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Explaining the Musudan

New Insights on the North Korean SS-N-6 Technology

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The so-called Musudan missile is commonly seen as an operational North Korean Intermediate Range Ballistic Missile (IRBM) with a range of more than 3,000 km. There seems to be a consensus in the open source literature that this missile is based on the Soviet SS-N-6 submarine missile, and that the second stage of the North Korean Unha-2/-3 satellite launcher is related to the Musudan, or that it actually is an original SS-N-6. New photos of the Unha-3 second stage indicate a different situation.

Figure 1: The North Korean Musudan Missile

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Common View of the Musudan Missile

The Musudan missile, also sometimes designated the BM-25 or the Nodong-B, is commonly seen as another example for the North Korean capability to design and produce missiles based on available technology from other countries.

According to the common view, earlier North Korean missiles, for example the so-called Scud C or the Nodong, were based on the Soviet Scud B technology from the late 1950s that North Korea had acquired by reverse engineering the Soviet Scud B missile in the 1980s.

Somewhat later, North Korea is said to have gained access to the more advanced Soviet R-27/SS-N-6 missile that features technologies that – even though developed in the early 1960s – can still be seen as high-end even today. Open source literature usually states that the North Koreans managed to adapt this technology, just as they did with the comparatively rugged Scud technology, and with that knowledge they designed and produced the Musudan missile. Some assessments claim the use of old Soviet SS-N-6 parts in these missiles, others assume completely indigenous production.

When photos of the North Korean satellite launcher Unha-2 were published in 2009, analysts noted that the rocket's second stage closely resembled an SS-N-6 in appearance and dimensions. One year earlier, elements of the SS-N-6 had been identified in the upper stage of the Iranian Safir satellite launcher, and a certain level of cooperation between Iran and North Korea is widely assumed. Therefore, it seemed consequent to identify the Unha-2 second stage as a modified SS-N-6, which also underscored the rumors at that time of a road-mobile SS-N-6-based North Korean IRBM – the Musudan.

Figure 2: Musudan, SS-N-6, and Unha-2 Second Stage (roughly in scale)

In October 2010, North Korea finally seemed to confirm these rumors by displaying the Musudan at a parade in Pyongyang.

What Is Special About SS-N-6 Technology?

Before the Unha-2 and the Musudan, North Korea was believed to only have access to Scud technology. Even though the Scud B still is a formidable weapon system with combat-proven and reliable technology, this technology has certain limits. Due to the cold equations of rocketry, missiles with Scud technology quickly grow in size once a certain range threshold is crossed: An ICBM with Scud technology (and aluminum structures!) would easily weigh about 80 t, while a satellite launcher for very small payloads would weigh almost 50 t.

The Iranian Safir satellite launcher illustrates how the use of SS-N-6 technology can reduce a rocket's size: With a launch mass of less than 25 t (according to reconstruction done at Schmucker Technologie), the Safir can orbit microsatellites of up to 50 kg, and perhaps even more, even though the Safir only seems to use some SS-N-6 propulsion system elements in its upper stage: The vernier engines (with the according propellants) and the turbo pump.

However, the SS-N-6 offers many more advances over the Scud technology:

- Extreme lightweight aluminum isogrid structures
- Engine submerged in the fuel tank
- Efficient main engine with staged combustion cycle instead of gas generator cycle
- Propellants that are more energetic (NTO/UDMH instead of IRFNA/kerosene)

Another comparison may illustrate the potential of this technology. Weighing little more than 14 t, the SS-N-6 offers a range of 2,400 km, perhaps even more. With the same warhead mass and a comparable launch mass of around 15 t, the Nodong or Shahab 3 – based on Scud technology – only offers half that range.

The Unha-3 Second Stage

As portrayed, the second stage of the Unha-2 satellite launcher had played a key role in the claim that North Korea has mastered SS-N-6 technology. In April 2012, North Korea launched a rocket designated Unha-3, with the first and second stage apparently the same as Unha-2. High resolution photos of the second stage now allow a detailed analysis, with an unexpected result.

To save weight and space, the SS-N-6 has a common bulkhead between the oxidizer tank on top and the fuel tank below. The oxidizer tank is divided, and the lower compartment is emptied first to keep the center of gravity at the front.

The Unha-3 second stage, however, clearly shows an area with several rivet joints in the lower half of the stage (see Figure 3). This is a clear sign for an empty space between the oxidizer tank and the fuel tank, meaning that there is no common bulkhead. The rivets indicate the use of internal stringers to stiffen this part of the structure. This is further underlined by a retro rocket that is mounted at this position (see also Figure 3). The different sizes of the tanks and the color scheme of the filling or draining valves (typical Soviet color code: red for oxidizer, yellow for fuel), as well as the Korean markings/abbreviations at these valves all indicate that the upper tank is the oxidizer tank, and the lower tank is the fuel tank.

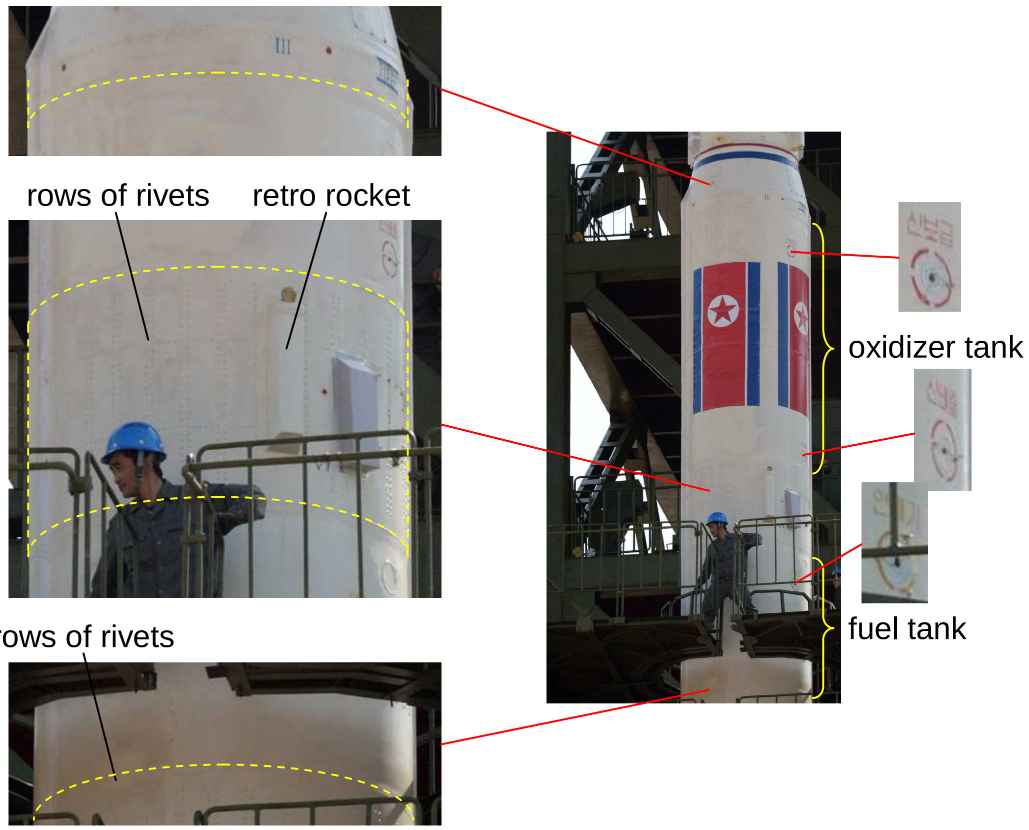

Figure 3: The Unha-3 Second Stage

The tank dimensions are clearly visible. Assuming standard domes for these tanks that extend beyond the visible cylindrical parts (in Figure 3, only the cylindrical sections are marked!), the propellant volumes are easily calculated with close to 6.2 m^3 for the upper tank and around 3.8 m^3 for the lower tank. Taking the required ullage (empty space when filled) and the feedline from the upper tank through the lower tank into account (which is usually also filled with the respective propellant), the effective propellant volumes are estimated with around 6 m^3 and 3.5 m^3. The resulting effective volume ratio is 1.7 – a number that is far from the typical value of around 1.4 for the NTO/UDMH propellant combination that a SS-N-6 engine would require. However, values around 1.7 are typical for the IRFNA/kerosene combination that is used by the Scud and the Nodong.

Assuming that the rocket stage uses these Scud/Nodong propellants, the analysis yielded a propellant mass of 9.5 t IRFNA and 3 t kerosene. These numbers are a perfect match for the Nodong's estimated oxidizer mass, and deviate from the Nodong's estimated fuel mass by only a few percent.

The upper end of the Unha-3 second stage's engine compartment is easy to locate (see Figure 3). A submerged engine would further reduce the fuel mass, further increasing the effective volume ratio of oxidizer and fuel toward a value of 2. This alone is a show-stopper that rules out the option of a submerged engine for the Unha-3 second stage.

Therefore, the engine has to be located below the fuel tank, and not submerged in it. With that, there only is enough room for an engine below the fuel tank if it is situated in the conical structure. At this configuration, a complete engine compartment might have a length of up to 2.5 m. With a length of about 2.4 m, the Nodong's engine compartment would fit in nicely.

It is also noteworthy that the thrust level of the Nodong engine is fully sufficient to be used as the Unha-3 second stage engine.

With the mentioned indications of

- propellant type (same as Nodong),
- propellant mass (same as Nodong),
- engine compartment length (same as Nodong),
- engine thrust level (compatible with Nodong)

and, of course, the known availability of the Nodong in North Korea (opposed to the assumed(!) availability of SS-N-6 technology), it seems reasonable to assume that the Unha-3 second stage is not related to the SS-N-6. It also seems reasonable to assume that this stage is based on the well known original Nodong missile.

In this case, adding Tonka to the kerosene would be a logical step to create a hypergolic oxidizer/fuel combination and guarantee second stage ignition. This would not be very hard to do. However, this is speculation.

The choice of a 1.5 m diameter for this rocket stage seems logical. The 1.25 m diameter of the original Nodong would invite structural problems: A 1.25 m second stage mounted on a 2.4 m first stage, perhaps with a third stage on top, would not only look very strange, it would also be very sensitive to loads induced by crosswinds and other effects. Since there are no photos available of the first Taepodong II launch in 2006, it cannot be ruled out that this rocket was equipped with a 1.25 m Nodong second stage, and the North Koreans had to learn their lesson about structural loads the hard way.

A diameter of 2.4 m would have been too large for the stage's small fuel tank. The tank shape would resemble that of a lentil and would have been hard to manufacture. The new stage diameter therefore had to be somewhere between 1.3 m and perhaps 2 m. Therefore, the choice of 1.5 m seems reasonable. It might be coincidence that this is the same diameter as that of the SS-N-6. However, it cannot be ruled out that the diameter was selected with the intent of creating the impression of a relation to the SS-N-6.

Anyway, it is clear now that the Unha second stage is in no way related to the SS-N-6.

The BM-25 Transfer to Iran

There are rumors about the transfer of BM-25 missiles to Iran around 2005. It is not known if these missiles were based on the SS-N-6, but it is generally assumed in open source literature. It is hard to tell how substantiated these rumors are, and the Musudan does not necessarily have to be the same missile as the so-called BM-25. Anyway, there are four possibilities:

- Iran received BM-25 missiles that were based on the SS-N-6.
- Iran received BM-25 missiles that were not based on the SS-N-6.
- Iran received original SS-N-6 missiles that were only transferred via North Korea.
- There never was a BM-25 transfer.

Without further information, none of the four options can be dismissed with total certainty. However, it is important to note that there is no convincing evidence available in open source literature that the BM-25 missiles were related to a SS-N-6 based Musudan missile – they could as well have been decommissioned original SS-N-6 missiles, or Musudan missiles that have no relation to SS-N-6 technology.

The Musudan Warhead

The Musudan missiles displayed in October 2010, and again in April 2012, featured a warhead that resembled the original warhead of the Soviet SS-N-6 (see Figure 4).

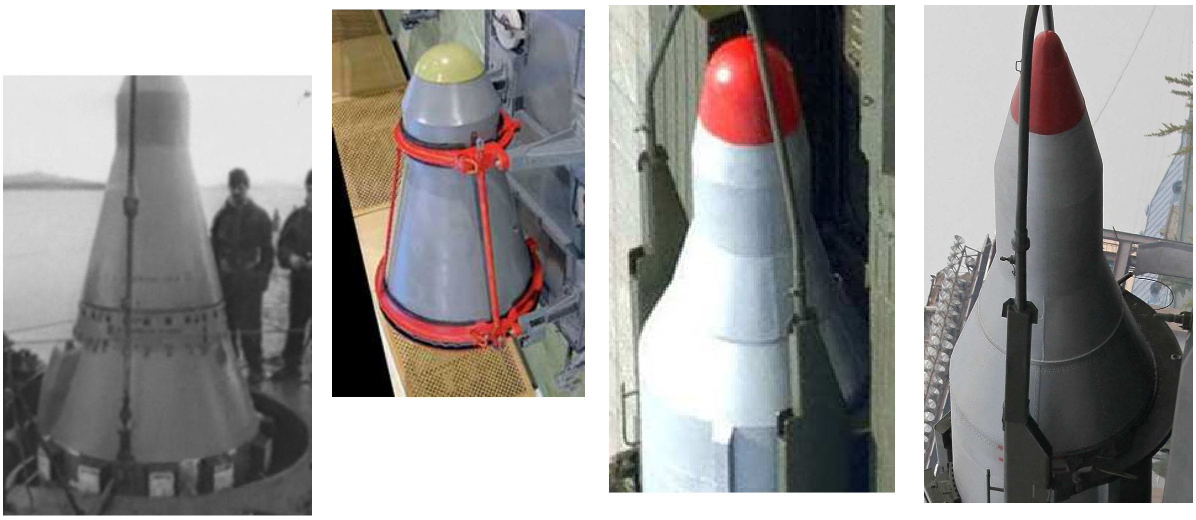

Figure 2: Warheads: SS-N-6 (real), SS-N-6, Musudan, Nodong (all mock-ups)

There are three reasons why the Musudan cannot have the original SS-N-6 warhead. First, the missile and warhead were always stored separately in the Soviet Union (except when they were mated for silo or submarine deployment), they were developed by different teams and design bureaus, and the warheads were not produced at the missile factory, or even by the missile company. Second, the SS-N-6 only had a nuclear warhead, and it is highly unlikely that any Soviet nuclear warheads found their way out of Russia. Third, the SS-N-6 warhead only resembles the Musudan warhead at a first look – overall shape and details are different (as is, by the way, also true for the missile bodies).

Therefore, North Korea has to use an indigenous warhead on its Musudan. The displayed Musudan warhead looks different than the displayed Nodong warhead. This raises the question why North Korean engineers would take the effort to design a new warhead for the Musudan, and not use the available warhead of the Nodong – it should be much easier to mount an existing warhead on a missile than to design a new one.

Displaying a Musudan with a Nodong warhead would have been plausible. But displaying a Musudan with a SS-N-6-like warhead leaves the impression that the North Koreans wanted to force observers into believing that the Musudan is based on the SS-N-6.

Consequences for the Musudan Missile

As stated in the previous paragraphs, the SS-N-6 technology is highly demanding. There only are three pieces of open source “evidence” known to the author that North Korea actually mastered this technology and is using it for its rocket programs: The claimed use of SS-N-6 technology in the Unha second stage, the claimed transfer of BM-25 missiles to Iran, and the displayed Musudan mock-ups that somehow resemble the SS-N-6.

The closer look on these three pieces of “evidence” revealed that

- the Unha second stage cannot be based on SS-N-6 technology,
- the alleged BM-25 transfer could have involved SS-N-6 technology just as well as not, or might not have occurred at all,
- it seems that the displayed Musudan mock-ups were intentionally designed to resemble the SS-N-6 missile.

With that state of knowledge, it seems more plausible to assume that North Korea is still limited to Scud technology at best, then to assume that North Korea has mastered the SS-N-6 technology.

This has consequences for the Musudan missile, assuming that it really exists.

According to photo analysis, the total length of the Unha-3 second stage is between 8.5 and 9 m. Adding a warhead with a length of around 2.5 m, and using a cylindrical structure for the propulsion section instead of the conical structure for the Unha second stage application, this stage would match the reported dimensions of the Musudan and would look like the Musudan mock-ups that were displayed in Pyongyang.

Therefore, assuming that there really is a functional Musudan missile in North Korea, it seems more reasonable to assume that this Musudan is in fact a modified Nodong than to assume that the Musudan is an elongated SS-N-6.

The performance of this Musudan would be much lower than that of a SS-N-6 based missile. It seems that the airframe of the Unha-3 was made of aluminum, and not of steel, so the same can be assumed for the Musudan. As a rough guide value, such a Musudan missile could achieve a range of around 1,500 km with a 0.7 t warhead. If available, this would reduce the North Korean threat radius from the commonly cited range of 3,000 km for the SS-N-6 based Musudan down to half that range.