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An Analysis of North Korea's Unha-2 Launch Vehicle

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Summary
North Korea has announced that it will attempt to launch a satellite into orbit in early April 2009 using its Unha-2 launcher. Few details are known about the launch vehicle since it has not been successfully flight tested. This paper attempts to model North Korea's launch vehicle based on publicly available information, assuming that it uses a similar level of technology as past North Korean missiles. This analysis suggests the launcher could place a payload of about 100 kilograms (kg) into orbit at 400 kilometers (km) altitude. Moreover, if used as a ballistic missile, it may be able to carry a 500 kg payload to a range of approximately 9,000 km, and a 1,000 kg payload 6,000 km; however, the missile structure may not be able to accommodate such a large increase in payload mass. While this would be a significant increase in range over North Korea's current missiles, it does not represent a true intercontinental nuclear delivery capability since developing a first generation warhead and heatshield with a mass of 500 kg or less is likely to be a significant challenge for North Korea.

The paper then looks at the kind of technical improvements that could be made to a launcher that would allow it to place several times as much mass in orbit, and that would increase the payload and range capability if used as a ballistic missile. It is unclear whether North Korea has the technical capability to take these steps. Information from the upcoming launch will provide information that may help to clarify the actual capabilities of the launcher.

Introduction

North Korea has announced that it will attempt to launch an experimental communication satellite named the Kwangmyongsong 2 from its Musudan-ri launch site[2] during the period from April 4 to 8, 2009.

The launcher North Korea is planning to use, which it calls the Unha-2, is believed to be derived from the TaepoDong 2 (TD-2) missile that North Korea began developing in the 1990s but has never successfully launched.

Key questions about the launch include what technology the launcher will use and what capability such a launcher would have if used as a ballistic missile.

The question of technology is particularly interesting following the Iranian launch of a small satellite in early February. The launcher Iran used in the launch, the Safir-2, is approximately the same size as the TaepoDong 1 (TD-1) launcher that North Korea used in its unsuccessful satellite launch attempt in 1998. However, the Safir-2 apparently has only two stages, while the TD-1 had three stages, which implies significant differences in the technology.[3] The new TD-2/Unha-2 launcher is considerably larger than either the TD-1 or Safir-2.

The TD-1, like the Nodong missile and North Korea's other previous rockets, is believed to have relied on technology closely related to that used in the Soviet Scud-B missile, which was developed in the 1960s. North Korea's first missiles were, in fact, copies of Scud-B missiles, and there is convincing evidence that these missiles relied very heavily on technology and assistance from Russian missile experts, although possibly without involvement of the Russian government.[4]

The question of past foreign assistance is important. If North Korea's past missile developments relied heavily on foreign technology and expertise and its indigenous design capabilities remain limited, and if it is no longer getting significant foreign help, then the TD-2/Unha-2 launcher is likely to rely on the same general components and level of technology as previous missiles. If this is true, then efforts to further limit foreign assistance to the program could be useful.

For this analysis, I first look at the case in which North Korea's TD-2/Unha-2 launch vehicle continues to be based on technology similar to that used in the TD-1 missile.

I then discuss possible steps that countries building space launchers and long-range missiles have made to improve the capability of those systems. It remains unclear whether North Korea is able to incorporate such steps into its launchers.

North Korea's Satellite Launcher

The Unha-2 launcher is believed to be a version of the TaepoDong 2 (TD-2) missile, which North Korea has never flight tested.

As noted above, this launcher is much larger than the TD-1 and Iranian Safir-2 launchers. The Safir-2 has a diameter of 1.25 meters (m), a length of about 22 m, and a mass of 26 tons. In contrast, the TD-2 is believed to have a first-stage diameter of about 2.25 m, and a total mass three times larger than the Safir 2 (approximately 80 tons).

In preparation for its launch, North Korea recently announced public hazard zones for shipping and aviation; these zones are the regions where the first two stages of the launcher are expected to fall into the ocean.[5] By giving approximate locations of the two splashdown points, North Korea has provided useful information about the launch.

First, this announcement indicates that the launcher will have three stages (if the launch is successful, the third stage will remain in orbit with the satellite). Second, it indicates that the launch direction will be due east, similar to the TD-1 launch. Such a direction is what you would expect for a satellite launch since it allows the launcher to gain speed from the Earth's rotation (0.35 km/s in this case).[6] This launch direction will take the launcher over the Pacific and in the general direction of Hawaii, but not toward the continental United States. Unfortunately, it will also take the launcher over the northern tip of the main Japanese island of Honshu early in flight, which Japan saw as threatening and reacted strongly against following the TD-1 launch.

Finally, one can use the distances of the splashdown zones from the launch site as information in developing computer models of the launcher. In particular, in simulating the launch, one must choose technical parameters of the launcher that cause the stages to fall into these regions. The locations of the hazard zones indicate that the first stage is expected to land between 500 and 750 km from the launch site, and the second stage is expected to land between approximately 3,150 and 3,950 km from the launch site.

The final stage carrying the satellite must reach the altitude of the orbit—probably in the neighborhood of 400 km altitude—with a speed equal to the orbital speed for an object at that altitude. The orbital speed of an object in a circular orbit at 400 to 500 km is 7.62 to 7.67 kilometers per second (km/s). Since 0.35 km/s second will be contributed by the rotation of the Earth, the launch vehicle must be able to accelerate the satellite to a speed of approximately 7.3 km/s.

A Model of the TD-2/Unha-2 Launcher

As discussed above, North Korea's development of rockets has relied heavily on extensions of Scud-level technology. In this section I discuss a model of the TD-2/Unha-2 launcher that continues to rely on that technology, and examine its capability as a ballistic missile. I then discuss how that capability would increase if North Korea incorporated more advanced technology into its designs.

It is important to emphasize that few details are known about North Korea's program, and developing models relies on inferences as well as educated guesses based on the historical development of rocket technology capability by other countries. The specific parameter values are therefore approximate, and some of the underlying assumptions may turn out to be wrong.

The large first stage of the TD-2/Unha-2 launcher is new and North Korea has not successfully flight tested it. The only previous flight test was in July 2006 when this stage failed approximately 40 seconds into the launch, causing the launcher to fall a few kilometers from the launch site. I assume this stage uses a cluster of four engines similar to the single large engine used in North Korea's Nodong missile. By clustering four engines, North Korea could use an existing engine to develop a stage with four times the thrust of the Nodong, and would be following a development path that was used by other countries in building larger rocket stages. Moreover, the size of the TD-2 first stage is consistent with a cluster of four such engines and the volume of propellant they would require.

I assume the second stage uses a single Nodong engine, or an engine of similar capability, modified to be used at high altitude. Indeed, for many years it was expected that the second stage of the TD-2 would essentially be a Nodong missile, and most drawings show a second stage diameter that is smaller than the first stage diameter. This configuration was seen in satellite images of early mock-ups of the TD-2 missile, but it is not known publicly whether that configuration was used in the 2006 launch. North Korea might instead design a stage that uses this engine but has the same diameter as the first stage, which can reduce the mass of the stage.

It is important to note that there are typically differences in the design of space launchers and ballistic missiles. For example, the duration of the boost phase—the time before the rocket engines stop burning—is typically longer for a satellite launcher than a ballistic missile since the launcher must reach a high altitude when the engines stop burning and the rocket has achieved its maximum speed. The stages of a satellite launcher therefore typically will have longer burn times than a ballistic missile.[7] In addition, an unpowered coast phase is often added before the final stage ignites, especially if the satellite is intended to orbit at altitudes above a few hundred kilometers.

For this case I assume there is no coast phase prior to third stage ignition, since that would require an attitude control system for the third stage before its engine ignited. As a result, I assume the burn times of the first two stages have been increased compared to the burn time of the Nodong missile. This option would allow a satellite to be launched into low orbits, but could not be used for higher orbits.

An alternate possibility for the second stage of the TD-2/Unha-2 is a modified SA-5 engine,[8] which was designed to be used in a surface-to-air missile. The thrust of the engine is designed to be varied and could be used to give a short, high-thrust phase followed by a longer, low-thrust phase in lieu of a coast phase. Maintaining low thrust during this phase would control the attitude of the third stage and payload. Such a stage could be used to place satellites in higher orbits if the booster was powerful enough. My estimates of the overall capability of the launcher should not depend in detail on which option is used for this stage.

Observation of the North Korean launch should give information about the details of the stages. A relatively long burn time would suggest that the launcher has been optimized for a satellite launch and not for use as a ballistic missile.

In constructing a model for the launcher, I was guided by the design of China's first space-launch vehicle, the Long March 1 (LM-1), which is essentially the same size as the TD-2/Unha-2, although somewhat more advanced.[9] Technical information about this launcher is summarized in Appendix A.

In particular, I assume that the ratio of first and second stage masses is similar to the LM-1. I assume that North Korea has worked to reduce the mass of the structure of its launcher compared to the TD-1, but has not achieved the high fuel fractions (the ratio of fuel mass to total mass of a stage) seen in the LM-1.

I also assume the TD-2/Unha-2 uses nitric acid (AK27) as an oxidizer and kerosene (TM-185) as the fuel[10] (similar to a Scud), and therefore will have somewhat lower specific impulse than the LM-1, which uses AK27 and UDHM. My estimate of the specific impulse of the first stage engines comes from my analysis of the 1998 TD-1 launch.[11]

As noted above, I constructed my model so that the first and second stages fall to Earth at distances that put them within the announced safety zones, assuming the empty stages have low ballistic coefficients (500 to 2500 N/m2, or 10-50 lb/sf).

The parameters I used in modeling the missile are in Appendix B.

If the TD-2/Unha-2 has characteristics similar to this model, then I estimate it could place a payload of about 100 kg into orbit at 400 km altitude. This value appears consistent with the fact that the LM-1 launcher, which was likely a more advanced design, is reported to be able to launch 300 kg into low Earth orbit.

If launched on a ballistic missile trajectory, a missile with the characteristics of this model would be able to carry a 500 kg payload approximately 9,000 km, and a 1,000 kg payload approximately 6,000 km. Since it may be difficult for North Korea to build a first generation warhead and heatshield with a mass of 500 kg, this would not represent a true intercontinental nuclear capability.

Moreover, the structural strength and mass distribution of this missile may not be compatible with placing a much larger payload on the third stage, so significant modifications may be required to use it in this mode. Nonetheless, a successful launch would demonstrate a number of important technical steps.

Increasing the Capability of a Launcher

The model considered above assumes that North Korea continues to use technology similar to that in its TD-1 launcher, since it has not demonstrated the ability to go beyond that in its existing missiles. That assumption may not be correct. I consider here advances that could increase the capability of the launcher; it is not known if North Korea has the ability to incorporate such changes.

The two primary steps for going beyond the technology exhibited in North Korea's existing missiles are: (1) making the rocket body out of lighter weight materials, such as aluminum alloy rather than steel, to reduce the structural mass of the launcher; and (2) increasing the thrust of the engines by using different propellants. For example, there are combinations of storable liquid propellants that have been used for decades that have significantly better performance than used in the Scud.

As noted above, China's Long March 1 (LM-1) launch vehicle illustrates the improvements such steps could provide. The LM-1 is essentially the same size and configuration as the TD-2/Unha-2 and was first launched in 1970. The first stage is approximately the same diameter as the first stage of the TD-2 and uses a cluster of four engines, with jet vanes for guidance. China built this launcher out of an aluminum alloy to give it a lightweight structure, and used more energetic propellants (AK27 and UDMH) than are used in the Scud.[12]

The LM-1 therefore provides a model that can be used to estimate the potential capabilities of an upgraded launcher. This launcher is rated as being able to place a payload of 300 kg into orbit at an altitude of a few hundred kilometers, compared to 100 kg for my model of the TD-2/Unha-2. Launched as a ballistic missile, the LM-1 would be able to carry 1,000 kg to a range of 8,500 km and 500 kg over 12,000 km.

Upgrades to the LM-1 included using even higher performance fuels (N_2O_4 and UDMH) and replacing the third stage with a more capable and more massive stage (with a mass of nearly 2 tons), while keeping the overall configuration of the launcher essentially the same. These changes allowed the launcher to place approximately four times as much payload into low Earth orbit, and would give a ballistic missile with a payload of 1,000 kg true intercontinental range.

To achieve significantly greater capability, starting with the Long March 2 launchers China developed a much larger launch vehicle, with a diameter of 3.35 m and a launch mass of 200 tons.

While these kinds of technical steps have been incorporated into space launch vehicles for several decades, they pose various materials and manufacturing challenges, as is suggested by the fact that they have not been used more widely by countries developing missiles. Making these changes would therefore be expected to take some time, depending again on the amount of foreign assistance that might be available. Increasing the size of launchers can be particularly challenging because it is difficult to keep the structural mass low while accommodating the increased forces that such a launcher will experience.

Appendix A: Details of China's Long March-1 Space Launcher

The LM-1 space launcher has a total mass of 81 tons and a length of 29 m.[13] China first launched the LM-1 in 1970. It was built using technology China developed for its Dong Feng (DF) series of ballistic missiles, including its first ICBM (the DF-5 missile). The first two stages use a fuel combination of nitric acid (AK27) and UDMH, which is more energetic than the combination used in the Scud (nitric acid and kerosene), but less energetic than the propellant China uses in the Long March 2 (LM-2) and later launch vehicles (N_2O_4 and UDMH). The thrust a rocket engine can produce is proportional to its specific impulse, which describes how efficiently an engine uses propellant. The specific impulse (at sea level) of Scud-B engines is about 218 seconds (s), while that of the LM-1 first stage is 241 s, and that of the LM-2 first stage is 260 s. The specific impulse (in vacuum) for the LM-1 second stage is 287 s.

The fuel masses for the first and second stages of the LM-1 are about 60 tons and 12 tons, respectively, and the fuel fractions (the ratio of propellant mass to total stage mass) are 93.7% and 83.3%, respectively.

The original LM-1 launcher had a first stage thrust of 104 tons, which was increased to 112 tons in the upgraded LM-1D. The second stage had a thrust of 30 tons. The burn times of the first and second stages were about 132 s and 113 s, respectively. To reach higher altitudes, the launcher used a coast stage between burnout of the second stage and ignition of the third stage, and had a separate attitude control system that was used during the coast phase.

Characteristics of the LM-1 third stage are unknown publicly, but it is likely similar to that of the LM-1D, which carried 625 km of solid propellant. The LM-1 is listed as being able to launch 300 km into low Earth orbit. The LM-1D is listed as being able to launch 600 to 920 km into low Earth orbit.

Appendix B: Estimated Parameter Values for TD-2/Unha-2 Model

This model assumes the TD-2/Unha-2 launcher uses a level of technology similar to that in the Nodong and TD-1 missiles. I assume that the launcher releases the shroud surrounding the payload and third stage midway through second stage burn, as North Korea did during the TD-1 launch in 1998. Because few details are know about the launcher, these values are approximate.

Total launch mass: 78 tons
Maximum diameter: 2.25 m

Stage 1:

Total stage mass:	65.9 tons
Propellant mass:	60.0 tons
Fuel fraction:	0.91
Specific impulse:	225 s (sea level) to 252 s (vacuum)
Burn time:	120 s
Thrust:	112 tons (sea level)

Stage 2:

Total stage mass:	11.1 tons
Propellant mass:	9.0 tons
Fuel fraction:	0.81
Specific impulse:	255 s (vacuum)
Burn time:	110 s
Thrust:	21 tons

Stage 3:

Total stage mass:	1.0 tons
Propellant mass:	0.80 tons
Fuel fraction:	0.80
Specific impulse:	270 s (vacuum)
Burn time:	40 s
Thrust:	5.4 tons

Payload:	100 kg
Shroud mass:	400 kg
Shroud release:	180 s

Ignoring the speed contribution of the rotation of the Earth, this model gives a first-stage burnout at an altitude of 70 km with a speed of 2.31 km/s, a second-stage burnout at an altitude of 310 km with a speed of 4.71 km/s, and a third-stage burnout at 400 km with a speed of 7.32 km/s. On this trajectory, the first stage splashes down 630 km from the launch site, and the second stage at 3,570 km, which are in the middle of the safety zones announced by North Korea.

References and Notes

[1] Co-Director and Senior Scientist, Global Security Program, Union of Concerned Scientists.
[2] The launch site is in Hwadae county, North Hamgyong Province, at 40.52N, 129.45E.
[3] D. Wright, "A Model of the Safir 2 Launch Vehicle," http://www.ucsusa.org/nuclear_weapons_and_global_security/missile_defense/technical_issues/model-of-a-2-stage-safir.html; G. Forden, "Safir When Ready," *Jane's Intelligence Review*, October 2008, pp. 2-5; G. Forden, "Safir—Iran Jumps Off the Scud Bandwagon," 25 August 2008, http://web.mit.edu/stgs/pdfs/Safir--Iran%20Hops%20Off%20the%20SCUD%20Bandwagon1.pdf. Since Iran is believed to have gotten significant technical assistance early in its missile program from North Korea, a key question is whether it has passed these advances on to North Korea.
[4] See, for example, T. McCarthy, "North Korean Ballistic Missile Programs: Soviet and Russian Legacies," in *WMD Threats 2001: Critical Choices for the Bush Administration,* M. Barletta, ed., Occasional Paper No. 6, Center for Nonproliferation Studies, Monterey Institute of International Studies, p. 9-11 available at http://cns.miis.edu/pubs/opapers/op6/index.htm; R. H. Schmucker, "3rd World Missile Development: A New Assessment Based on UNSCOM Field Experience and Data Evaluation," 12th Multinational Conference on Theater Missile Defense, 1-4 June 1999, Edinburgh, Scotland.
[5] International Maritime Organization, SN.1/Circ.278, 12 March 2009, http://www.globalsecurity.org/space/library/news/2009/space-090312-imo01.htm; International Civil Aviation Organization, "ICAO Officially Advised of DPRK Plans for Rocket Launch, 12 March 2009, http://www.icao.int/icao/en/nr/2009/pio200902_e.pdf ; G.Forden, "DPRK's Stay Clear Zones," 13 March 2009, http://www.armscontrolwonk.com/2220/dprks-stay-clear-zones#comment
[6] The speed of a point on the Earth at the equator is 0.456 km/s due to the Earth's rotation. The North Korean Musudan-ri launch site is at a latitude of 40 degrees north, so its speed 0.456 cos(40) = 0.35 km/s.
[7] A long burn time will tend to increase gravity loses and therefore reduce the burnout velocity and the range of a ballistic missile.
[8] This option has been discussed by T. Postol (personal communication, 16 March 2009) and in Schmucker, "3rd World Missile Development."
[9] This comparison is not intended to imply that North Korea has received assistance or technology for this launcher from China, although it may have been guided by how other countries solved design problems. As noted above, it is believed that the North Korean program has instead benefited significantly from Russian expertise.
[10] AK27 consists of 73% nitric acid and 27% N_2O_4. TM-185 consists of 80% kerosene and 20% gasoline.
[11] Similar values were found in Schmucker, "3rd World Development," 1999.
[12] Z. Huang and X. Ren, "Long March Launch Vehicle Family," *Space Technology* 8:4, 1988, pp. 371-375; Z. Huang, "Long March Vehicles in the 1990s," in *Space Commercialization: Launch Vehicles and Programs,* ed. F. Shahrokhi, J. Greenberg, T. Al-Saud, (Washington, DC: American Institute of Aeronautics and Astronautics, 1990), pp. 1-6; J. Lewis and D. Hua, "China's Ballistic Missile Programs," *International Security,* 17:2, Fall 1992, pp. 5-33.
[13] Information in this appendix comes from Huang and Ren, "Long March Vehicle Family," and Huang, "Long March Vehicles."