The secret to North Korea's ICBM success

How has North Korea managed to make such astounding progress with its long-range missile programme over the last two years? Here, Michael Elleman shares the first solid evidence that North Korea has acquired a high-performance liquid-propellant engine from illicit networks in Russia and Ukraine.

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North Korea's missile programme has made astounding strides over the past two years. An arsenal that had been based on short- and medium-range missiles along with an intermediate-range *Musudan* that repeatedly failed flight tests, has suddenly been supplemented by two new missiles: the intermediate-range *Hwasong*-12 and the intercontinental ballistic missile (ICBM), *Hwasong*-14. No other country has transitioned from a medium-range capability to an ICBM in such a short time. What explains this rapid progression? The answer is simple. North Korea has acquired a high-performance liquid-propellant engine (LPE) from a foreign source.

Available evidence clearly indicates that the LPE is based on the Soviet RD-250 family of engines, and has been modified to operate as the boosting force for the *Hwasong*-12 and -14. An unknown number of these engines were probably acquired though illicit channels operating in Russia and/or Ukraine. North Korea's need for an alternative to the failing *Musudan* and the recent appearance of the RD-250 engine along with other evidence, suggests the transfers occurred within the past two years.

Tests reveal recent technical gains

North Korea ground tested a large LPE in September 2016, which it claimed could generate 80 tonnes' thrust. The same LPE was again ground tested in March 2017. This test included four smaller, steering engines. On 14 May 2017, with Kim Jong-un overseeing test preparations, North Korea launched a new intermediate-range ballistic missile, the *Hwasong*-12. The single-stage missile flew on a very steep trajectory, reaching a peak altitude of over 2,000km. If the *Hwasong*-12 had used a normal flight path, it would have travelled between 4,000 and 4,500km, placing Guam, just 3,400km away, within range.

The success of the *Hwasong*-12 flight in May gave North Korean engineers the confidence needed to pursue a more ambitious goal: the initial flight testing of a two-stage missile capable of reaching the continental United States. Less than two months after the *Hwasong*-12 test, the two-stage *Hwasong*-14 was launched on 4 July. A second *Hwasong*-14 was tested on 28 July. The *Hwasong*-14 launches flew on very steep flight paths, with the first shot reaching an apogee of 2,700km. The second test peaked at about 3,800km.

North Korea's announced results were independently confirmed by the Republic of Korea, Japan and US. In both tests, the mock warheads plummeted towards the East Sea, 900–1,000km from the launch point. If flown on a trajectory that maximises range instead of peak altitude, the two missiles would have reached about 7,000km and 9,000km respectively, well exceeding the 5,500km minimum distance for a system to be categorised as an ICBM.

The dimensions and visible features of the *Hwasong*-12 indicate an overall mass of between 24,000 and 25,000kg. The *Hwasong*-12's acceleration at lift-off, as determined by the launch video aired by KCNA, is about 8.5 to 9.0m/s^2. Assuming North Korea did not manipulate the launch video, the thrust generated by the *Hwasong*-12's complete engine assembly is between 45 and 47 tonnes' thrust; the main engine contributes between 39 to 41 tonnes' force, and the auxiliary engines about 6 tonnes' force. The *Hwasong*-14 has an estimated mass of 33,000–34,000kg, and an initial acceleration rate of about 4–4.5m/s^2, resulting in a total thrust of 46–48 tonnes' force.

Identifying the new LPE and its origins

The origins of the new engine (see **Figures 1** and **2**) are difficult to determine with certainty. However, a process of elimination sharply narrows the possibilities.

There is no evidence to suggest that North Korea successfully designed and developed the LPE indigenously. Even if, after importing *Scud* and *Nodong* engines, North Korea had mastered the production of clones, which remains debateable, this does not mean that it could design, develop and manufacture a large LPE from scratch, especially one that uses higher-performance propellants and generates 40 tonnes' thrust.

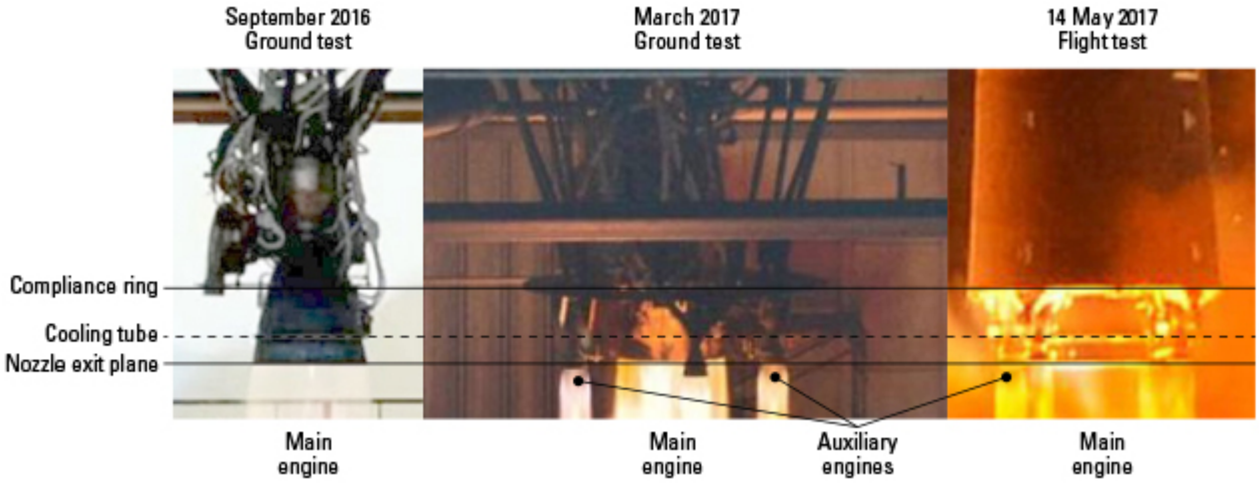

Figure 1: The liquid-propellant engines ground tested in September 2016 and March 2017 appear to be the same, though only the second ground test and the *Hwasong*-12 flight test operate with four auxiliary or vernier engines, which steer the missile. See larger version.

Claims that the LPE is a North Korean product would be more believable if the country's experts had in the recent past developed and tested a series of smaller, less powerful engines, but there are no reports of such activities. Indeed, prior to the *Hwasong*-12 and -14 flights, every liquid-fuelled missile launched by North Korea – all of the *Scud*s and *Nodong*s, even the *Musudan* – was powered by an engine developed and originally produced by the Russian enterprise named for A.M. Isayev; the *Scud, Nodong* and R-27 (from which the *Musudan* is derived) missiles were designed and originally produced by the Russian concern named after V.P. Makeyev. It is, therefore, far more likely that the *Hwasong*-12 and -14 are powered by an LPE imported from an established missile power.

If this engine was imported, most potential sources can be eliminated because the external features, propellant combination and performance profile of the LPE in question are unique. The engine tested by North Korea does not physically resemble any LPE manufactured by the US, France, China, Japan, India or Iran. Nor do any of these countries produce an engine that uses storable propellants and generates the thrust delivered by the *Hwasong*-12 and -14 LPE. This leaves the former Soviet Union as the most likely source.

Figure 2: The three missiles tested by North Korea are powered by the same engine complex, with one main engine and four steering engines. See larger version.

Given North Korea’s reliance to date on technologies originating with the Isayev and Makeyev enterprises, one might suspect one or both as the probable supplier. However, neither enterprise has been associated with an engine that matches the performance of LPE used by *Hwasong*-12 and -14.

An exhaustive search of engines produced by other manufacturers in the former Soviet Union yields a couple of possibilities, all of which are associated with the Russian enterprise named after V.P. Glushko, now known as Energomash. The RD-217, RD-225 and RD-250 engine families use high-energy, storable-liquid propellants similar to those employed by engines tested by North Korea. Neither the RD-217 nor RD-225 have external features matching those of North Korea’s new engine. The RD-250 is the only match.

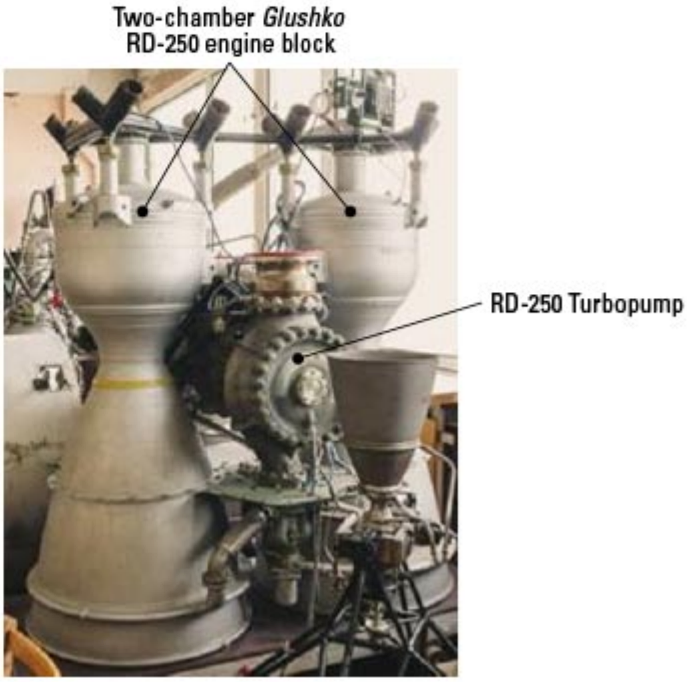

Figure 3: The RD-250 engine consists of a pair of combustion chambers fed by a single turbopump. Each chamber produces about 394k Newtons of thrust, or about 40 tonnes’ force, when relying on UDMH as the fuel, and N_2O_4 as the oxidiser. The RD-250’s nozzle also features a cooling tube and a compliance ring that resemble those found on the engines tested by North Korea. The small engine with its nozzle pointed upward and displayed in the foreground is not associated with the RD-250 engine. See larger version.

The RD-250 engine is normally configured as a pair of combustion chambers, which receive propellant from a single turbopump, as shown in **Figure 3**. When operated in tandem, the two chambers generate roughly 78-80 tonnes’ thrust. This level of thrust is similar to the claims North Korea made when the first ground test was conducted and publicised in September 2016.

It gradually became clear, however, that the *Hwasong*-12 and -14 used single-chamber engines. Note, for example, that Pyongyang claimed that a new pump design was used for the September ground test. This makes sense, because operating the RD-250 as a single chamber LPE would necessitate a new or modified turbopump. Having no demonstrated experience modifying or developing large LPE turbopumps, Pyongyang's engineers would have been hard pressed to make the modifications themselves. Rather, the technical skills needed to modify the existing RD-250 turbopump, or fashioning a new one capable of feeding propellant to a single chamber would reside with experts with a rich history of working with the RD-250. Such expertise is available at Russia's Energomash concern and Ukraine's KB Yuzhnoye. One has to conclude that the modified engines were made in those factories.

The alternative hypothesis, that Russian/Ukraine engineers were employed in North Korea is less likely, given the absence of any known production facility in North Korea for such engines. In addition, Western experts who visited KB Yuzhnoye Ukraine within the past year told the author that a single-chamber version was on display at a nearby university and that a local engineer boasted about producing it.

Why single-chamber engines were transferred rather than the more powerful double-chamber original versions is unclear. One possible hypothesis is that the exporters, for whatever reason, exercised restraint in what they were willing to transfer to North Korea. Combined with a second stage, however, the single-chamber RD-250 engine is powerful enough to send an ICBM to cities on the American West Coast at least.

The RD-250 was originally designed by the Glushko enterprise of Russia, and produced and incorporated into the first stage of the R-36 (SS-9) ICBM and the *Tsiklon-2* satellite launcher by KB Yuzhnoye of Ukraine. The *Tsiklon-2* carrier rocket lofted its first satellite into orbit in 1969, with the last of 106 launches occurring in 2006. While Yuzhnoye was responsible for producing the *Tsiklon*-2 rocket, Russian entities launched the satellite. The relationship survived the break-up of the Soviet Union in 1991 primarily because of long-standing institutional linkages, and the commercial interests of both enterprises and countries. However, despite the *Tsiklon*-2's unsurpassed reliability record, Russia stopped purchasing the Yuzhnoye rocket in 2006 in favour of an indigenous system. Yuzhnoye's repeated attempts to market the rocket and related technologies to other potential customers, including Boeing and Brazil, yielded little. The once vaunted KB Yuzhnoye has been near financial collapse since roughly 2015.

The total number of RD-250 engines fabricated in Russia and Ukraine is not known. However, there are almost certainly hundreds, if not more, of spares stored at KB Yuzhnoye's facilities and at warehouses in Russia where the *Tsiklon*-2 was used. Spares may also exist at one or more of Energomash's many facilities spread across Russia. Because the RD-250 is no longer employed by operational missiles or launchers, facilities warehousing the obsolete LPEs are probably loosely guarded. A small team of disgruntled employees or underpaid guards at any one of the storage sites, and with access to the LPEs, could be enticed to steal a few dozen engines by one of the many illicit arms dealers, criminal networks, or transnational smugglers operating in the former Soviet Union. The engines (less than two metres tall and one metre wide) can be flown or, more likely, transported by train through Russia to North Korea.

Pyongyang has many connections in Russia, including with the illicit network that funnelled *Scud*, *Nodong* and R-27 (*Musudan*) hardware to North Korea in the 1980s and 1990s. United Nations sanctions imposed on Pyongyang have likely strengthened the Kim regime's ties to these criminal networks. North Korean agents seeking missile technology are also known to operate in Ukraine. In 2012, for example, two North Korean nationals were arrested and convicted by Ukrainian authorities for attempting to procure missile hardware from Yuzhnoye. Today, Yuzhnoye's facilities lie close to the front lines of the Russian-controlled secessionist territory. Clearly, there is no shortage of potential routes through which North Korea might have acquired the few dozen RD-250 engines that would be needed for an ICBM programme.

How did North Korea acquire the RD-250 engine?

When and from where RD-250 engines may have been shipped to North Korea is difficult to determine. It is possible the transfers occurred in the 1990s, when North Korea was actively procuring *Scud*- and *Nodong*-related hardware, as well as R-27 technology and its Isayev 4D10 engine. But this seems unlikely for three reasons.

Firstly, the network North Korea relied on in the 1990s focused on products originating from Russia's Makeyev and Isayev enterprises. Energomash and Yuzhnoye had limited connections to Makeyev or Isayev; indeed, they were rival enterprises competing for contracts as the Soviet Union crumbled. It is, therefore, a stretch to assume the illicit channels Pyongyang was using in the 1990s had access to products manufactured or used at either Yuzhnoye or Energomash two decades ago.

Secondly, until recently, North Korea appeared to focus on exploiting R-27 hardware for its long-range missile ambitions. Pyongyang's first intermediate-range missile, the *Musudan*, which was first displayed in a 2010 parade, is derived from the R-27 technology acquired in the 1990s. Moreover, until the *Hwasong*-12 launch in

March 2017, Pyongyang's design concepts for a prospective ICBM featured a first stage powered by a cluster of two Isayev 4D10 LPEs. Photographs taken while Kim Jong-un toured a missile plant in March 2016 captured the back end of an ICBM prototype that appeared to house a pair of 4D10 engines, not a single RD-250 LPE. A month later, Kim attended the ground test featuring a cluster of two 4D10 engines operating in tandem, a clear indication that North Korea's future ICBM would rely on this configuration. There is no evidence during this period to suggest that North Korea was developing a missile based on the RD-250 engine.

Thirdly, the Isayev 4D10 engine, which relies on staged combustion, is a complicated closed-cycle system that is integrated within the missile's fuel tank. If the open-cycle, externally mounted RD-250 engine had been available in 2015, engineers would have likely preferred to use it to power a new long-range missile, as it shares many features with the engines North Korea has worked with for decades.

However, when North Korean specialists began flight testing the *Musudan* in 2016, the missile repeatedly failed soon after ignition. Only one flight test is believed to have been successful. The cause of the string of failures cannot be determined from media reports. That many failed very early in flight suggests that problems with either the engine itself, or the unique 'submerged' configuration of the engine, were responsible. If this was the case, North Korea's engineers may have recognised that they could not easily overcome the challenges. This might explain why the *Musudan* has not been tested since 2016.

The maiden appearance of the modified RD-250 in September 2016 roughly coincides with North Korea's decision to halt *Musudan* testing. It is reasonable to speculate that Kim's engineers knew the *Musudan* presented grim or insurmountable technical challenges, which prompted a search for an alternative. If North Korea began its quest to identify and procure a new LPE in 2016, the start of the search would have occurred in the same year Yuzhnoye was experiencing the full impact of its financial shortfalls. This is not to suggest that the Ukrainian government was involved, and not necessarily Yuzhnoye executives. Workers at Yuzhnoye facilities in Dnipropetrovsk and Pavlograd were likely the first ones to suffer the consequences of the economic misfortunes, leaving them susceptible to exploitation by unscrupulous traders, arms dealers and transnational criminals operating in Russia, Ukraine and elsewhere.

North Korea's ICBM still a work in progress

Acquisition of the modified RD-250 engine enabled North Korea to bypass the failing *Musudan* development effort and begin work on creating an ICBM sooner than previously expected. The *Hwasong*-14, however, is not yet an operationally viable system. Additional flight tests are needed to assess the missile's navigation and guidance capabilities, overall performance under operational conditions and its reliability. Empirical data derived from tests to validate the efficacy of warhead re-entry technologies is also needed. Pyongyang could elect to deploy the *Hwasong*-14 as early as 2018, after only a handful of additional test launches, but at the risk of fielding a missile with marginal reliability. The risks could be reduced over time by continuing flight trials after the missile is assigned to combat units.

Further, the *Hwasong*-14 employs an underpowered second stage, which could limit Kim Jong-un to threatening only those American cities situated along the Pacific Coast. Arguably, Pyongyang will want a more powerful ICBM, one that can target the entire US mainland. The modified RD-250 engine can be clustered to provide a basis for an improved ICBM, but development of a new missile will require time.

It is not too late for the US and its allies, along with China and perhaps Russia, to negotiate an agreement that bans future missile testing, and effectively prevents North Korea from perfecting its capacity to terrorise America with nuclear weapons. But the window of opportunity will soon close, so diplomatic action must be taken immediately.