6 May 2012

An Assessment of the North Korean KN-08 ICBM (if it really exists)

John Schilling[1]

Introduction:

On 15 April 2012, North Korea displayed what appeared to be six road-mobile intercontinental ballistic missiles on transporter-erector-launcher (TEL) vehicles at a military parade in Pyongyang. It had been reported by, among others, former US Secretary of Defense Robert Gates that North Korea was developing such a missile, but the reports seemed incredible as such a weapon was widely seen as beyond North Korea's capabilities.

A close analysis of the missiles, henceforth referred to as the "KN-08", did little to dispel that assessment. The missiles on display in Pyongyang were simple mock-ups. See, for example, http://lewis.armscontrolwonk.com/files/2012/04/KN-08_Analysis_Schiller_Schmucker.pdf. In particular, it is apparent on close examination that each "missile" differs from its neighbors in small but significant details such as the placement of cable guides, access panels, and stage-separation rockets.

If the items on parade are mock-ups, they do not necessarily represent a hoax. It is plausible that North Korea intended and still intends to build a road-mobile ICBM and that it intended to display that actual ICBM at the parade celebrating Kim Il-Sung's centennial. Given the history of the North Korean missile program to date, it is all but certain that actual missile development would have fallen behind the inflexible schedule of a centennial celebration, leading to the display of mock-ups rather than admission of failure. The display items may have been hastily assembled for the parade, or they may be engineering models accumulated over the course of the missile's development (which could explain the differences in fine detail). In either case, the mock-ups will match the appearance of the actual missile to the extent that its design was known when they were built.

It is, of course, also plausible that the whole thing was a hoax, a deception, or a case of severe technological optimism such that no missile will be built to match the appearance of KN-08. North Korea may believe that the illusion of an ICBM is as effective a deterrent as the real thing. Possibly the intent is to build a completely different missile, with the KN-08 serving to focus attention elsewhere while the actual program proceeds unseen and unmolested. But, so long as this uncertainty is kept in mind, there is value in attempting to reverse-engineer the design of an actual missile behind the KN-08 mockups. The display of actual strategic weapons systems in celebratory parades, often

[1] Dr. John Schilling, john.schilling@alumni.usc.edu (661) 718-0955

well in advance of operational deployment, is hardly unprecedented in the history of communist regimes with cult-of-personality governments.

What follows is such an analysis, based on the key assumptions are that the actual missile will match those dimensions and features all the displayed KN-08s have in common, and that to the extent possible it will missile technologies North Korea has already demonstrated with at least partial success in previous work. Many analysts have correctly noted that North Korea cannot build modern ICBMs. The question is, can they build an "obsolete" but functional ICBM to match the KN-08 with technologies they do possess?

Dimensions:

Figure 1 shows one of several KN-08 missiles displayed on what appear to be Wanshan Special Vehicle Company WS-51200 heavy-duty special off-road vehicle . A wire-frame model is overlaid on the image for dimensional analysis, along with critical dimensions from Wanshan marketing materials. There is some uncertainty as to whether the 20.11 meter overall length of the WS-51200 is for the short-cab version seen in North Korea or the long-cab version seen elsewhere; if the 20.11 meter figure is for the long-cab version, the estimates of KN-08 longitudinal dimensions here will be 2-3% high. Longitudinal dimensions are in any event subject to small uncertainty due to foreshortening of the missile in the best available images, which can be estimated but is difficult to calculate to high precision.

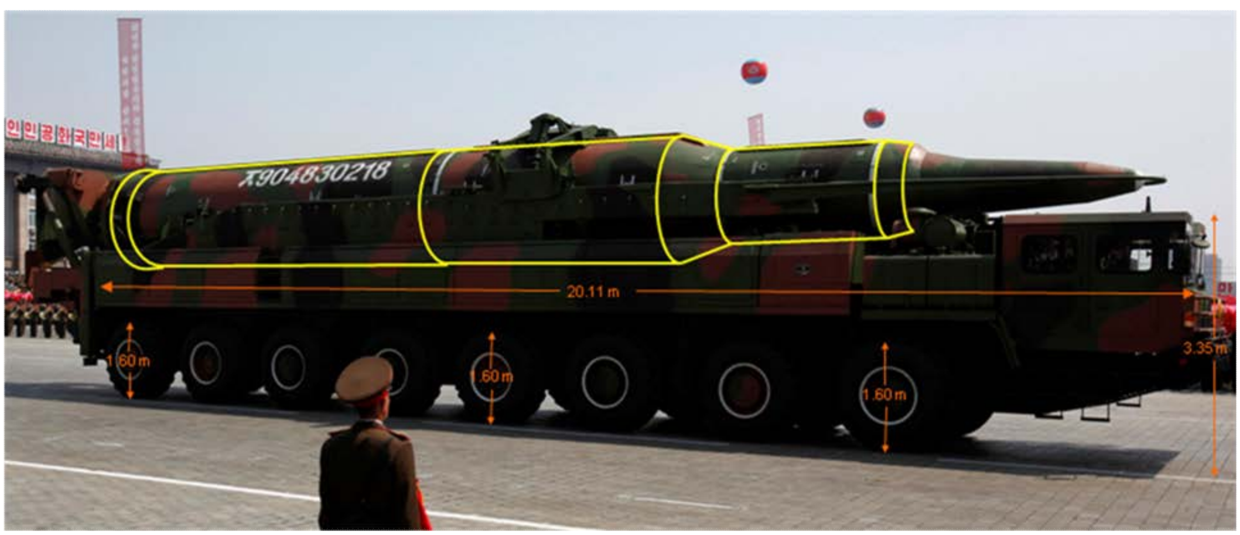

Figure 1: KN-08 mock-up on WS-51200 TEL

Figure 2 shows a drawing of a notional "KN-08A" missile taken from the image in Figure 1. Estimated locations of propellant tanks and engine bays are also given. Engine bays are sized for the most probable engines for their respective stages, as will be discussed later. Propellant tanks are sized to fill the available volume in their stage, maintaining clearance from the engines and from such external access ports, ullage/separation rocket nozzles, and cable pass-throughs as are visible in images of the

KN-08 mockups. Guidance and control electronics are assumed to be located above the third-stage propellant tank. Overall length of the missile is 19.2 meters; length exclusive of the warhead is 16.1 meters. Diameter, again exclusive of warhead varies from 2.0 meters to 1.275 meters. It is possible that the short, slightly-tapered section at the front of the third stage is part of the warhead base. If so, it will nonetheless probably be hollow and available to house protruding elements of the third stage; as will be discussed below the bulk of the warhead mass will be located well forward of the separation plane.

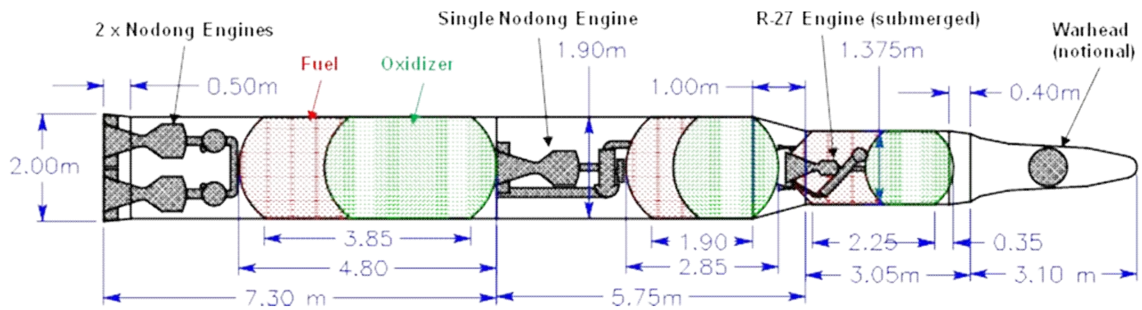

Figure 2: Postulated "KN-08A" internal configuration

Figures 3 through 5 show alternate "KN-08B", "KN-08C", and "KN-08D" configurations with different engine and warhead options. As will be discussed below, there are several possible engine combinations for the second stage of the KN-08. Only dimensions which have changed from the "KN-08A" are indicated

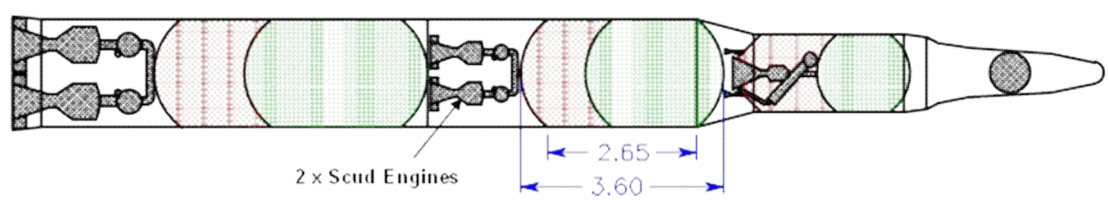

Figure 3: Postulated "KN-08B" internal configuration

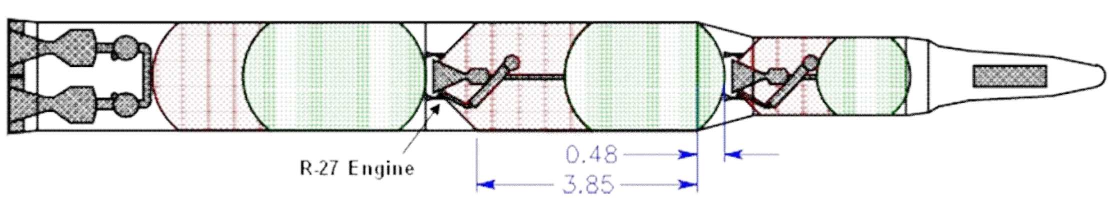

Figure 4: Postulated "KN-08C" internal configuration

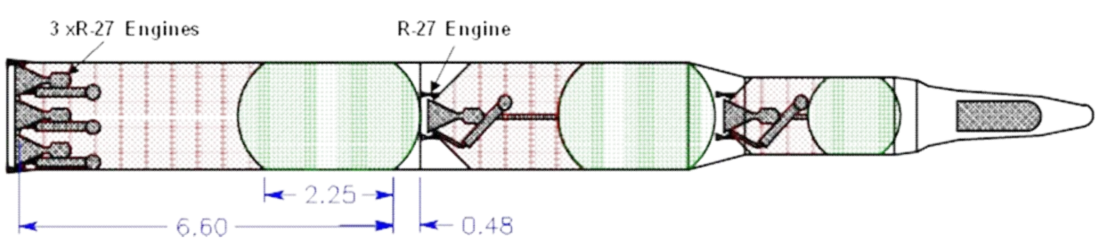

Figure 5: Postulated "KN-08D" internal configuration

The development and testing of a large liquid rocket engine is an extremely demanding undertaking, which may be beyond North Korea's technical ability. Past North Korean missile and space launch efforts have been based entirely on heritage Soviet engines, perhaps reverse-engineered and modified by North Korean engineers. If engines from such sources were at all suitable for the KN-08 missile, it seems unlikely that the North Koreans would chose instead to design a new engine – and if they did, the probability of success would be greatly reduced. As the intent here is to analyze missiles North Korea might succeed in building in the near future, and as suitable engines are available, hypothetical new engines will not be considered.

In particular, solid rocket motors will not be considered here. Large solid rocket motors are unquestionably more durable than comparable liquid rocket systems, and thus generally preferred for mobile missiles. They are also well beyond North Korea's technological capability. This is not a matter of solid rockets being more "advanced" than liquid (or vice versa), simply different. North Korea has chosen to specialize in liquid-propellant rockets, and it has taken roughly a generation to reach the point where ICBM-class vehicles are within reach. North Korea's solid-fuel expertise is limited to much smaller battlefield systems - the KN-02 "Toska" is less than one-tenth the size of the KN-08 first stage, and the KN-02 is a direct copy of a Soviet missile. An indigenous North Korean solid-fuel ICBM is not a credible technical possibility at this time, and the KN-08 does not appear to match the design of any Russian or Chinese missile.

North Korea has demonstrated three liquid-fuel engines potentially suitable for use in the KN-08 missile. The first of these is the Hwasong engine derived from the ex-Soviet R-17 (aka "Scud-B") missiles, which has been in use by North Korea for over thirty years. The Nodong engine appears to be an upscaled Hwasong/Scud engine and is similar to that of the ex-Soviet R-13 (aka SS-N-4 "Sark") or R-15; the basic Nodong missile and engine were first demonstrated in 1993, and an upgraded version appears to have been used in recent space launch attempts by Iran (successful) and North Korea (unsuccessful). Finally and most recently, North Korea appears to have obtained a supply ex-soviet R-27 submarine-launched ballistic missile engines and airframes, or possibly manufacturing technology for these. These serve as the basis for North Korea's Musudan missiles, which have never been flight-tested, but elements of the R-27 have also been used in both Iranian and North Korean space launch attempts. North Korea also possesses engines from smaller ex-Soviet surface-to-surface and surface-to-air missiles - some of these could be used for the upper stage of the KN-08, particularly if clustered, but would offer no performance advantage over the Hwasong, Nodong, or R-27 systems and are not further considered here.

North Korea's ability to manufacture these engines domestically is in some doubt; certainly some degree of Russian technical assistance was required in the past, and it may be that North Korea is even now dependant on stockpiled ex-Soviet hardware for the more complex and sophisticated components of these engines. However, both the Hwasong and Nodong missiles have been produced in substantial quantity and exported to Iran, Pakistan, and Syria, and the missiles have evolved beyond direct copies of ex-Soviet systems. Dependence on external assistance and/or legacy hardware does not appear to be a major limitation on the use of these systems. With regard to the R-27 missiles and engines the situation is less clear; North Korea's own use appears limited to a handful of Musudan missiles that have never been tested along with three unsuccessful space launch attempts. Three successful Iranian space launches have been conducted using R-27 vernier engines (but not main engines or airframes) apparently obtained from North Korea. It is unlikely that North Korea has a robust domestic manufacturing capability for this system.

The North Koreans do not publish performance data on their engines, nor would they be trusted if they did. Fortunately, the end of the Cold War has resulted in an increase in the quantity and quality of technical data available from Russian sources, much of which is relevant to the North Korean engines. It is also possible to estimate the performance of these engines by observing the launch acceleration and burn time of North Korean missiles during tests. Exports of Scud and Nodong missiles to nations such as Iran and Pakistan allows further opportunities for such observation. Estimates of North Korean rocket engine performance vary by several percent, which will have a small effect on estimated KN-08 performance. There is also some uncertainty regarding the exact propellant combinations used; most notably sources differ as to whether the R-27 uses an IRFNA or NTO-based oxidizer. For this analysis, engine performance is assumed as follows:

Scud/Hwasong Engine

Thrust:	130 kN (Sea Level)
	145 kN (Vacuum)
Isp:	225 seconds (Sea Level)
	255 seconds (Vacuum)
Oxidizer:	AK-27I (HNO_3/N_2O_4 blend)
Fuel:	TM-185 (Kerosene/Gasoline blend)
Mixture:	3.5:1

Nodong Engine

Thrust:	285 kN (Sea Level)
	315 kN (Vacuum)
Isp:	225 seconds (Sea Level)
	250 seconds (Vacuum)
Oxidizer:	AK-27I (HNO_3/N_2O_4 blend)
Fuel:	TM-185 (Kerosene/Gasoline blend)
Mixture:	3.5:1

R-27 Engine including vernier rockets

Thrust:	265 kN (Sea Level)
	290 kN (Vacuum)
	32.5 kN (Verniers only)
Isp:	265 seconds (Sea Level)

	290 seconds (Vacuum)
	255 seconds (Verniers only)
Oxidizer:	MON-10 (N_2O_4/NO blend)
Fuel:	UDMH (Unsymmetrical Dimethylhydrazine)
Mixture:	2.0:1

Why Three Stages?

Solid-fuel ICBMs typically use a three-stage configuration, but it is extremely rare for liquid-fuel missiles to use more than two. Yet the KN-08 is unquestionably a three-stage system missile. Not only are the cable guides, access panels, etc, positioned for a stage separation roughly midway down the 1.9-meter cylindrical section, but the upper 1.4-meter cylindrical section is far too small to be the second stage of a balanced two-stage design. The observed shape and features of the KN-08 are only consistent with a three-stage design.

The answer seems to lie in the restricted selection of engines available. The Nodong/Hwasong heritage engines, with a vacuum specific impulse of only 250 seconds, are too inefficient to allow a practical two-stage ICBM. To deliver even the lightest plausible warhead to CONUS targets, such a missile would have to weigh in excess of 120 tons at launch. The more efficient R-27 engine would allow the construction of a two-stage ICBM, with a compact 35-ton missile being able to strike CONUS targets, but a single R-27 engine cannot lift a 35-ton missile. And the R-27 engine uses a complex set of pumps and propellant manifolds, tightly integrated with the engine and tank, that precludes clustering without a substantial redesign of the engine.

Thus, the North Koreans are constrained to use relatively inefficient but easily clustered Nodong engines on at least the first stage of their ICBM, and this inefficiency requires the use of a third stage to provide adequate performance in a compact, mobile missile.

Configuration:

The first stage is assumed to use two Nodong engines. North Korea has demonstrated a four-engine Nodong cluster on the first stage of the Unha series of space launch vehicles, which have a base diameter of 2.4 meters. A two-engine cluster would fit a vehicle with a 2.0 meter base diameter with almost exactly the same clearances, and would have sufficient thrust to provide about 1.5 g launch acceleration. The bulky pump arrangement of the Nodong engine, in a clustered installation, would require a 2.5 meter engine bay.

A cluster of four Scud/Hwasong-type engines would also fit in the base of the KN-08, and would allow for a somewhat shorter engine bay. This would have the advantage of allowing an extra 3,600 kg of fuel to be carried. Unfortunately, the lower performance of the Scud/Hwasong engine coupled with the increased weight of the vehicle would reduce the launch acceleration to a rather marginal 1.25 g. Most of the additional propellant would be spent fighting gravity losses, and the overall performance of the missile would be reduced.

The R-27 is a submerged engine, tightly integrated with the base of the propellant tank. This allows a much greater packaging density, which is advantageous for a mobile missile. However, as has already been noted, the R-27 engine cannot be clustered without substantial redesign. This is probably beyond North Korea's ability. Even if an R-27 cluster were possible, no more than two such engines would easily fit in the KN-08 first stage, and the heavy propellant load with such a tightly packaged installation would reduce the launch acceleration to less than 1.10 g. Nonetheless, a "KN-08D" option will be considered using a cluster of three modified R-27 engines in the first stage.

The second stage could use a single Nodong engine, a pair of Scud/Hwasong engines, or a single R-27 engine. All three combinations will be considered, and will be referred to as the "KN-08A" (Nodong 2^{nd} stage), "KN-08B" (dual Scud 2^{nd} stage), and "KN-08C" (R-27 2^{nd} stage). The Scud engine would require a ~50% increase in operating life for this application; the R-27 would require a ~30% increase and would have to be integrated to a tank of substantially larger than normal diameter – as the engine would remain on the centerline, the critical engine/tank interface could remain unchanged.

For the upper stage, only the R-27 is considered. Because of the short overall length of the upper stage, the engine bay required for a Nodong or even Scud/Hwasong engine would leave little room for propellant tanks. The stage length, along with the location of visible cable ducts, fill ports, and access panels, strongly suggests a submerged-engine design, and the R-27 is the only submerged engine North Korea is known to possess.

In this application, the R-27 engine would be integrated into a somewhat smaller tank / airframe than is the case on the original R-27 missile. The existence of the Musudan missile suggests that North Korea is comfortable with the idea of altering the tankage of an R-27. As can be seen from the cross-section in Figure 2, the third stage of the KN-08 is close to the minimum size needed to accommodate an R-27 engine without repositioning the turbopump and associated plumbing, which is perhaps not coincidental.

In all three stages, propellant tanks are assumed to fill all space not required by engine bays or other equipment, with a minimum of 5 cm of dynamic clearance between engines and tanks of successive stages. Conventional dome tank ends are assumed, along with a common bulkhead between fuel and oxidizer tanks. Common-bulkhead tanks have not traditionally been used with Hwasong/Nodong-heritage missiles, but are part of the R-27 technology base. The performance of the KN-08A, B, and C would be reduced somewhat if separate tanks are used in the first stage.

Guidance and Control:

Long-range ballistic missiles almost invariably use inertial guidance; radio command guidance is also possible and has been used on early cold-war era weapons, but is subject to jamming. North Korea has demonstrated the ability to use basic inertial guidance with its Nodong missiles and to some extent its Unha space launch vehicles; it is assumed that inertial guidance is used here. In its simplest form, this involves aligning the vehicle's gyro axis with the desired launch azimuth (either on the launch platform or via a roll maneuver immediately after launch), and flying a precalculated pitch vs. time profile. Engine cutoff is performed when an integrating accelerometer determines that the appropriate velocity has been reached. More sophisticated strategies are possible.

For steering, it is assumed that stages using Scud/Hwasong or Nodong engines use the thrust vanes typically associated with those engines. Thrust vanes do reduce the performance of the engine by several percent, with most nations having adopted gimbaled main engines as a more efficient means of controlling rockets and missiles. North Korea has never demonstrated this technology, and there would be substantial additional risk in trying it for the first time here.

The effect of thrust vanes on engine performance and packaging has already been accounted for in the figures given earlier. In particular, it should be noted that the KN-08 has a slightly flared skirt at the base of the first stage, with a diameter ~10 cm greater than that of the rest of the stage. The cable guide running the full length of the first stage, disappears into that flared skirt. This is consistent with a requirement to run cables, hydraulic, or plumbing lines to thrust vanes at the base of a tightly-packaged first stage.

Stages using the R-27 engine are assumed to use the R-27 vernier rockets for this purpose. The verniers can be operated independently; it will be assumed that the third stage shifts to vernier-only operation at least ten seconds before shutoff to facilitate fine velocity control. A similar system was probably used on the Soviet R-27 missile, and allows somewhat greater accuracy than would be possible with the coarse thrust termination profile of the main engine.

The actual guidance system is almost certainly located in the third stage, and from packaging considerations probably above the third-stage oxidizer tank. The R-27 placed the guidance system in a sealed compartment within the tank, and such a configuration cannot be ruled out here. Actual guidance hardware would consist of gyros (probably mechanical), accelerometers, and either a basic computer or a set of sequencers and feedback controllers. The details cannot be determined at this time, but will probably include common heritage with North Korea's previous missiles and/or with the R-27. Guidance commands are sent to lower stages via the external cable guides clearly visible on KN-08 imagery.

Weight and Volume:

The weight of the propellants can be determined from the estimated volume of the propellant tanks and the density of the propellants. As this is a mobile missile, caution is required – it will not be possible to completely load the tanks to maximum density at short notice in a remote site. It will be assumed that the propellant load is constrained to leave 2.5% ullage volume in the tanks after allowing for thermal expansion to 30 ^{o}C. For stages using the submerged-engine R-27, this will be increased to 3.5% due to the possible difficulty of achieving a complete fill with the more complex tank geometry.

Weight of engines, airframes, and guidance hardware is much more difficult to estimate. Here the best that can likely be done is to make an estimate by comparison to other known systems. Guidance systems of early US ICBMs had weights of 100-300kg; as North Korea has some access to modern electronics it will be assumed that they can at least match the lower figure. The North Korean Nodong missile has been exported to several nations and conducted a number of highly visible test flights; from this it is possible to estimate that the total dry mass (exclusive of warhead and guidance) is 11% of the launch weight of the missile. For the ex-Soviet R-27 missile, Russian data suggests a 9.5% stage mass fraction (again exclusive of warhead and guidance). As the KN-08 will use North Korean airframes even were R-27 engines are used, this analysis will assume a 10.5% mass fraction for R-27 based stages and an 11% mass fraction for Scud/Hwasong and Nodong-based stages.

The nominal 100 kg guidance system will be carried by the third stage only. As described below, warhead weights of 500-1500 kg will be considered.

A final consideration is propellant residuals. It is impossible to completely drain a missile of propellant. There is always some propellant trapped in dead volumes of the plumbing. It is also impossible to precisely balance the fuel and oxidizer load so that both are exhausted at the same time – and it is important to shut down the engine before either propellant is completely exhausted, or the turbopump will overspeed and destroy the engine. Standard practice is to provide a slight excess of fuel, and shut down the engine at the first warning of oxidizer depletion. In modern rockets and spacecraft, it is sometimes possible to consume as much as 99.5% of the propellant. For North Korea's more basic designs, this analysis will assume 2% residual propellant in Scud/Hwasong and Nodong-based stages, with 3% residual propellant in stages based on the submerged-engine R-27. Based on these assumptions, the mass breakdown of the notional KN-08 is:

KN-08A/B/C First Stage (dual Nodong engine)

Total propellant:	16,250 kg
Usable propellant:	15,925 kg
Dry Mass:	2,000 kg
Total Wet Mass:	18,250 kg
Burnout Mass:	2,325 kg

KN-08D First Stage (triple R-27 engine)

Total propellant:	19,700 kg
Usable propellant:	19,100 kg
Dry Mass:	2,300 kg
Total Wet Mass:	22,000 kg
Burnout Mass:	2,900 kg

KN-08A Second Stage (single Nodong engine)

Total propellant:	8,900 kg
Usable propellant:	8,725 kg
Dry Mass:	1,100 kg
Total Wet Mass:	10,000 kg
Burnout Mass:	1,275 kg

KN-08B Second Stage (dual Scud engine)

Total propellant:	11,750 kg
Usable propellant:	11,515 kg
Dry Mass:	1,450 kg
Total Wet Mass:	13,200 kg
Burnout Mass:	1,685 kg

KN-08C/D Second Stage (R-27 engine)

Total propellant:	13,650 kg
Usable propellant:	13,250 kg
Dry Mass:	1,600 kg
Total Wet Mass:	15,250 kg
Burnout Mass:	2,000 kg

KN-08 Third Stage (R-27 Engine)

Total propellant:	4,100 kg
Usable propellant:	3,975 kg
Dry Mass:	575 kg
Total Wet Mass:	4,675 kg
Burnout Mass:	700 kg

Gross weight of the missile at launch, assuming a 1000 kg warhead, would be roughly would be approximately 34 metric tons for the KN-08A, 37 metric tons for the KN-08B, 39 metric tons for the KN-08C, or 43 tons for the KN-09D configuration.

Warhead:

The KN-08 uses a triconic warhead of slightly greater than 3 meters overall length. Modern US, Russian, British, and French warheads use slender single-cone designs which offer better terminal performance – reduced drag translates to greater accuracy and higher terminal velocity (i.e. less exposure to terminal-phase missile defenses). However, the tip of a slender warhead reentering the Earth's atmosphere at ICBM velocities is subject to an extremely challenging thermal environment. Also, the single-cone design makes it difficult to package a large-diameter nuclear device while preserving balance and aerodynamic stability. The triconic warhead is a reasonable compromise between terminal performance, thermal design, and payload packaging.

It is important to note that in a triconic warhead, the rear conical region is primarily a drag device to moderate terminal velocity and ensure aerodynamic stability. Weight and balance considerations demand that the bulk of the payload mass be in the central cylindrical region or, if possible, the forward tip. Thus the rear cone can be largely empty space. While it is unclear exactly where the third stage / warhead separation plane of the KN-08 is located, there should be no difficulty with the third-stage oxidizer tank or guidance package projecting forward into the conical base of the warhead.

The weight of North Korea's nuclear weapons is unknown, and subject to a great deal of speculation. If indeed North Korea is unable to produce devices smaller than the Trinity Gadget or Hiroshima's "Little Boy", there is no prospect of a nuclear-tipped Korean ICBM. However, this seems unlikely – every technique ultimately used to produce lightweight nuclear weapons in the early 1950s was known to the Manhattan project team in 1945 and was successful in its first postwar test. The first generation of US lightweight nuclear weapons included the Mark 5 (1400kg total weight, 120 kiloton yield) and Mark 7 (750 kg, 60 kT), both introduced in 1952, and 1954's Mark 7 (450 kg, 15 kT). Comparable devices were developed in Britain, France, Russia, and China shortly after their first nuclear tests.

It is reasonable to assume that North Korea's first missile-delivered warhead will fall within the same approximate weight range, if not yield Indeed, the low yield of North Korea's nuclear tests to date suggests they may be attempting to produce as light and compact a weapon as their technology will allow. It should be noted that these early weapons were aircraft-delivered bombs and short-range missile warheads. An ICBM warhead will necessarily be somewhat heavier due to the increased requirement for thermal protection. However, as noted earlier, the triconic warhead design reduces the peak thermal load. And even the Apollo spacecraft, with a vastly more challenging thermal environment, had a head shield weighing no more than 15% of the total reentry mass. A range of 500-1500 kg total mass should cover any plausible first-generation North Korean ICBM warhead.

Warhead diameter is also a concern. The warhead shown in Figure 2 includes an approximate representation of the Mark 7 implosion assembly, the largest irreducible component of the weapon. The KN-08 warhead is adequate for packaging first-generation lightweight nuclear weapons. Indeed, it seems excessively long for such purposes, leading to some suspicion of alternative payloads.

Two possibilities would be gun-assembly fission bombs and first-generation thermonuclear weapons with cylindrical primaries. The notional missile in Figure 4 is shown carrying a US Mark 10 gun-assembly device of 700 kg total weight and 15 kiloton yield. Figure 5 includes the physics package of a W-28 thermonuclear weapon, yielding 1.4 megatons with a 900 kg total weight. The intent is not to suggest that the North Koreans will use copies or even similar designs to these weapons, but to show that the KN-08's long triconic warhead allows substantial flexibility in warhead packaging. Thermonuclear weapons, in particular, are almost certainly well beyond North Korea's present capabilities, but perhaps not beyond North Korean ambitions.

Performance:

With assumed stage mass and engine performance values, it is possible to estimate the performance of the KN-08 missile. A high-fidelity performance model would also require aerodynamic data, moments of inertia, control system authority and response times, detailed operational constraints, etc, to support a full six-degree-of-freedom model of the vehicle's trajectory. While estimates can be made for these parameters, they would be estimates only – and given the uncertainties already accepted in weights and engine performance, excessive effort along these lines is not warranted. At best only an approximate prediction of range vs. performance can be made, with an accuracy of perhaps $\pm$15% in range.

One operational constraint that must be considered even at this level of analysis is 3rd stage burnout acceleration. If the postulated KN-08 third stage is flown to (near) propellant depletion with a light warhead, the acceleration at burnout will be roughly 25g. This is unprecedented in an ICBM or space launch vehicle, and would require an unusually heavy structure to withstand the associated loads. Therefore, it may be necessary to shut down the R-27 core engine early and complete the third-stage burn using vernier rockets only if flying with a light warhead. As the nominal burnout acceleration of the R-27 SLBM was approximately 13.5 g, it will be assumed that the KN-08 third stage must "throttle down" to vernier-only operation when acceleration reaches 13.5 g.

Because the effect of the Earth's rotation is not negligible for ICBM-type trajectories, one cannot simply give a precise range – the location of the launch site, and the direction of the launch, will affect the distance traveled. As the KN-08 is apparently a mobile missile, the launch site could in principle be anywhere in North Korea. This analysis will assume a launch out of Musudan-ri with a launch azimuth of 45^{o}. Any launch from North Korea against a CONUS target will approximate this trajectory; against targets in Europe or Asia the range of the KN-08 would be somewhat reduced.

The resulting prediction of throw weight vs. range for the four postulated KN-08 variants is shown in Figure 6, below. "Throw weight" refers in this case to the complete mass of the separated warhead section; as noted earlier 500-1500 kg covers the plausible range for first-generation fission warheads. Also shown is the performance of a nominal two-stage missile of similar weight using only R-27 engines (clustered for the first stage). A two-stage missile using only Nodong engines would barely appear at this scale, with a range of little more than 5000 km with the lightest plausible warhead.

As can be seen, the postulated "KN-08A" and "KN-08B" variants, using Nodong/Scud technology for the first two stages, have a maximum range of roughly 7500 km with the lightest possible warhead. This is barely adequate to reach CONUS targets under ideal conditions; while the margin for error in this analysis is too high to entirely rule out a threat to the United States by such a system, it is unlikely.

The "KN-08C", using a Nondong-based first stage and R-27 engines for the second and third stages, has substantially greater performance. Such a missile would almost certainly have the performance to reach CONUS targets with a light payload, probably reaching Seattle with a 750 kg warhead and as far as Los Angeles or Denver with 500 kg. All of Asia and Central Europe would also be within reach. Only with the most optimistic assumptions would Western Europe or the US East Coast be within range.

The "KN-08D", with R-27 engines for all three stages, is capable of reaching virtually all of United States and Western Europe with a light warhead. As has been noted this is probably not feasible given the technical limits of the R-27 engine. Furthermore, if the North Koreans can build a tightly-clustered R-27 system, they could obtain comparable performance with a two-stage missile and so greatly reduce the cost and complexity of the system.

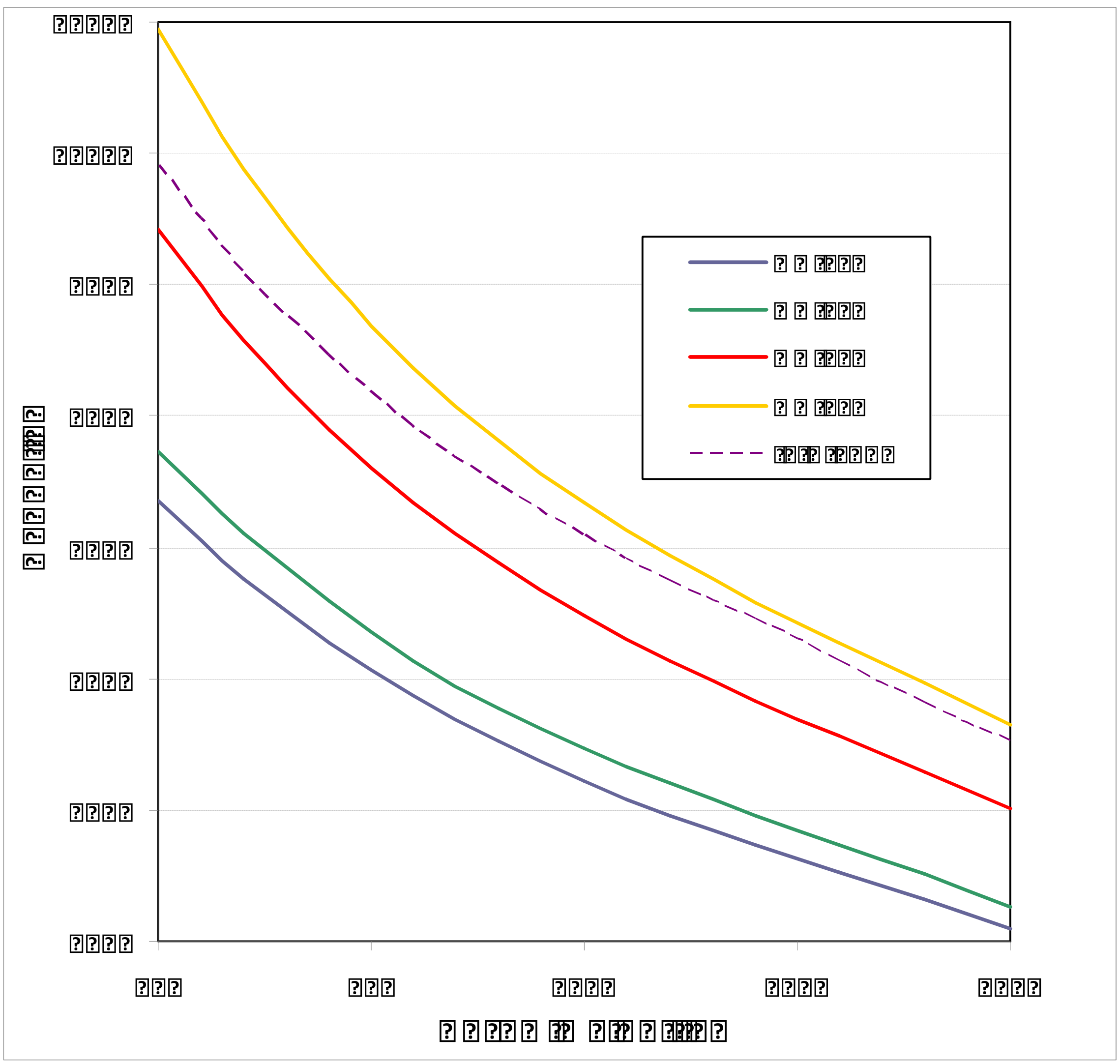

Figure 6 - Predicted KN-08 Performance

While a fair quantitative prediction of range and payload can be made from the external dimensions and geometry of the missile, accuracy will depend on details of the guidance and control hardware that are harder to predict. The R-27 missile on which the upper stage(s) of the KN-08 are assumed to be based, had a circular error probable (CEP) of 1.9 km at a range of 2400 km, according to Russian sources. Ballistic-missile accuracy is largely a function of velocity errors at burnout; if the KN-08 uses R-27 vernier rockets for fine control and can at least match R-27 inertial measurement accuracy (perhaps by using heritage R-27 accelerometers and gyros), it should have similar velocity errors.

As the KN-08 will have a substantially longer time of flight than the R-27, the accuracy will be proportionately reduced - velocity errors will have more time to impact the final trajectory. At a range of 8000 km, a KN-08 which can match the stated guidance performance of the R-27 would have an error ellipse of approximately 4 km cross-range and 8 km downrange - half of all missiles fired would be expected to fall within such an ellipse. If the North Koreans can only match the accuracy demonstrated by their previous Nodong missiles, the error ellipse of the KN-08 would be roughly 10 x 20 km at intercontinental ranges.

North Korea's most powerful nuclear test had a yield of no more than 6 kilotons, sufficient to destroy soft targets within a 1.3 km radius. The largest first-generation fission warhead that could plausibly be delivered to CONUS targets by a KN-08 missile would have a yield roughly an order of magnitude higher, which still corresponds to a soft-target destruction radius of only 3.0 km. A KN-08 missile cannot reliably be used to destroy any specific target, and certainly not a hardened military target. It would probably be sufficiently accurate to hit large urban areas, but not to target specific neighborhoods or districts.

Mobility:

The KN-08 mockups were displayed on what appear to be Transporter-Erector-Launcher (TEL) vehicles with substantial cross-country performance. The chassis, at least, is probably similar to that used on China's DF-31 mobile ICBMs. This gives the impression of a highly mobile field-deployed military system, capable of being dispersed anywhere in North Korea and rapidly relocated to evade attack. Such a capability is seen with smaller mobile missiles such as the Scud/Hwasong series, and is of obvious value to a nation like North Korea whose limited strategic military forces are almost constantly in the crosshairs of vastly more powerful nations.

Unfortunately for North Korea's military planners, it is difficult to make a large liquid-fueled missile highly mobile. Mobile IRBM and ICBM-class weapons are almost invariably solid-fuel rockets. Liquid fuel tanks are inherently less robust than solid motor casings, and at large scale the loads associated with transporting a liquid-fuel rocket on an off-road vehicle would become prohibitive. Even on-road travel, except at very low speed on a flat paved road, would risk damaging a fully-fueled KN-08.

It probably would be possible to achieve a high degree of on-road mobility with an empty KN-08; the fuel represents more than eighty percent of the weight and thus strain on the missile structure. This would then require that the missile be fuelled at the launch site, after being transported and (perhaps) erected. Similar systems were used in the early Cold War era; the US Redstone and Jupiter missiles could be fueled within fifteen minutes. While these were of similar scale to the KN-08, they were single-stage vehicles. Fueling a KN-08, with three stages and two propellant combinations, would probably take half an hour or so. Other steps necessary to prepare and fire the missile, not all of which can be conducted in parallel with fueling, would probably increase the prelaunch time scale to at least an hour.

It would also be necessary to accompany the KN-08 TEL with a small fleet of support vehicles. At least four fuel tanker trucks would be required, and probably a mobile launch control center. And it is unlikely that the North Koreans would deploy such a valuable asset without robust security, maintenance, and communications capabilities. Far from the image of a rugged cross-country vehicle playing hide-and-seek in the North Korean mountains while prepared to launch a nuclear strike on a minute’s notice, a KN-08 missile would probably be the center of a significant military force, at least a dozen vehicles, tied to the local road network, and would require an hour or more for launch operations.

As North Korea is a geographically small opportunity subject to intense foreign scrutiny, this raises the possibility that a KN-08 could be destroyed on the ground before it could fire. Such preemption would require constant surveillance and a highly responsive strike capability, preferably locally based (i.e. in South Korea or on warships in the Yellow Sea or Sea of Japan), and a willingness to order decisive military action in short notice. During an acute crisis justifying an elevated alert posture, it could be an effective means of neutralizing a small KN-08 force.

An alternate concept of operations would be to maintain the actual KN-08 missiles in hardened caves or tunnels, using the TELs only to roll the missiles out to prepared launch sites immediately outside. China is known to have deployed some of its early ICBMs in this fashion, and it would probably be possible to transport and erect a fully-fueled KN-08 if the trip were only a few hundred meters along a paved road. An additional advantage with semi-fixed basing is that the missiles could be fueled in a climate-controlled environment. The analysis given previously assumed a requirement that the missile withstand temperatures from -25 to +30 ^{o}C; more propellant can be loaded if the missile can be maintained at room temperature, corresponding to a range increase of up to 250 km. Reliability would also be greatly enhanced.

TELs could also be used to shuffle real and dummy missiles between a large number of hardened sites in peacetime, to complicate any attempt at a preemptive strike. While the North Koreans are certainly willing to show off KN-08 mock-ups to confuse their adversaries, they appear to have purchased only half a dozen suitable TELs and it is unclear whether future procurement from China will be possible.

Operational Availability

There is almost no possibility that actual KN-08 missiles exist at present. It is in principle possible that the most recently-constructed mock-up represents the final design and that a flight missile has been assembled in the weeks since the Pyongyang display, but it seems unlikely. We are seeing a work in progress, and there is probably some work left to be done.

Furthermore, the recent failure of the third Unha space launch vehicle would cast doubt on any design sharing that technological heritage. It is most unlikely that North Korea is racing to build a KN-08 to a design recently committed to paper without first digesting the lessons learned from the Unha failure - and if they do, they will most likely just repeat that failure. At a minimum, it will take several months to analyze the Unha failure and probably several more to manufacture a prototype KN-08 incorporating any lessons learned.

However, the shared heritage of the postulated KN-08 and the observed Unha means that the North Koreans will not have to conduct an entire development program from scratch to build and fly a KN-08. The Unha vehicle is the result of at least six years of effort, presumably in parallel with North Korea's current ICBM development program (whether KN-08 or otherwise), and as the Unha has entered flight testing it seems unlikely that another six years will be required for an ICBM.

If the KN-08 does in fact represent North Korea's planned ICBM, the first prototype will probably be available in at least six months but no more than six years. A prototype, it must be emphasized, is not an operational missile.

For a KN-08 to deliver a warhead - neglecting for the moment the unreliability of North Korean nuclear warheads - three independent rocket stages must each work properly. Two staging events must occur properly. And a high-energy atmospheric reentry must be successfully performed. North Korea has attempted three launches of a rocket stage based on clustered Nodong technology, one or two of which failed. Probably three stages based on R-27 missiles have also flown, with two being destroyed in the failure of their booster rockets and one apparent success. North Korea has attempted five staging events with one or two failures, again discounting cases where booster failures rendered staging moot. There have been no successful North Korean re-entry tests at anywhere close to ICBM velocities.

Considering only North Korea's relevant flight test history, Bayesian statistics suggest the probability of the first KN-08 launch being fully successful is only 5.4%. Extensive ground testing of the individual stages could at most increase this to 26%, as staging and re-entry cannot be meaningfully tested on the ground. And even a single successful test would not give high confidence in the system, given the past history of failures. The KN-08 is unlikely to enter service as an operational weapon until several flight tests have been completed. Some of these tests may masquerade as satellite launch attempts, but they cannot be entirely hidden and so the KN-08 cannot achieve a real operational capability without warning.

If and when a KN-08 ICBM does become available, it will almost certainly be in very limited numbers. A KN-08 based on current North Korean technology will require at least one and probably two R-27 engines. Unless North Korea manages to establish an independent ability to mass-produce this engine, they will be dependent on ex-Soviet missiles. There are perhaps 100 flightworthy R-27 airframes not otherwise accounted for, to support all North Korean Musudan and KN-08 missile production, Unha space launch attempts, and associated ground testing. And, as noted earlier, the supply of suitable TELs may be limited now that it has been made clear to all concerned that an WS-51200 in North Korean hands is a missile transporter.

Conclusion

While the "KN-08" missiles paraded through Pyongyang last month were almost certainly non-functional mock-ups, it is possible that they represent a missile presently under development. If this is the case, it is unlikely that the missile will reach operational capability for at least a year, possibly much longer, and in any event with multiple flight tests as a warning.

Based on the exterior appearance of the KN-08 mockups, and on North Korea's relevant experience in large rocket and missile development, it is possible to reconstruct a range of credible designs for a KN-08 ICBM within North Korea's current technological capabilities – obsolete by modern standards, but still functional. All credible designs three-stage, liquid fueled missiles with marginal intercontinental performance. At least one credible design would be capable of delivering a first-generation fission warhead of low yield to CONUS targets, though a probable maximum range of 9,500 km would leave the Midwest and East Coast out of reach.

If an operational KN-08 is deployed, it will be a weapon of extremely limited capability. It will not be a truly mobile missile, requiring substantial support infrastructure at the launch site. At best this support infrastructure could be transported by truck and set up in the hours immediately prior to launch. Based on previous North Korean experience with large multistage rockets, reliability will be poor. Accuracy also is likely to be poor, though sufficient to hit large urban areas.

Again, it must be noted that this is an analysis of North Korean capabilities in light of their recent display; capability is not intent. It is also plausible that North Korea intends to build an entirely different long-range missile, or none at all. And it is possible that their intent is to build a missile that is in fact beyond their technological capabilities, such that no operational system will ever emerge from behind the KN-08 veil.

The message of the KN-08's recent display is that North Korea will soon have a nuclear deterrent capable of holding the United States at bay by threatening the destruction of American cities. That message may be a bluff. It is, just barely, credible.

Acknowledgements

The author would like to thank Michael Elleman and David Wright for providing additional information on the Scud and Nodong family of rocket engines, and also Jeffrey Lewis, Markus Schiller, and George Herbert for their valuable feedback and discussions.