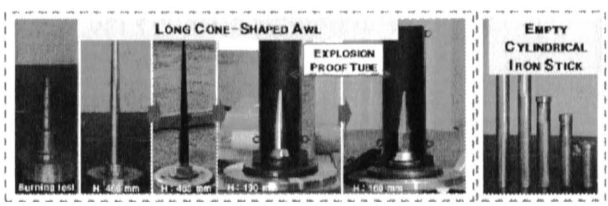


Figure 14–5: Tools to charge propellant cases.

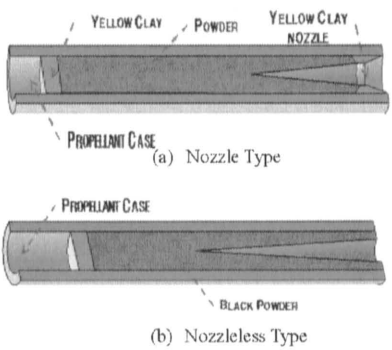
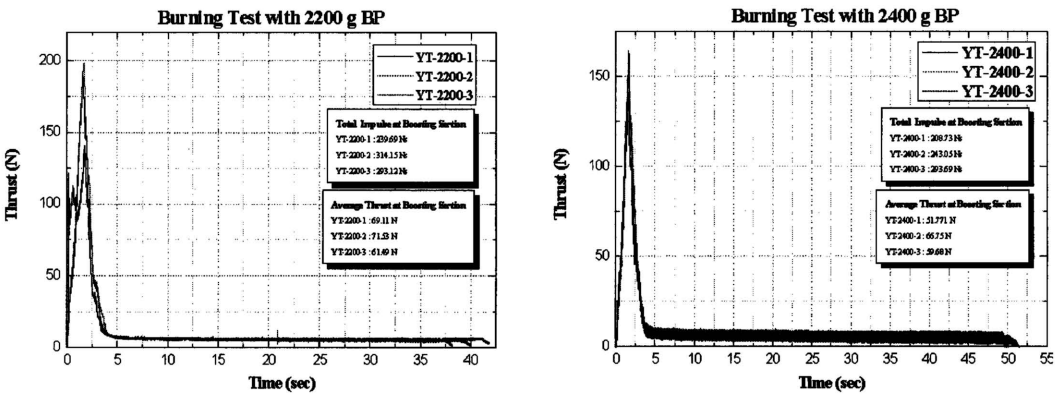


Figure 14–6: Two types of propellant case.

Figure 14–7: Failure case of burning test.

Ground Firing Test and Thrust Measurements

The authors performed ground firing tests for 10 propellant cases, with different types of nozzles, quantity of black power, and cavity length. Figure 14–8 represents the first ground firing test results, with the amount of black power at 2,200 grams and 2,400 grams, respectively.



(a) 2200g Black powder (b) 2400g Black Powder

Figure 14–8: First ground firing test results.

Table 14–3 summarizes the first test results—burn time of about 40 seconds, boosting time of about 4 seconds, average thrust during boosting time of 51–71 Newtons. Cavity length was fixed to 160 mm, and nozzle type used for the first ground firing test.

Type	Burn Time (s)	Boosting Time (s)	Boosting Total Impulse (Ns)	Boosting Avg Thrust (N)	Remarks
YT-22-1	42.80	3.86	266.79	69.11	
YT-22-2	38.20	4.39	314.15	71.53	Nozzle Types
YT-22-3	39.97	4.77	203.12	61.49	
YT-24-1	51.41	4.03	308.73	51.77	Height of the
YT-24-2	49.90	3.64	243.05	66.75	Cone Shaped
YT-24-3	51.06	4.02	293.69	59.68	AWL: 160 mm

Table 14–3: Summary of the First Ground Firing Test.

To increase the average thrust during the boosting time, the authors increased cavity length to 280 mm and used a nozzleless type propellant case. Figure 14–9 represents the second ground firing test results, with the amount of black power at 2,600 grams and 3,000 grams, respectively.

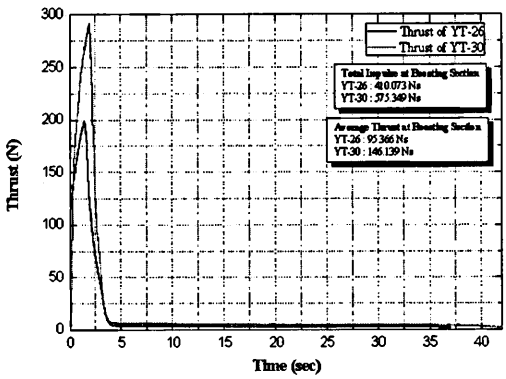


Figure 14–9: Second ground firing test results.

Table 14–4 summarizes the second test results—burn time of about 40 seconds, boosting time of about 4 seconds, average thrust during boosting time of 95–146 Newtons.

In order to obtain the maximum thrust for the propellant case to withstand, the authors further increased the cavity length to 365 mm, which gives higher initial combustion area. Figure 14–10 represents the third ground firing test results, with the amount of black powder at 3,000 grams and a nozzleless type propellant case.

Type	Burn Time (s)	Boosting Time (s)	Boosting Total Impulse (Ns)	Boosting Avg Thrust (N)	Remarks
YT-NN-26	39.80	4.30	410.07	95.37	Nozzleless Types
YT-NN-30	42.52	3.94	575.35	146.14	Height of the Cone Shaped AWL: 280 mm

Table 14–4: Summary of the Second Ground Firing Test.

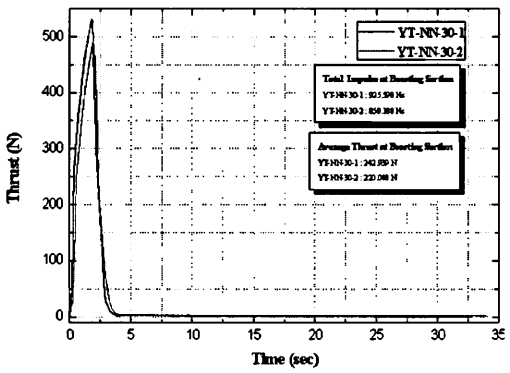


Figure 14–10: Third ground firing test results.

Table 14–5 summarizes the third test results—burn time of about 33 seconds, boosting time of about 3.85 seconds, average thrust during boosting time of 220–243 N.

Type	Burn Time (s)	Boosting Time (s)	Boosting Total Impulse (Ns)	Boosting Avg Thrust (N)	Remarks
YT-NN-30-1	32.77	3.81	925.60	242.94	Nozzleless Types
YT-NN-30-2	34.05	3.90	858.19	220.05	Height of the Cone Shaped AWL: 355 mm

Table 14–5: Summary of the Third Ground Firing Test.

Flight Tests

Flight tests were conducted in September and November 2008. Figure 14–11 shows photographs of the first flight test on 19 September 2008. The test area was a cornfield near the Nak-Dong River, South Korea.

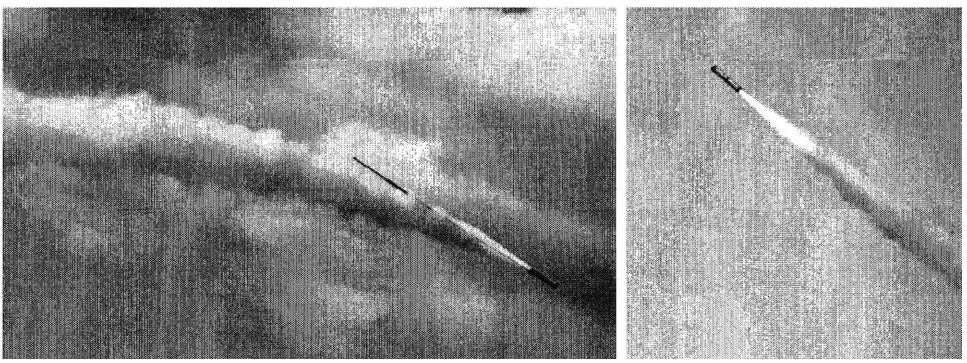


Figure 14–11: Flight tests.

Flight distance of the Dae-Sin-Gi-Jeon was approximately 600–700 meters for the first flight test, with the second ground firing test results. After two months, the authors could double the average thrust during boosting time, by increasing the cavity length of a nozzleless propellant case. Finally, in the second flight test, the flight distance of the Dae-Sin-Gi-Jeon increased to 900–1,000 meters, which was enough for the research purposes.

Summary and Conclusions

1. Restored and tested the Dae-Sin-Gi-Jeon, the 15th-century Korean rocket and gunpowder weapons that were developed in 1448.
   - propellant case made of Korean traditional paper
   - propellant case charged with black power
     - KNO_3 75 percent, charcoal 15 percent, sulfur 10 percent
     - density (ρ) = 1.788–2.138 g/cm^3
     - additives: 40 percent ethanol up to 6 percent (mass based) of total black powder
2. Average thrust was 242.94 Newtons, total impulse was 925.60 Newton-sec during the boosting 4 seconds after ignition.
3. Flight distance of the Dae-Sin-Gi-Jeon was approximately 900–1,000 meters.

References

[1] "Firearms Illustration," *Guk Cho Ore Sorye*, Vol. 4 (1474): pp. 20–21.

[2] Yeon Seok Chae, "A Study of Early Korean Rockets (1377–1600)," *Acta Astronautica*, Vol. 11, No. 7–8 (1984): pp. 387–392. Also published in *History of Rocketry and Astronautics*, Proceedings of the Seventeenth History Symposium of the International Academy of Astronautics (held in conjunction with the 34th International Astronautical Congress, 10–15 October 1983, Budapest, Hungary), J. L. Sloop, editor, Volume 12, AAS History Series (San Diego: Univelt, Inc., 1991), pp. 3–16.

[3] "Firearms Illustration," *Guk Cho Ore Sorye*, Vol. 4 (1474): pp. 17–18.

[4] "Firearms Illustration," *Guk Cho Ore Sorye*, Vol. 4 (1474): p. 17.

[5] Yeon Seok Chae, "Our Rockets and Chemical Weapons," (1998).