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Chapter 13

The History of Korean Rockets (1377–2009)—From Ju-hwa to KSLV-1*

Yeon Seok Chae†

Abstract

In 1983, the Korean traditional rockets, Ju-haw (running fire) and Sin-gi-geon (magical-machine-arrow) were introduced by the author. Ju-hwa was developed into four kinds of Sin-gi-geon: small, medium, large and fire-scattering up until 1448. The large Sin-gi-jeon is 5.5 m long, 5 kg in weight and has a 700–800 m range. It is the largest paper-propellant case rocket in the world. The fire-scattering Sin-gi-jeon is the early type of the multi-stage rocket. The first National Space Development Plan which includes the Korea Sounding Rocket (KSR) and the Korea Space Launch Vehicle (KSLV) program was made in 1996. The Korea Aerospace Research Institute (KARI) launched its first sounding rocket, KSR-I, in 1993. KSR-IIs were launched in 1997 and 1998 as two-stage sounding rockets. KARI successfully launched the liquid propellant sounding rocket, KSR-III on 28 November 2002. Korea plans to develop a small satellite launch vehicle (KSLV-1).

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† Research Fellow, Korea Aerospace Research Institute, Daejeon, Republic of Korea. Currently: Professor, University of Science and Technology, Daejeon, Republic of Korea.

Ancient Rockets of Korea

14th Century Rocket, Ju-hwa

The development of Korean rockets as a tactical weapon began in the late 14th century. According to *Koryo-sa* (*The History of the Koryo Dynasty*) and *Choson-wang-cho-silok* (*The Historical Records of the Choson Dynasty*), King Wu (reign 1377–1389) of the Koryo dynasty (918–1392) gave an order to establish Hwa-tong-dogam (The General Bureau of Gunpowder Artillery) in 1377 on the recommendation of Choi Mu-Son (?–1395). Commissioned temporarily at the height of Japanese piracy, the bureau was charged with administering the manufacture of gun powder and firearms.[1]

The first Korean rocket, Ju-hwa, literally meaning "running-fire," was manufactured by Choi Mu-Son in Hwa-tong-do-gam between 1377 and 1389, near the end of the Koryo dynasty. According to *Kuk-cho-ore-sorye*, the arrow shaft is said to be made of a bamboo stick, and the arrowhead is made of iron. The tail fins of the arrow are made of feathers. The range of Ju-hwa was 100–150 m.[2]

15th Century Rocket, Sin-gi-jeon

Ju-hwa was developed into four kinds of Sin-gi-jeon: Dae, San-hwa, Chung and So, until 1448.

Dae-sin-gi-jeon (Large-Magical-Machine-Arrow)

The propellant case filled with black powder is a cylindrical tube made of paper. It is 695 mm long, 18 mm thick, the internal diameter is 63 mm, and the external diameter is 99 mm. Both ends of the propellant case are sealed with paper several times and attached to the frontal end of the bamboo shaft by strings. At the bottom end of the propellant case, opposite the warhead, a hole is made to allow exhaust fumes to exit. The bamboo shaft is 5.3 m long, with the cross-sectional diameter increasing from 10 mm at the front to 30 mm at the rear. At the rear of the bamboo shaft three feathers are evenly distributed in between. The "Firearms Illustration" in *Kuk-cho-ore-sorye* records that they are bird feathers. The first Dae-sin-gi-jeon blasted off 19 September 2008 and reached about 500 m from the launch pad with an elevation of 60° (right photo in Figure 13–2).[4]

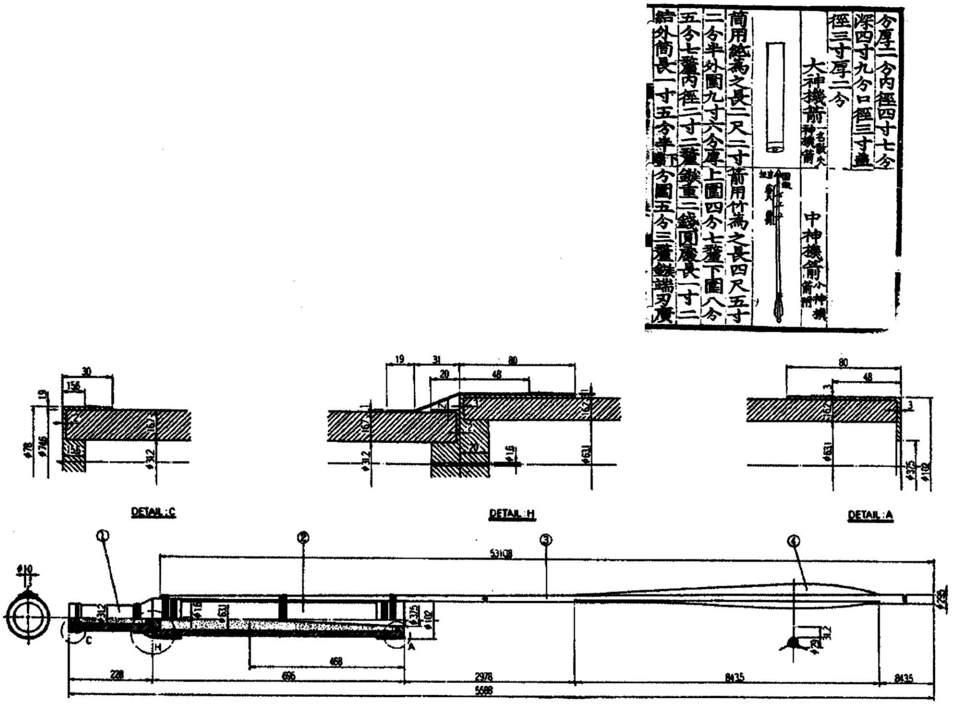

Figure 13–1: 15C Korean rockets, Sin-gi-jeon (magical-machine-arrow) drawing from the *Kuk-cho-ore-sorye* (published in 1474) and the author's new drawing of the Dae-sin-gi-jeon for reconstruction in "A Study of Early Korean Rockets (1377–1600)."[3] 1: warhead, 2: propellant case, 3: bamboo shaft, 4: fins.

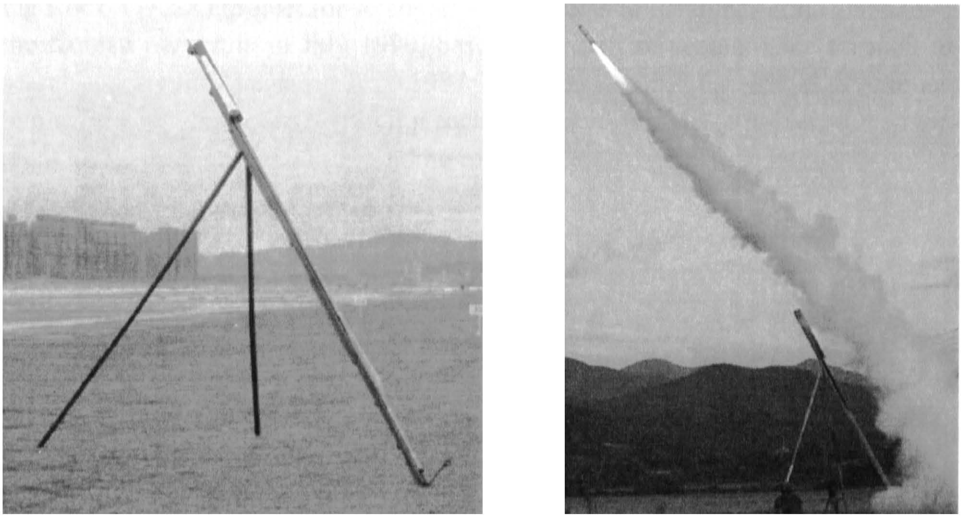

Figure 13–2: Author's reconstruction of Dae-sin-gi-jeon and its launch pad in 1993 (left) and its test flight in 2008 (right).

San-hwa-sin-gi-jeon (Multiple-Bomblets-Magical-Machine-Arrow)

The multiple-bomblets-magical-arrow is similar to large-magical-machine-arrow in size, but differs in the warhead system. A propellant case serves as a warhead instead of an explosive tube installed in front of the propellant case in the case of large-magical-machine-arrows. The lower part of the propellant case was bound with twine as is the large-magical-machine-arrow. The propellant case was charged with powder up to the height of 580 mm, leaving an empty space corresponding to the height of 116 mm. Several layers of paper were attached to the top surface of the powder. Several land-fire-tubes (Ji-hwa-tong) attached to small explosive-tubes (So-bal-hwa-tong) were placed on the top of the propellant case with their fuses attached to the propellant charge. It was designed to disperse the paper explosives tube ignited when it is near the target.

Chung-sin-gi-jeon (Medium-Magical-Machine-Arrow)

Chung-sin-gi-jeon employs a 1.4 m long bamboo shaft with a 200 mm long propellant case attached to the front. An arrowhead of weight 5.5 g is fixed at the front end of Chung-sin-gi-jeon, and at the rear end are attached bird feathers of length 18 cm. There is no mention on the range of Chung-sin-gi-jeon, but it is estimated to range from 150 m to 200 m.

So-sin-gi-jeon (Small–Magical-Machine-Arrow)

It is the smallest Sin-gi-jeon. Its size is same as Ju-hwa. The range is estimated about 100 m (Figure 13–3).


Figure 13–3: Ju-hwa was fired from a launch pad (left) and chung-sin-gi-jeon was fired from a fire-cart at the Daejeon Exposition in 1993.

Hwa-cha (Fire-Cart)

It was during the reign of King Moon-jong (1450–1452) that proper launch pads were developed for the Sin-gi-jeon. King Moon-jong himself was interested in the development of firearms. When he was a crown prince he assumed some responsibility of the Bureau of Weapons. He also played a pivotal role in developing a Hwa-cha (fire-cart). Hwa-cha could be loaded with a launch pad capable of launching 100 Sin-gi-jeons in sequence. The cart invented during the reign of King Moon-jong employed a column on and in the middle of the axle of the wheel, which enabled the inclination of the launch pad up to 43 degrees. The first Hwa-cha was dispatched in 1451.

In order to verify the technical feasibility of drawings and manufacturing methods in *Kuk-cho-ore-sorye*, small and medium Sin-gi-jeons were reconstructed together with its fire-cart and launch pad for a flight test at the Daejeon Exposition in 1993. Figure 13–3 depicts the moment of the flight test of 100 So and Chung Sin-gi-jeons in 1993. The Sin-gi-jeons traveled between 100 and 200 m in distance.[5]

KARI's Sounding Rocket Project

Solid Propellant Sounding Rocket Project (KSR-I, II)

The Korea Aerospace Research Institute (KARI) began the Korea Sounding Rocket (KSR) project for scientific experiments in the upper atmosphere over the Korean peninsula in July 1990, based on expertise accumulated through research work which began in June 1987. It produced KSR-I and KSR-II, one and two-stage solid propellant sounding rockets, in the 1990s. KARI began development of the liquid propellant sounding rocket, KSR-III, in December 1997.

KSR-I Sounding Rocket

The KARI started the sounding rocket program in July 1990. The first KSR-420S-1 blasted off 4 June 1993 and reached an altitude of 39 km with an elevation of 70°. This Korean first solid propellant sounding rocket had featured unguided, single-stage, 6.7 m long, 42 cm diameter, and 1.1 ton rocket. Total flight time was 189.7 sec, the range was 77.1 km, and the maximum velocity of the rocket was 988.9 m/s. An ultraviolet (UV) radiometer, as a main scientific payload for ozone measurements, was onboard the rocket. The KSR-I had successfully measured the vertical ozone density profile over the Korean peninsula. The KSR-420S-2, which was successfully launched in September 1993, had attained 49.4 km and also obtained the ozone profile. Total flight time was 213.5

seconds with a range of 213.5 km. The launch angle was 70°. The maximum velocity of the rocket was 1,123.5 m/s.[6]

Figure 13–4: KSR-I-1 was fired from a launch pad on the west coast of Korea in 1993.

The specifications of KSR-I can be viewed in Table 13–1.

Items	First Stage	Payload Module	Total
Launch mass (kg)	1,235	175	1,410
Overall length (m)	4.0	2.7	6.7
Principal diameter (m)	0.42	0.42	0.42
Specific impulse (vacuum, sec)	235	—	235
Average thrust (vacuum, kgf)	8,771	—	8,771
Burn time (sec)	20	—	20

Table 13–1: KSR-I Specifications.

KSR-II Sounding Rocket

The KSR-II series was the upgraded version of the KSR-I, having two-stage solid propellant. The inertial navigation system (INS) and flight termination system (FTS) were adopted. The 11 m long, 42 cm diameter, and 2 ton weight rocket had flown with 150 kg scientific payloads reaching 137 km and measured ionosphere properties, celestial X-rays, and ozone concentrations. The first flight of KSR-II failed due to an unknown telecommunications problem. The ground station lost the telemetry data at 20.8 seconds after lift-off. KSR-II-2 was successfully launched in June 1998 and reached an altitude of 137.2 km before falling into the Yellow Sea, 123.9 km from the launch pad. Total flight time was 365.4 seconds. The elevation angle was 79.05°. The maximum velocity of the rocket was 1547.6 m/s.[7]

Figure 13–5: KSR-II-2 was fired from a launch pad on the west coast of Korea in 1998.

The specifications of the KSR-II rocket can be viewed in Table 13–2.

Items	First Stage	Second Stage	Payload Module	Total
Launch mass (kg)	780	1,270	205	2,225
Overall length (m)	3.6	6.97	3.5	11.07
Principal diameter (m)	0.42	0.42	0.42	0.42
Specific impulse (vacuum, sec)	—	235	—	—
Average thrust (vacuum, kgf)	21,500	8,800	—	—
Burn time (sec)	5.9	18.2	—	24.1

Table 13–2: KSR-II Specifications.

Liquid Propellant Sounding Rocket Project (KSR-III)

KSR-III established itself as the first-ever bi-propellant liquid rocket designed and manufactured in Korea, which was fueled by pressure-fed, liquid oxygen and kerosene. The KSR-III project began in December 1997.[8] The main objectives of the development of KSR-III were to acquire prerequisite experiences in the development of satellite launchers and to further strengthen the capability of domestic industries related to low-cost liquid propellant rocket technology. KSR-III was successfully launched from a launch pad on the west coast at 14:52:26 pm on 28 November 2002, local time. The length of the rocket was 14 m, the total weight was 6 tones, and the diameter was 1 m. The onboard INS was enhanced to the launch vehicle applicable grade system. It reached an altitude of 42.7 km with a maximum speed of 902 m/s and flew over 79.5 km in 231.44 seconds. The elevation angle was 82.5°. The maximum velocity of the rocket was 899 m/s.[9]

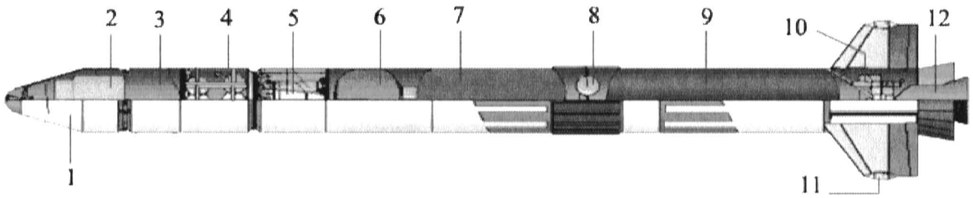

Figure 13–6: 1: nose cone, 2: payload, 3: guidance and control system, 4: attitude control system, 5: second stage solid propellant motor, 6 and 8: high pressure gas tank, 7: fuel tank, 9: oxidizer tank, 10: gimbals, 11: gas jet system, 12: liquid propellant main engine.

The project has been accomplished by going through many development stages, such as subscale model and full-scale engine combustion tests, propellant feeding system tests, integrated power plant tests, an eventually a flight test. Each development stage underwent various technical difficulties and challenges that had to be resolved and verified with reliable processes to minimize trials and errors. The sub-scale model combustion test provided useful data about the combustion efficiency of a split-triplet (F-OO-F) injector and suggested the best injector arrangement. Two types of sub-scale thrust chambers allowed reviewers to determine the design of an injector and a face plate for the full-scale thrust chamber. The on-ground combustion tests of a full-scale thrust chamber had verified its performance and the endurance of hardware including ablative material. The thrust and chamber pressure of the engine are 12,500 kgf at sea level and 13.6 atm, respectively, which lasts for 59 seconds. A composite baffle successfully suppressed troublesome high frequency combustion instability at the beginning of the development. Throughout the program, three different versions of full-scale chambers had been designed and manufactured for the optimization of performance and weight. The propellant feeding system was tested and verified through water flow tests and each component showed acceptable performance for flight use. Eventually, the thrust chamber assembly and the propellant feeding system were vertically integrated to check the functionality of subsystems and verify the performance of the whole propulsion system and thus, a stage qualification test had been conducted before a final flight test. At long last, the series of all these tests resulted in the successful flight test of KSR-III.

The specifications of the KSR-III rocket can be viewed in Table 13–3.

Items	First Stage	Payload Module	Total
Launch mass (kg)	5,000	1,000	6,000
Overall length (m)	9.6	4.4	14
Principal diameter (m)	1	1	1
Specific impulse (vacuum, sec)	280	—	280
Average thrust (vacuum, kgf)	12,500	—	12,500
Burn time (sec)	59	—	59

Table 13–3: KSR-III Specifications.

Figure 13–7: KSR-III was fired from a launch pad on the west coast of Korea in 2002.

Naro Space Center

Naro Space Center, located on the southwest edge of the Korean peninsula, is being developed as a national project for the space development program. The 5 million square meter complex will be constructed in stages. The first phase will be completed by 2009 for launching *Korean Scientific Satellite-2* (100 kg) with a small space launch vehicle, KSLV-1. In the second phase, by the end of 2018, the space center will have the capability to launch a medium size space launch vehicle.

The space center will be equipped with a rocket launching complex, including storage and supply facilities for liquid propellants. Also, in the center's complex, there will be a payload processing building, a range control system, a vehicle assembly building, a maintenance support building, rocket engine test facilities, et cetera. These facilities will be part of the infrastructure of the national space development program. In addition to support of the national space program, the space center will play a central role in educating visitors about state-of-the-art space science and technology and in helping them to understand its importance.

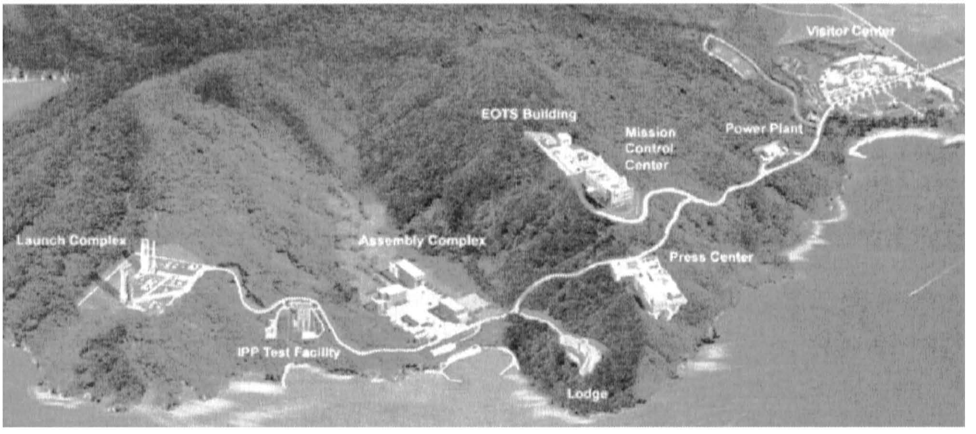

Figure 13–8: The plan directly shows details of Naro Space Center.

Korea Space Launch Vehicle (KSLV-1)

In 2002, the KSLV-1 (Naro-1) program was initiated as one of the major national aerospace programs to develop launch capabilities to deliver satellites of a 100 kg class into low Earth orbit. This space launch vehicle is under development, using the past experience of the sounding rockets. Therefore, since 2002, KARI has been developing the KSLV-1 program as a joint project with the Russian firm Khrunichev.[10]

The objective is to acquire space launch vehicle technology by developing a liquid propellant propulsion rocket.

KSLV-1 is a 140 ton booster that is 33 m tall and maximum diameter of the first stage is 2.9 m, not including the fins. Its 25.8 m long first stage uses one RD-151 engine, which is essentially the Russian RD-191 derated to 170 tons force (1,700 kN). The second stage contains solid propellant and has been designed and built by KARI. It is 2.4 m long, 1 m diameter, 6 tons, and has a thrust vector controlling system. The thrust of the second stage motor is 8,000 kgf at sea level. Its burning time is 58 seconds.

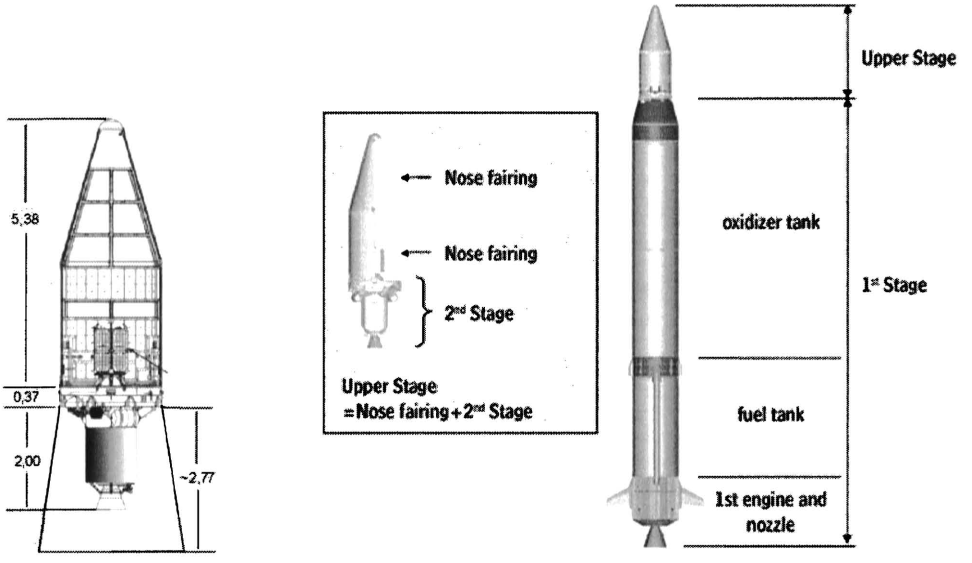

Figure 13–9: KSLV-1 space rocket (right). Detailed structure of the second stage and fairing with the Science and Technology Satellite (STSAT)-2 (left).

The specifications of the KSLV-1 space rocket can be viewed in Table 13–4.

Items	First Stage	Second Stage	Payload Module	Total
Launch mass (kg)	137,340	1,900	760	140,000
Overall length (m)	25.8	2.4	5.3	33.5
Principal diameter (m)	2.9	0.96	2	2.9
Specific impulse (vacuum, sec)	309	—	—	—
Average thrust (vacuum, kgf)	170,000	8,000	—	—
Burn time (sec)	263	67	—	330

Table 13–4: KSLV-1 Specifications.

Flight Sequence (see Figure 13–10)

The first stage is ignited 3.8 seconds before lift-off. Naro-1 endures maximum dynamic pressure at 55 seconds followed by fairing separation at 216 seconds into the launch. The STSAT-2 separated from the second stage rocket at 540 seconds into the flight. The second stage is ignited 395 seconds from lift-off after a 162 second controlled coast, utilizing an 8 tons force thrust solid propellant kick motor that burns out at 453 seconds with an active attitude control system. The satellite is separated at 540 seconds after lift-off. This will deliver 100 kg class satellites into low Earth orbit (300×1500 km).

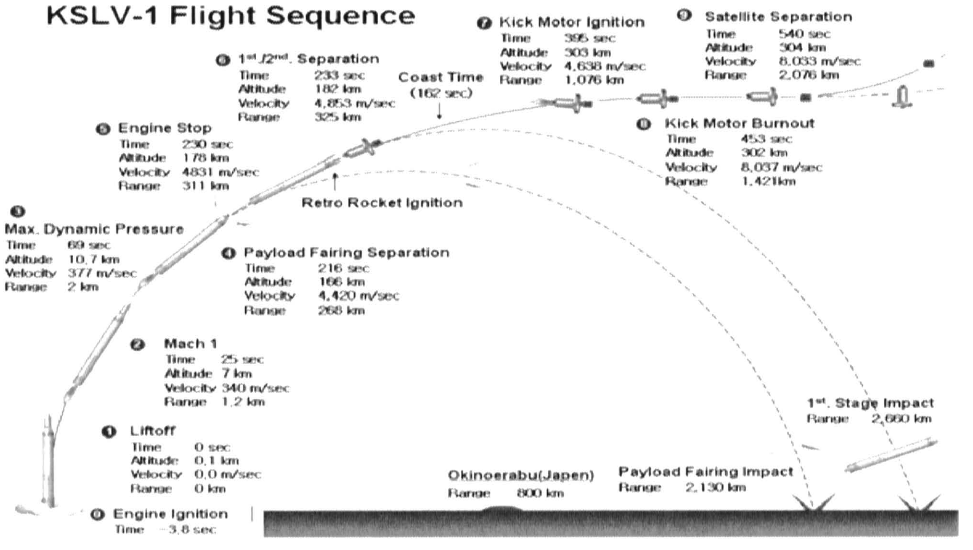

Figure 13–10: KSLV-1 typical flight sequence.

Launch History

The first KSLV-1 (also known as Naro-1) was launched at the Naro Space Center in Goheung, South Jeolla Province at 17:00:00 pm local time on 25 August 2009. But the payload fairing separation system malfunctioned and half of the satellite protective fairing stayed at the second stage. It caused a reducing velocity of the satellite to 6.2 km/sec. It is not enough velocity for a satellite. Finally, STSAT-2 reentered the atmosphere and was destroyed.[11]

Conclusion

The early Korean large rocket, Dae-sin-gi-jeon (large-magical-machine-arrow) is the largest and longest range (600–700 m) rocket ever made among those employing a propellant case made of paper in the 15th century. The San-hwa-sin-gi-jeon (multiple-bomblets-magical-machine-arrow), is a variant of Dae-sin-gi-jeon. This is an early type of multistage rocket in the world. The Sin-gi-jeon had a nozzle-less paper propellant rocket motor. Its drawing and detail manufacturing description of the Sin-gi-jeon and Hwa-cha (mobile launcher of the Sin-gi-jeon) is in *Kuk-cho-ore-sorye*, a book compiled in 1474. This book is a very important book for research of early rocketry in the world. This author researched the Korean old rocket Sin-gi-jeons and modern rockets, especially low-cost liquid propellant sounding rocket, for the past 38 years, and test-fired all kinds of Sin-gi-jeons.

Korea has a long-term space development program. Korea aims to hoist 20 satellites into orbit, including 5 communications satellites, 8 multi-purpose satellites, and 7 science satellites, by 2015. Korea is also planning to launch most of the science satellites and some of the multipurpose satellites by KSLV-2 to low Earth orbit from Naro Space Center in the future.

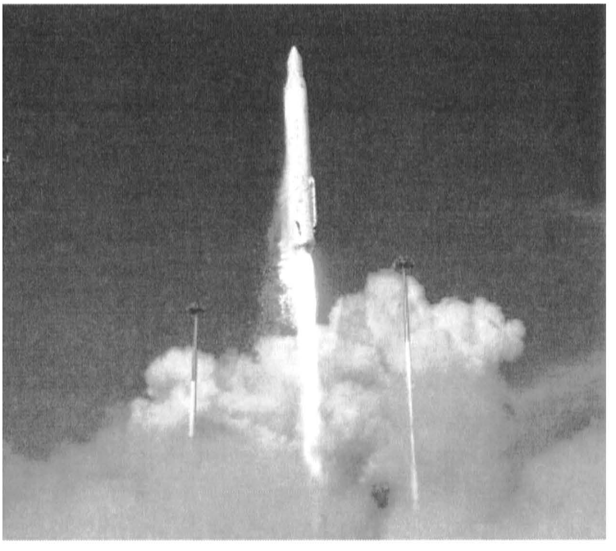

Figure 13–11: Naro-1 was fired from Naro Space Center on 25 August 2009.

Endnotes

[1] Yeon Seok Chae, "A Study of Ju-Hwa and Sin-gi-jeon," *Journal of the Korean Historical Association*, Vol. 70 (1976): pp. 15–18.

[2] Author reconstructs ju-hwa and chung-sin-gi-jeon in 1992, and so and chung-sin-gi-jeon was fired from a fire-cart at the Daejeon Exposition in 1993.

[3] 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.

[4] Hwanil Huh, Yong Wu Lee, Yeon Seok Chae, "Study on the 15th-Century Korean Rocket, Dae-sin-gi-jeon," IAC-09-E4.3.04, presented at the 60th International Astronautical Congress, Daejeon, Republic of Korea, 12–16 October 2009. See Chapter 14 in this volume.

[5] Author reconstructs ju-hwa and chung-sin-gi-jeon in 1992, and So and chung-sin-gi-jeon was fired from a fire-cart at the Daejeon Exposition in 1993.

[6] Author was a research-and-development manager of the KSR-1 propulsion system in KARI.

[7] Author was a research-and-development manager of the KSR-2 propulsion system in KARI.

[8] Author was a project manager of the KSR-3 project in KARI.

[9] Yeon-Seok Chae, "Development of a Liquid Propellant Rocket, Korea Sounding Rocket (KSR)-III," Fifth International Symposium on Liquid Space Propulsion, Chattanooga, Tennessee, 2003.

[10] On 26 October 2004, the author was the President of KARI, signed the contract with KARI to develop a KSLV-1 with Khrunichev.

[11] The third KSLV-1 was successfully launched, lofting the STSAT-2C satellite into orbit, on 30 January 2013.