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A Revised Assessment of the North Korean KN-08 ICBM

John Schilling

University of Southern California, Los Angeles, California, USA

The mobile ICBM displayed in Pyongyang last April is analyzed in light of North Korea's known and reasonably suspected capabilities in the field, particularly those demonstrated in the recent and successful Unha-3 launch. Several possible configurations for the "KN-08" missile are given, and performance estimates are presented. While the displayed missiles are clearly mock-ups, they are consistent with an ongoing development program for a missile with limited intercontinental capability using only existing North Korean technology. The lack of flight testing strongly suggests that operational deployment is still months or years in the future, though an initial test could come at any time. Even with a successful test program, any such North Korean ICBM would likely be unreliable, limited in mobility and performance, and available only in small numbers.

INTRODUCTION

On 19 January 2013, the *New York Times* reported that North Korea had begun initial deployment of a long-range mobile missile referred to as the "KN-08."[1] This missile had first been seen on 15 April 2012, when what appeared to be six road-mobile intercontinental ballistic missiles were displayed on transporter-erector-launcher (TEL) vehicles at a military parade in Pyongyang. It had been reported by, among others, former U.S. 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 displayed in 2012 were simple mock-ups.[2]

That the missiles displayed on parade were mock-ups, does not indicate that they represented a hoax. Historically, missiles displayed in parades are frequently mock-ups even when operational systems are available. Displaying

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Address correspondence to Dr. John Schilling, 3111 Lemonwood Drive, Lancaster, CA 93536, USA. E-mail: john.schilling@alumni.usc.edu

mock-ups is safer in several respects. And it allows the display of missiles in advance of actual production. The former Soviet Union's various military parades through Red Square included mock-ups of operational missiles, mock-ups of missiles under development, and mock-ups of missiles whose development had been cancelled but which still served to impress crowds and mislead western analysts. No firm conclusion can be made either way from the fact that the missiles displayed in Pyongyang were mock-ups.

But even if only mock-ups were available a year ago, much can change in a year. There have been many reports, though difficult to confirm, that North Korea has been conducting an extensive ground-test program for engines and other hardware associated with the KN-08.[3,4] More obviously and spectacularly, on 12 December 2012 North Korea successfully launched a satellite into Low Earth Orbit using an Unha-3 rocket.[5] Satellite launchers and long-range missiles are fundamentally similar technologies—indeed, many satellites are launched by repurposed military intercontinental ballistic missiles, and even if the overall configuration is different it is common for a nation's first satellite launch vehicles and ICBMs to share common hardware. If nothing else, the successful launch of the Unha-3 greatly weakens the argument that North Korea is a nation of technological illiterates incapable of complex missile development programs. Reports of shoddy manufacturing processes in North Korea's industries abound, but North Korea's missile designers have clearly learned to work within such limitations and can produce effective long-range rockets—though perhaps not consistently or reliably.

It is still plausible that the KN-08 parade was nonetheless a hoax, a deception, or a case of severe technological optimism such that no missile will be built to match the appearance of the displayed 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.

What follows is such an analysis, based on the key assumptions that the actual missile will match those dimensions and features that the various displayed KN-08s have in common, and that to the extent possible it will use technologies North Korea has already demonstrated with at least partial success in previous work. In particular, it will be assumed that the Unha-3 satellite launcher serves also as a technology demonstrator for the KN-08 missile, with a similar technological heritage and with common hardware used wherever practical.

It is clear that North Korea does not have the ability to build a modern road-mobile ICBM. In particular, most modern and virtually all mobile ICBMs use solid-fuel rockets, and large solid rockets are a technology that North

Figure 1: KN-08 mock-up on WS51200 TEL.

Korea has never demonstrated. But a missile does not need to be modern to be effective. The question is, can North Korea build an "obsolete" but functional ICBM matching the appearance of the KN-08, using technologies they do possess?

DIMENSIONS

Figure 1 shows one of several KN-08 missiles displayed on what appear to be Wanshan Special Vehicle Company WS51200 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.[6] There is some uncertainty as to whether the 20.11 meter overall length specified for the WS51200 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 2 displays only the wire-frame model, in orthogonal projection and with key dimensions of the missile itself. There is some degree of uncertainty in these dimensions, and the diameter of the missile stages in particular may be off by as much as 5%.

INTERIOR CONFIGURATION

Figures 3, Figure 4, and Figure 5 show the estimated internal layout, and key dimensions, of three plausible models of the KN-08 missiles. These models,

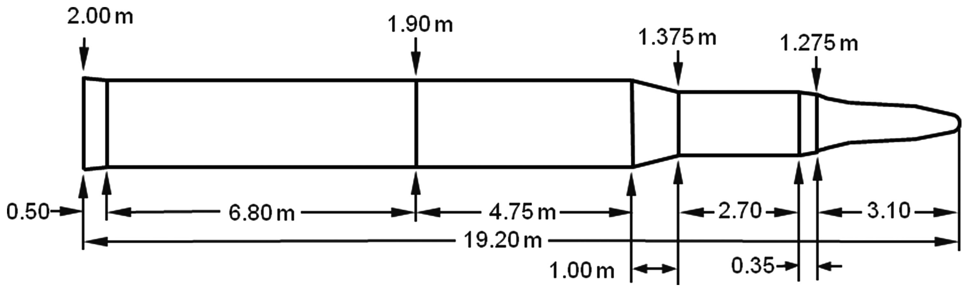

Figure 2: Geometry and Dimensions of the KN-08A.

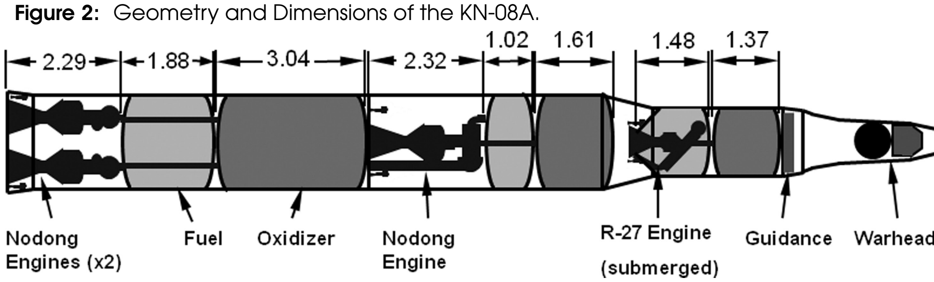

Figure 3: Postulated "KN-08A" internal configuration.

referred to as "KN-08A," "KN-08B," and "KN-08C," differ primarily in the choice of engines for the various stages, as will be discussed later. 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 at the appropriate propellant mixture ratio, 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. 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.

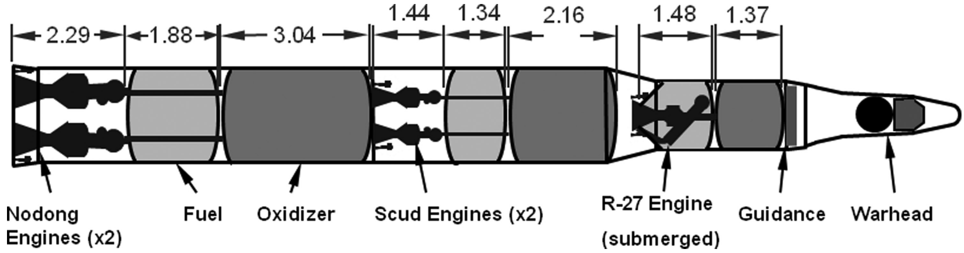

Figure 4: Postulated "KN-08B" internal configuration.

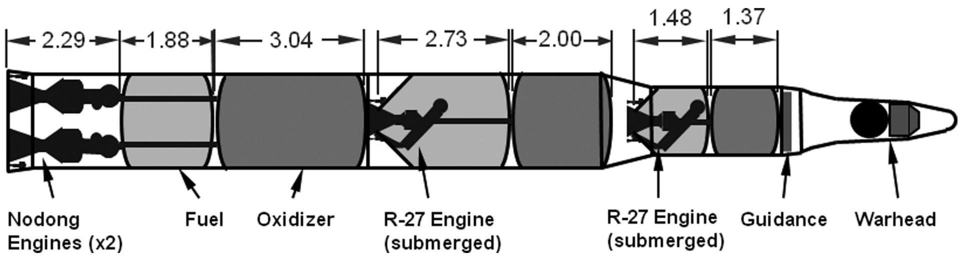

Figure 5: Postulated "KN-08C" internal configuration.

Figures 6 and 7 give details of two further configurations, "KN-08 Minimum" and "KN-08 Maximum," included as bounding cases. The KN-08 Minimum uses only engines that North Korea is known with high confidence to have successfully tested, whereas the KN-08 Maximum assumes that North Korea has successfully reverse-engineered the most sophisticated ex-Soviet engines in its arsenal and can heavily modify these engines to meet the specific requirements of the KN-08 missile. Both of these are considered relatively unlikely, the former on the grounds of limited utility and the latter as being beyond North Korea's technical ability, but they are included for the sake of completeness and to establish upper and lower bounds on the possible KN-08 performance envelope.

ENGINES

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,[7] 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 choose 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

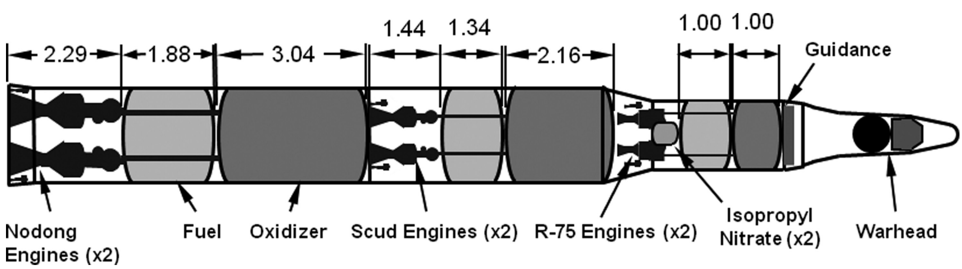

Figure 6: Postulated "KN-08 Minimum" internal configuration.

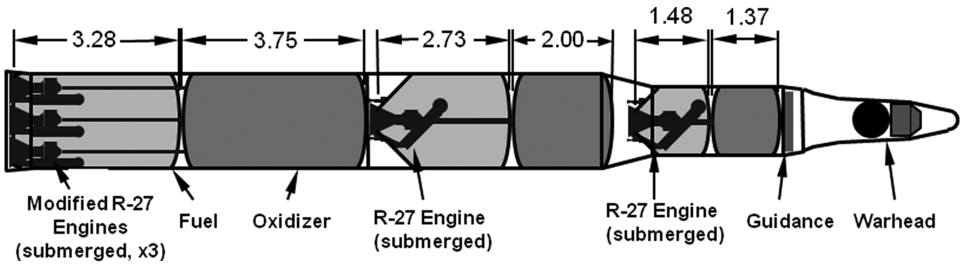

Figure 7: Postulated "KN-08 Maximum" internal configuration.

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 "Tochka" 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.

North Korea has demonstrated two engines reasonably well suited for use in the KN-08 missile, and is believed to possess two others. The first of these is the Scud engine derived from the ex-Soviet R-17 (aka "Hwasong-6" or "Scud-B") missiles, which has been in use by North Korea for over 30 years.[8] The second is the Nodong engine, which appears to be simply an enlarged Scud engine. The basic Nodong engine was first demonstrated the late 1980s, and an upgraded version appears to have been used in recent space launches by Iran and North Korea.[9] It should be noted that increasing the size of a rocket engine is not in fact a simple matter, and it is not clear whether this upscaling was performed by North Korean, Soviet, or ex-Soviet engineers.

Finally and most recently, North Korea is widely reported to have obtained a supply ex-Soviet R-27 (aka SS-N-6 "Serb") submarine-launched ballistic missile engines and airframes.[10,11] Widespread speculation is that these engines serve as the basis for North Korea's Musudan missiles. The R-27 includes two smaller vernier (control) rocket engines, which can be operated even when the main engine is shut down. Iran's Safir satellite launch vehicle uses what appear to be just the R-27 vernier rockets on its upper stage, indicating that the verniers can (perhaps with some difficulty) be physically separated from the main engine and used as the basis for a smaller, independent propulsion system.[12] Close similarities between the observed dimensions and estimated performance of the upper stages of the Safir and Unha launch vehicles, along with the known collaboration between North Korea and Iran in liquid-propellant rocketry, suggest that the North Korean Unha also uses engines derived from the R-27 verniers as its primary propulsion system.

North Korea also possesses engines from smaller ex-Soviet surface-to-surface and surface-to-air missiles, which would not normally be suited for use in a large missile such as the KN-08. Only one such engine will be considered, that of the S-75 (aka SA-2 "Guideline") surface-to-air missile.[13] This engine can be adapted for use in ballistic missiles, as demonstrated by the use of two S-75 engines in the Indian Prithvi series of short-range nuclear-capable missiles. It is considered here because it is the only engine confirmed to be available and flight-tested in North Korea that would fit in the small third stage of the KN-08 while leaving enough room for reasonable propellant tanks.

North Korea's ability to manufacture these engines domestically is in some doubt; certainly extensive 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-6 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.[14] 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 probably never been tested along with the possible use of R-27 verniers (but not main engines) in three unsuccessful and one successful space launch attempts.[15] It is unlikely that North Korea has a robust domestic manufacturing capability for this system, and the best available estimate is that perhaps 150 such engines are unaccounted for from ex-Soviet production.[16] Three successful Iranian space launches have also been conducted using modified R-27 verniers, or small engines very similar to them. With Iranian assistance, North Korea may be able to manufacture these smaller engines.

North Korean missile engines have traditionally incorporated jet vanes for steering; a practice inherited from the former Soviet Union. This is an effective technique, but reduces the performance of the engine by several percent. The R-27 missile instead used a pair of separate vernier engines on gimbaled mounts for this purpose, a rather more efficient technique. Similar verniers were found on the Nodong-powered first stage of the Unha-3 launch vehicle. This represents an improvement over the original Nodong missile, which used a nearly identical main engine with jet vanes rather than vernier engines. The Unha first-stage verniers used propellants tapped from the main engine pumps rather than an independent propellant feed, but were otherwise of similar size and appearance to the vernier engines of the Soviet R-27 missile and to the main propulsion system of the Iranian Safir launch vehicle.[17]

Sources suggest thrust values of 15–30 kN for the Unha-3 first stage vernier engine; the larger value is possible, but given the operating cycle would most likely come at the cost of reduced thrust from the main engine. It will be assumed here that any Nodong engines used on the KN-08 will incorporate Unha-style verniers of 15 kN net thrust, similar to the R-27 but incapable of independent operation. Scud and S-75 engines adapted for the KN-08 will be assumed to have similar, but proportionately smaller, verniers. Where multiple engines are used in a stage, each main engine is assumed to be coupled to a single vernier, the same approach used on the Unha-3 first stage.

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.[18,19,20] 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 Hwasong-6 and Nodong missiles to nations such as Iran and Pakistan allow 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, which will affect propellant density and tank volume calculations.

For this analysis, engine performance is assumed as follows. Performance of the Scud and Nodong engines will be somewhat higher than generally accepted values due to the presumed replacement of thrust vanes with vernier rockets (see Table 1).

Table 1: Potential North Korean missile engines

Engine	S-75	Scud	Nodong	R-27	R-27 (Vernier Only)
Verniers	1	1	1	2	0
Thrust, Sea Level	30 kN	140 kN	300 kN	265 kN	N/A
Thrust, Vacuum	34 kN	155 kN	330 kN	290 kN	32.5 Kn
Isp, Sea Level	224 s	230 s	235 s	265 s	N/A
Isp, Vacuum	252.5 s	260 s	260 s	290 s	255 s[1]
Oxidizer	AK-20I	AK-27I	AK-27I	MON-10	MON-10
Fuel	TG-02	TM-185	TM-185	UDMH	UDMH
Mixture Ratio	3.2 : 1	3.5 : 1	3.5 : 1	2.0 : 1	2.0 : 1
Availability	Confirmed	Confirmed	Confirmed	Possible	Probable

Note: [1]280 seconds with nozzle extensions.

The propellants used in these engines are believed to be as follows:

- AK-20I: 80% Nitric Acid, 20% Nitrogen Tetroxide, plus stabilizers
- AK-27I: 73% Nitric Acid, 27% Nitrogen Tetroxide, plus stabilizers
- MON-10: 90% Nitrogen Tetroxide, 10% Nitric Oxide
- TG-02: 50% Xylidine, 50% Triethylamine
- TM-185: 80% Kerosene, 20% Gasoline
- UDMH: Unsymmetrical Dimethylhydrazine

In addition, it is assumed that the S-75 engine requires a separate supply of isopropyl nitrate estimated at 2.75% of the main propellant flow to drive the turbopumps.

AIRFRAME

Virtually all long-range missiles and satellite launch vehicles use the propellant tanks as the main structural elements of each stage, and examination of the Unha-3 wreckage shows North Korea follows the same practice. While the North Koreans have never demonstrated the ability or intent to develop new rocket engines, they have repeatedly and successfully integrated existing engines into new airframes of their own design. It is thus reasonable to assume that the KN-08 will use new propellant tanks and structural elements optimized for its requirements, built around existing engines.

Wreckage recovered from the most recent Unha-3 launch included a largely intact first stage oxidizer tank with associated structure and plumbing.[21] The tank was of semi-monococque (structural sheet metal welded to an underlying frame) construction, using aluminum-magnesium alloy. The tank's bulkheads were of conventional dome geometry with an aspect ratio of 0.25, and it appears that separate bulkheads were used for the fuel and oxidizer tanks. Common-bulkhead tanks would allow a somewhat greater propellant load, and are part of the R-27 technology base, but have not traditionally been used with North Korean Scud/Nodong-heritage missiles and were not seen on the Unha-3.

This analysis will assume the same geometry, structure, and materials are used in the KN-08. 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 the same or successive stages. This also is consistent with the observed design of the Unha-3. The performance of the KN-08 would be increased slightly if common-bulkhead tanks were used on upper, R-27 heritage stages.

For stages using the R-27 engine, it is assumed that the engine is submerged in the rear of the fuel tank as was done in the original Soviet R-27 missile. In addition to providing a more efficient packaging, this is probably necessary to provide adequate cooling and fuel feed to the engine, and to transfer the thrust of the engine to the missile's airframe.

In addition to the fuel and oxidizer tanks, each stage will require smaller tanks of compressed gas (either helium or nitrogen) to pressurize the main propellant tanks and possibly to drive pneumatic actuators. These tanks are typically spherical, located around the periphery of the engine bays or interstage regions, and are not depicted in the configuration drawings above. It is also assumed that the S-75 engine requires tanks of isopropyl nitrate monopropellant to drive the propellant pumps; as these tanks do influence the size and layout of the engine bay they are shown in the drawing.

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 and 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. Third-stage engine cutoff is performed when an integrating accelerometer determines that the appropriate velocity has been reached.[22]

Guidance commands are implemented using the vernier engines referred to earlier, with two gimbaled engines per stage being sufficient for full three-axis flight control. First- and second-stage engines will most likely run at full throttle until the onset of propellant depletion is detected, at which point a sequencer will shut down the engine and activate explosive bolts and small solid rockets as required for stage separation. For the third stage of the KN-08, most likely powered by an R-27 engine, it will be assumed that the engine will shift to vernier-only operation at least 10 seconds before command shutoff to facilitate fine velocity control. A similar system was used on several early Soviet missiles, including the R-27, and allows somewhat greater accuracy than would be possible with the coarse thrust termination profile of the main engine.[23]

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.

CONFIGURATION DETAILS

The first stage is in most cases 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.[24] 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 1.8 g launch acceleration. The bulky pump arrangement of the Nodong engine, in a clustered installation, would require an engine bay roughly 2.3 meters long.

A cluster of four Scud-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 engine coupled with the increased weight of the vehicle would reduce the launch acceleration to only 1.4 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.[25] This allows a much greater packaging density, which is advantageous for a mobile missile, but it greatly complicates any attempt at clustering the engine. The R-27 is intended and optimized for centerline use; clustering it may be beyond North Korea's ability and certainly has not been demonstrated. Furthermore, a three-engine cluster would be required to provide sufficient thrust, and the R-27 is too bulky to fit three engines in a 2-meter vehicle without substantial redesign.

Increased first-stage performance could also be achieved with a single, larger engine using R-27 technology. The ex-Soviet R-29 missile engine would be a good fit, but there is no evidence that this engine has reached North Korea. North Korea has never developed an engine in this class itself, and even its more modest engine development programs have probably required foreign assistance. These are all extremely remote possibilities. Nonetheless, in order to place an upper bound on KN-08 performance, a "KN-08 Maximum" configuration is presented using a cluster of three heavily-modified R-27 engines. A single R-29 or comparable North Korean engine would offer essentially identical performance.

The second stage could use a single Nodong engine, a pair of Scud engines, or a single R-27 engine. All three combinations will be considered, and will be referred to as the "KN-08A" (Nodong 2nd stage), "KN-08B" (dual Scud 2nd stage), and "KN-08C" (R-27 2nd stage). To be used as part of this arrangement, the Scud engine would require an approximate 50% increase in operating life; the R-27 would require an approximate 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 for the baseline configurations. Because of the short overall length of the upper stage, the engine bay required for a Nodong or even Scud 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 believed to possess.

In this application, an R-27 engine (including verniers) would be integrated into a somewhat smaller tank and airframe than is the case on the original R-27 missile. The appearance of the Musudan missile suggests that North Korea might be comfortable with the idea of integrating R-27 main engines with new tankage.[26] As can be seen from the cross-section in Figure 3, 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. This is perhaps not a coincidence; if a three-stage missile of the KN-08's approximate scale were built without constraints, an optimized third stage would be roughly two-thirds the size of that seen on the KN-08. A constraint to use a stock R-27 engine would explain this discrepancy.

Another possible use of R-27 technology would be to use just the vernier engines, as was done with the Iranian Safir and probably the North Korean Unha satellite launchers. A single pair of verniers, while optimal for deployment of small satellites, would provide inadequate thrust for delivering heavier warheads. There is, however, room for three pairs of verniers and their shared turbomachinery around the base of a KN-08 third stage. The verniers are in this case assumed to have nozzle extensions similar to those demonstrated by Iran, increasing specific impulse to 280 seconds. The "KN-08BV" configuration is identical to the "KN-08B" except for the use of a vernier-only upper stage; this represents the most potent missile North Korea could build if it has access to R-27 or similar verniers but not main engines.

If neither R-27 main engines nor their verniers are available to the North Koreans, the most plausible alternative is a pair of S-75 / SA-2 engines, and this forms the basis of the postulated "KN-08 Minimum" configuration. Other engines from ex-Soviet surface-to-air or short-ranged ballistic missiles might also be adapted, but would be unlikely to exceed the performance of the S-75 configuration considered here.

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°C. For stages using the submerged-engine R-27, this will be increased to 3.5% due to the possible difficulties of dealing 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. We do not have reliable measurements of the mass of the Unha-3 first stage, but as noted above it was of semi-monococque construction using aluminum-magnesium alloy. 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.[27] The Nodong uses the same semi-monococque construction of the Unha-3, but with heavier steel alloys. Russian data indicates the ex-Soviet R-27 missile has a 9.5% stage mass fraction (again exclusive of warhead and guidance), achieved with lightweight aluminum alloys, a more sophisticated orthogrid construction, and a more tightly integrated engine.[28]

The KN-08 is expected to fall between those values. It presumably draws from the same technological toolkit as the Unha-3, which itself is based on North Korea's Nodong heritage as well as some imported R-27 components. Stages using Scud/Nodong engines will thus be assumed to have a 10.5% mass fraction, and stages with the more sophisticated and tightly integrated R-27 engines a 10.0% mass fraction. These masses include structure, propellant tanks (which are themselves major structural elements), engines, plumbing, and ancillary hardware such as stage separation mechanisms and control actuators.

Guidance systems of early U.S. ICBMs had weights of 100–300kg, using technologies similar to those assumed for the KN-08.[29] North Korea demonstrated a certain degree of competence in torpedo and missile manufacture, which indicates an ability to produce mechanical or electromechanical guidance components of reasonable precision; the Unha wreckage showed a willingness and ability to supplement domestic manufacture with imported modern consumer-grade electronics. It is also possible that North Korea's access to ex-Soviet R-27 hardware includes useful guidance components. It is therefore reasonable to assume that North Korea can at least match the performance of the better early U.S. ICBMs in guidance system mass, if not precision.

As will be described, warhead weights of 500–1500 kg will be considered. This includes the complete reentry vehicle, including aeroshell and thermal protection system.

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.[30] For North Korea's more basic designs, this analysis will assume 2% residual propellant in Scud- 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 configurations are shown in Table 2.

WARHEAD

The KN-08 uses a triconic reentry vehicle (RV) of slightly greater than 3 meters overall length. Modern U.S., Russian, British, and French warheads use slender single-cone RVs 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 RV 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. So while it is unclear exactly where the KN-08 third stage/warhead separation plane 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

Table 2: KN-08 Missile Stage Mass Breakdown

Stage	Mass	KN-08 Min	KN-08A	KN-08B	KN-08BV	KN-08C	KN-08 Max
1st	Propellant, total	16,130 kg	16,130 kg	16,130 kg	16,130 kg	16,130 kg	16,640 kg
	Propellant, usable	15,805 kg	15,805 kg	15,805 kg	15,805 kg	15,805 kg	16,140 kg
	Total Dry	1,890 kg	1,890 kg	1,890 kg	1,890 kg	1,890 kg	1,850 kg
2nd	Propellant, total	11,250 kg	8150 kg	11,250 kg	11,250 kg	10,080 kg	10,080 kg
	Propellant, usable	11,025 kg	7985 kg	11,025 kg	11,025 kg	9,780 kg	9,780 kg
	Total Dry	1,545 kg	950 kg	1,545 kg	1,545 kg	1,120 kg	1,120 kg
3rd	Propellant, total	3330 kg	3,135 kg	3,135 kg	3700 kg	3,135 kg	3,135 kg
	Propellant, usable	3260 kg	3,040 kg	3,040 kg	3630 kg	3,040 kg	3,040 kg
	Total Dry	560 kg	450 kg	450 kg	535 kg	450 kg	450 kg
All	Total, w/o warhead	34,705 kg	30,705 kg	34,400 kg	35,050 kg	32,805 kg	33,275 kg

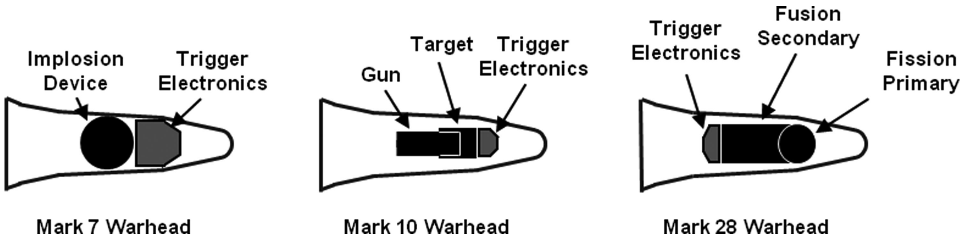

Figure 8: Possible KN-08 Warhead Packaging.

weapons in the early 1950s was known to the Manhattan project team in 1945, was successful in its first postwar test, and is now in the public domain.[31]

The first generation of U.S. lightweight nuclear weapons included the Mark 5 (1400 kg total weight, 120 kiloton maximum yield) and Mark 7 (750 kg, 60 kt), both introduced in 1952, and 1954's Mark 12 (450 kg, 15 kt). Comparable devices were developed in Russia, Britain, France, and China shortly after their first nuclear tests.[32] 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.

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. A range of 500–1500 kg total warhead mass should cover any plausible first-generation North Korean ICBM warhead. Warhead yield could plausibly be anywhere from four to sixty kilotons for a pure fission device; the largest North Korean test had a yield of perhaps ten kilotons, but a modest degree of upscaling is possible without additional testing.

Warhead dimensions are also a concern. Figure 8 shows three early U.S. nuclear warheads for which basic configuration data are publicly known, packaged in the KN-08 reentry vehicle. This is not meant to suggest that North Korea is actually copying old U.S. warhead designs; the limitations of nuclear weapons technology will drive any emerging nuclear power to fairly similar solutions. In particular, the U.S. Mark 7 represented an effort to develop a warhead light enough for delivery by tactical aircraft or ballistic missiles, with minimum technical risk and efficient use of scarce fissile materials. The KN-08 RV is clearly suitable for delivering a similar device.

Two other possibilities would be gun-assembly fission devices and first-generation thermonuclear weapons with cylindrical primaries. The second example in Figure 8 is based on a U.S. Mark 10 gun-assembly device of 700 kg total weight and 15 kiloton yield. This is a very simple weapon, easily within the capability of any nuclear power, but is rather inefficient in its use of fissile materials and consequently never entered U.S. service. The third example shows a Mark 28 thermonuclear weapon, the first lightweight thermonuclear device in the U.S. arsenal, yielding 1.4 megatons with a 900 kg total weight. Lightweight thermonuclear weapons 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 a stage powered by the R-27 engine is flown to (near) propellant depletion with a light warhead, the acceleration at burnout will be roughly 25 g. 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 shift 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°. 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 three postulated KN-08 variants is shown in Figure 9. "Throw weight" refers in this case to the

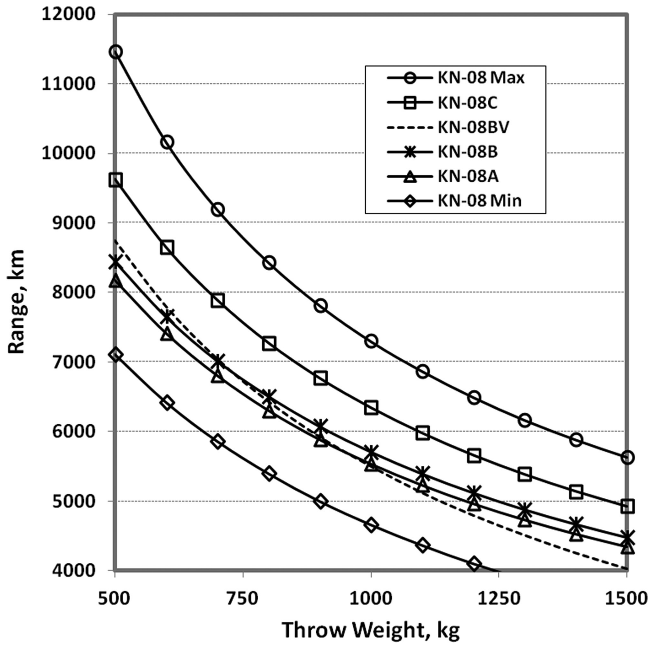

Figure 9: Predicted KN-08 Performance

complete mass of the separated warhead section; as noted earlier 500–1500 kg covers the plausible range for first-generation fission warheads.

As can be seen, the KN-08 "Minimum" configuration, using only Scud/Nodong technology, has a maximum range of just over 7,000 km with the lightest plausible warhead. As the distance from Musudan-ri to Seattle is approximately 7,950 km, such a missile would probably not pose a threat to CONUS targets though it could reach almost any target of interest in East Asia or the Pacific.

The KN-08A, B, BV, and C configurations, using mixed Scud/Nodong and R-27 technology, would have a limited ability to reach CONUS targets with light warheads. The KN-08A and B could perhaps deliver 500–600 kg warheads to Seattle or elsewhere in the Pacific Northwest, with the BV having slightly greater performance with light warheads. The postulated KN-08C configuration could reach such targets with 750 kg warheads or deliver lighter warheads as far as Los Angeles or Denver. Alternately, a lightweight warhead could be delivered to Seattle in the company of perhaps half a dozen credible decoys. Central Asia and Europe would also possibly be within reach.

The KN-08 "Maximum" configuration would be a much more formidable weapon, particularly with a lightweight warhead. Such a missile could reach targets as distant as New York or Washington, DC, or could attack any west coast target with either a heavier warhead or a light warhead plus decoys. As noted earlier, the KN-08 "Maximum" requires first-stage engines well beyond any capability North Korea has demonstrated or is generally believed to possess.

While a rough 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.[33] 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 $\times$ 20 km at intercontinental ranges.

North Korea's most powerful nuclear test had a yield of approximately 10 kilotons, sufficient to destroy soft targets within a 1.5 km radius.[34] The U.S. Mark 7 bomb/warhead, a reasonable proxy for the largest first-generation fission warhead that North Korea could plausibly deliver to CONUS targets by a KN-08 missile, had a maximum yield of 60 kilotons, which still corresponds to a soft-target destruction radius of only 2.8 km.[35] 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 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 80% of the weight and thus load. This would then require that the missile be fuelled at the launch site, after being transported and (probably) erected. Similar systems were used in the early Cold War era; the U.S. Redstone and Jupiter missiles could be fueled and launched within fifteen minutes.[36] While these were of similar scale to the KN-08, they were single-stage vehicles. Soviet R-9A (SS-8) missiles could be fueled and launched in 20 minutes – this time included installation of a missile on a launch pad (it should be noted, though, that the launch sequence was highly automated).[37] 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 launch. Such preemption would require 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.[38] 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 $+ 30°C$; 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 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 no more than eight suitable TELs and it is unclear whether future procurement from China will be possible.[39]

RELIABILITY AND TESTING

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 four launches of a rocket stage based on clustered Nodong technology, two of which have failed. At most nine rocket stages using a single Nodong engine have been flown by North Korea, with perhaps a single failure. The actual number may be smaller, as the details of some Korean missile tests are unclear. There have been no known tests of stages using the R-27 main engine, discounting unconfirmed reports of a test conducted in Iran using hardware supplied by North Korea. North Korea has attempted six staging events with one failure, discounting cases where booster failures rendered staging moot. There have been no successful North Korean re-entry tests at anywhere close to ICBM velocities.[40]

Considering only North Korea's relevant test history, a simple statistical analysis suggests the probability of the first KN-08 launch being fully successful is roughly 6%. Extensive ground testing of the individual stages could at most increase this to 22%, as staging and re-entry cannot be meaningfully tested on the ground. And even a single successful test would give only an estimated 35% reliability for the KN-08, given the past history of failures in similar systems. In order to establish even a minimal degree of confidence in the system, multiple flight tests would have to be conducted before the KN-08 could enter service as an operational weapon.

North Korea's crude manufacturing methods might suggest that North Korean missiles must be unreliable, but capable engineers can work around known manufacturing deficiencies. North Korean missile designers have no doubt ample experience in such matters. There is no substitute for actual flight testing in this process, however. Even the most aggressive ICBM development programs elsewhere would not consider a weapon to be operational without 5–10 test flights, to validate both the design and the manufacturing process, and North Korea's Nodong MRBM conducted perhaps five flight tests before operational deployment.[41]

It is conceivable that North Korea may attempt to deploy the KN-08 missile, and may consider it to be an operational weapon, without adequate flight testing. No other nation has ever deployed an ICBM in this manner, and it would be extremely unusual for North Korea to do so, but there is some precedent with similar systems. Both Germany and the United States entered World War II with torpedoes—the most complex weapons systems of their time—with a single successful live-fire test in the U.S. case and none in the German. These torpedoes suffered extremely high failure rates—up to 70%, in early operational service. New space launch vehicles, which are technically very similar to ICBMs, frequently carry operational payloads on their first flights. Approximately 50% of these launches fail, usually due to fundamental design faults that must be corrected before a successful launch can occur. And North Korea's Musudan IRBM, if it not a hoax, appears to have entered service with zero or one flight tests.

To deploy an untested strategic weapon may be foolish, but hubris is one of the more persistent human follies. And if North Korea intends to use its nuclear arsenal purely as a deterrent, it may not even be foolish—a deterrent weapon needs to be credible, which is not quite the same thing as being reliable. Successful tests enhance deterrence, failed tests weaken it, and the North Koreans may feel that an untested missile still poses enough of a threat to deter foreign attack. They may be right—in which case, why risk a test failure?

OPERATIONAL AVAILABILITY

The KN-08 probably did not exist as even a flyable prototype in April of 2012. While it is possible that the North Koreans would display mock-ups simply to avoid risk of damage to real missiles, the mock-ups in that case would be built to match the exterior design of the missiles—and as we have seen, the mock-ups do not even match each other.[42] It is possible that the parade mock-ups were constructed specifically for the parade, or alternately that they were originally engineering models constructed at different phases of the development process. In either case, the differences between the mock-ups may suggest that the detailed design of the KN-08 had not been finalized at the time they were built.

Some shared heritage of the postulated KN-08 and the observed Unha-3 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 eight and possibly as long as twenty-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 now been successfully tested, the relevant technology and even specific hardware for the KN-08 may have been validated.

It is unlikely that actual KN-08 missiles would have been built in advance of the successful Unha-3 test, as it could not have been known in advance that the test would have successfully validated shared elements of the design. If the KN-08 does in fact represent North Korea's planned ICBM, it would probably still require at least several months and possibly more than a year to incorporate the lessons learned from the Unha-3 flight and construct a flightworthy prototype missile. No KN-08 flight test has been observed as of this writing, though at this point one could plausibly occur at any time.

As noted above, it is conceivable that North Korea may proceed to deploy the KN-08 as an operational system without actual flight tests of that missile. This could be driven by internal political and economic constraints, or by the perception of an imminent external threat. If so, the North Koreans may very well deploy a fundamentally flawed weapon that cannot possibly work, and most likely will deploy an extremely unreliable weapon that works less than half the time. If this is the case, the January 2013 New York Times report may indicate the actual operational deployment of what North Korea believes is an operational weapon, presumably based on overconfidence following the successful flight of the related but not identical Unha-3.

More likely, any observed field operations represent pre-operational training activities. Before a weapon can be reliably operational, crews must train in the relevant operating procedures—particularly for a mobile liquid-fuel missile, where a launch site must be established in an austere field environment on short notice, and a complex fueling operation must be conducted with extremely toxic propellants. As North Korea clearly possesses real TELs and missile mockups, it is reasonable that launch crews may begin training some time in advance of actual availability of operational KN-08 missiles.

In this case, initial operational capability for the KN-08 would follow a successful flight test program, probably by several months. But, as noted above, it is unlikely that the first test will be successful, and each failed test would require at a minimum several months to investigate the cause and implement corrective action. And more than a single success would be required to establish reasonable confidence in the system. Initial availability for the KN-08 is therefore probably at least a year in the future, with highly visible flight test activity as an indication to outside observers. Without observed flight tests of the KN-08, we may assume that North Korea has foolishly deployed an untested and highly unreliable missile, or that the KN-08 is an outright hoax, or that the missile is still under development and may be operationally deployed sometime in the future.

If and when a KN-08 ICBM does become available, it will almost certainly be in very limited numbers. A KN-08 with intercontinental range will require at least one and probably two or more 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 probably about 150 flightworthy R-27 airframes not otherwise accounted for, to support all North Korean Musudan and KN-08 missile production, Unha space launch attempts, ground and flight testing, and export sales. Also, the supply of suitable TELs may be limited now that it has been made clear to all concerned that any WS51200 in North Korean hands is a missile transporter. The six to eight delivered TELs with two to three missiles per TEL may represent the whole of North Korea's planned ICBM force.

CONCLUSION

While the "KN-08" missiles paraded through Pyongyang last April were almost certainly non-functional mock-ups, it is quite possible that they represent a missile presently under development. If this is the case, it is unlikely that the missile is presently operational, and initial operational capability is probably several months to years in the future and would almost certainly be preceded by a series of flight tests.

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 assumed technological capabilities. If reports that North Korea has obtained ex-Soviet R-27 missiles (or at least their engines) are true, the KN-08 would likely be able to deliver first-generation fission warheads to at least some CONUS targets. Without R-27 engines, it is highly unlikely that the KN-08 would be able to reach any CONUS target, but it could threaten Alaska, Hawaii, and most of East Asia.

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. No more than one to two dozen missiles are likely to be available, and probably fewer launchers.

Again, it must be noted that this is an analysis of North Korean capabilities in light of their recent displays; 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 display, the Unha-3 satellite launch, and the February 2013 nuclear test 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.

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