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# Analysis of North Korea’s February 2016 Successful Space Launch

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## S. Chandrashekar, N. Ramani and Arun Vishwanathan[1]

### Introduction

The Democratic Peoples' Republic of Korea (DPRK) or North Korea succeeded in placing a 100 kg Earth Observation (EO) satellite *Kwangmyongsong-4* into a Sun Synchronous Orbit (SSO) on February 7, 2016. As it had done in earlier launches, the DPRK used its *Unha*-3 launch vehicle for the latest mission. The launch was conducted from the Sohae Space Center in Ch'o'lsan County, North Pyongyang Province.

North Korea has so far conducted **(See Table 1**) six space launches. The last two launches conducted in December 2012 and the recent February 2016 launch have been successful in placing small remote sensing satellites into "more difficult to reach" sun synchronous orbits.

**Table1: Details of North Korean space launches**

| Date | Launcher | Launch Site | Satellite | Comments |
|---|---|---|---|---|
| **Aug. 31, 1988** | TaepoDong-1 | Musudan-ri | *Kwangmyongsong*-1 (30 Kg) | Failure |
| **July 5, 2006)** | TaeopoDong-1 | Musudan-ri | **NA** | Mission failed 42 seconds after the launch.[2] |
| **April 5, 2009** | TaepoDong2/*Unha*2 New 3 stage Launcher | Tonghae | *Kwangmyongsong*-2 | Third Stage did not ignite[3] |
| **April 12, 2012** | *Unha*-3 North Korea added a slightly heavier third | Sohae | *Kwangmyongsong*-3 (100kg) | Failure of First Stage[5] |

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[2] Details of the payload carried in the July 2006 launch are not available. South Korea claimed that the missile flew for seven minutes after it veered off its course 42 seconds into the flight, "N. Korea May Try Launching Another Long-Range Missile," ChosunIlbo, July 6, 2006, available at http://web.archive.org/web/20060709022611/http://english.chosun.com/w21data/html/news/200607/200607060027.html

[3] David Wright, " An Analysis of North Korea's Unha-2 Launch Vehicle", *Union of Concerned Scientists*, March 20, 2012, available at http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/Wright-Analysis-of-NK-launcher-3-18-09.pdf

| Date | Launcher | Launch Site | Satellite | Comments |
|---|---|---|---|---|
| | stage[4] | | | |
| **Dec. 12, 2012** | *Unha* -3 | Sohae | *Kwangmyongsong*-3 (100 Kg) | **Succesful injection into SSO** Satellite began tumbling soon after injection |
| **Feb. 7, 2016** | *Unha*-3 | Sohae | *Kwangmyonsong*-4 (100kg) | **Succesful injection into SSO** No sign of tumbling of the satellite as yet. |

Based on available information put out by various agencies including official North Korean sources this report attempts to reconstruct the trajectory of the February 2016 launch. Using this reconstruction of the trajectory it goes on to make inferences about the technical parameters of the launcher. It builds upon and complements an earlier study carried out by the ISSSP on North Korea's successful launch of 2012 to provide an update on North Korea's launch and space capabilities.

**Comparison of December 2012 and February 2016 Stage Impact Points**

On February 2, 2016, the North Koreans had released information about an impending space launch to the International Maritime Organisation (IMO). The statement indicated a launch window stretching from February 8 to February 25, 2016.It also provided the area coordinates or impact zones for the spent stages and the shroud.[6] On February 6, 2016, the DPRK narrowed down the launch window to February 7-14.[7] The launch took place on February 7, 2016, the first day of the revised launch window.

The advancement of the launch window could have been due to several reasons. The mission team could have provided an all-clear following the successful fuel loading and completion of the pre-launch technical checks. Another reason as Martyn Williams points out, could have been clear weather over the launch location.[8]

In addition to the technical all-clear, advancing the launch might have also had political undertones to mark important anniversaries. As Jeffrey Lewis from the Middlebury Institute

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[5] "Report on North Korea's Missile Launch on December 12th, 2012", *Japanese Ministry of Defence*, January 25, 2013, available at http://www.mod.go.jp/e/d_act/bmd/report_20130125.html

[4] David Wright, " A Comparison of North Korea's Unha-2 and Unha-3", *All Things Nuclear: Union of Concerned Scientists*, April 8, 2012, available at http://allthingsnuclear.org/dwright/a-comparison-of-north-koreas-unha-2-and-unha-3

[6] Melissa Hanman, "DPRK Announcement of Rocket Launch", February 3, 2016, available at http://www.armscontrolwonk.com/archive/1200942/dprk-announcement-of-rocket-launch/

[7] Martyn Williams, "All systems go? DPRK brings forward launch window", North Korea Tech, February 7, 2016, available at http://www.northkoreatech.org/2016/02/07/all-systems-go-dprk-brings-forward-launch-window/

[8] Martyn Williams, "All systems go? DPRK brings forward launch window", North Korea Tech, February 7, 2016, available at http://www.northkoreatech.org/2016/02/07/all-systems-go-dprk-brings-forward-launch-window/

of International Studies points out, February 12 and February 16 are important public holidays in North Korea. February 12 is celebrated as "Generalissimo Day." In 2012, the late leader Kim Jong Il was posthumously awarded the title of "Generalissimo of the Democratic People's Republic of Korea." February 16 is important because it is the birthday of late North Korean leader Kim Jong Il and is celebrated as the "Day of the Shining Star."[9]

It is useful to compare the stage impact zones put out prior to the February 2016 launch and the December 2012 launch. Such a comparison will help us to place the current launch in the proper context of North Korea's evolving capabilities in satellite and launch technologies.

**Table 2** below provides the mid points of the impact zones for the first stage, the shroud as well as the second stage for both the 2012 and 2016 launches. The nominal impact point for normal performance of the launcher would be the mid points of the impact zones. A comparison therefore provides some indicators of how the two launch missions could differ from each other.

**Table 2: Nominal Impact Points February 2016 & December 2012 *Unha* 3 launches**

| Nominal Impact Point | February 2016 | | December 2012 | |
|---|---|---|---|---|
| | Latitude | Longitude | Latitude | Longitude |
| 1st Stage Impact Point | 35.692 | 124.70 | 35.357 | 124.723 |
| Shroud Impact Point | 32.813 | 124.663 | 33.036 | 124.662 |
| 2nd Stage Impact Point | 18.367 | 124.350 | 16.867 | 124.261 |

As we can see from Table 2 the mid-points of the First and the Second Stage impact zones in the case of the February 2016 launch occur earlier and closer to the launch site as compared to the mid points of the December 2012 launch. This would suggest that the Lift off Weight (LOW) of the February Launch is slightly more than the LOW of the December 2012 launch. Most probably the third stage of the February 2016 launch is slightly heavier than the third stage of the 2012 launch.

The nominal impact point for the shroud in the February 2016 launch however occurs farther down range from the launch site when compared to the December 2012 launch. This would suggest that the shroud release is taking place at a particular pre-determined altitude.

To provide an easy to use visualization, the comparison of nominal impact points of the December 2012 and February 2016 launches have been plotted using Google Earth. These can be viewed can be viewed below as **Figures 1, 2 and 3**.

[9] Jeffrey Lewis, "Coming Iran, DPRK Space Launches?"*Arms Control Wonk*, January 29, 2016, available athttp://www.armscontrolwonk.com/archive/1200917/1200917/

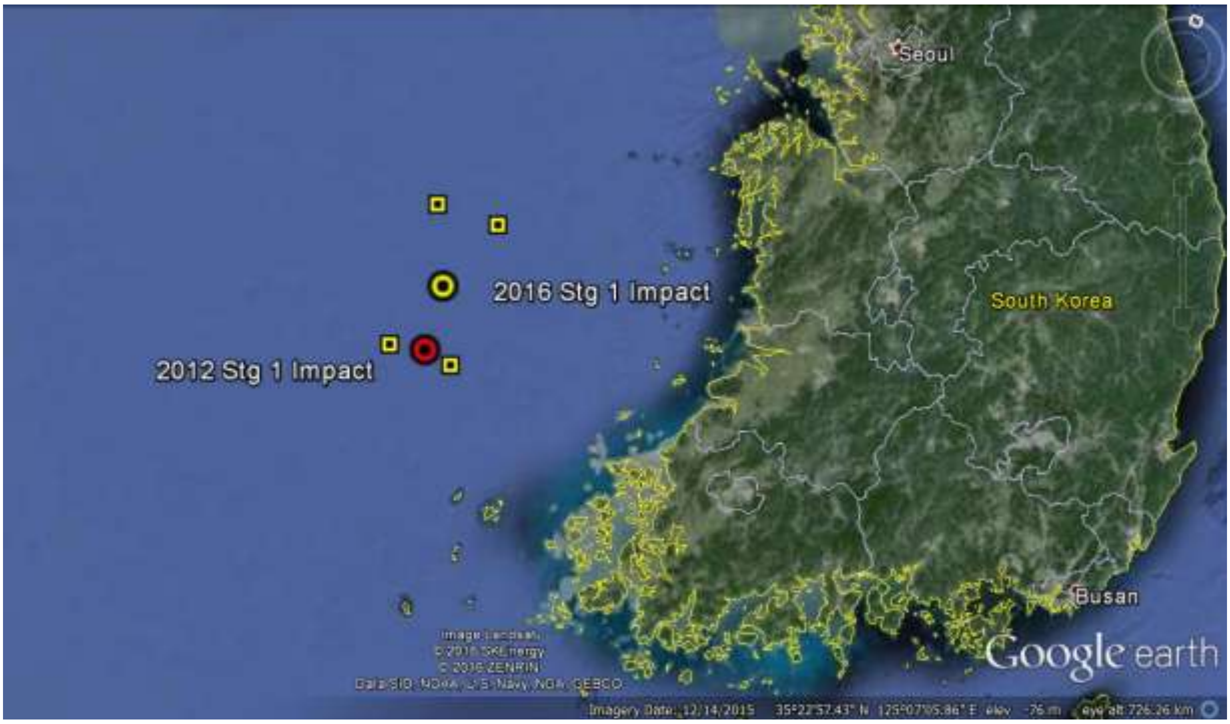


**Figure 1: First Stage Impact for December 2012 (Red) and February 2016 (Yellow) Launch**

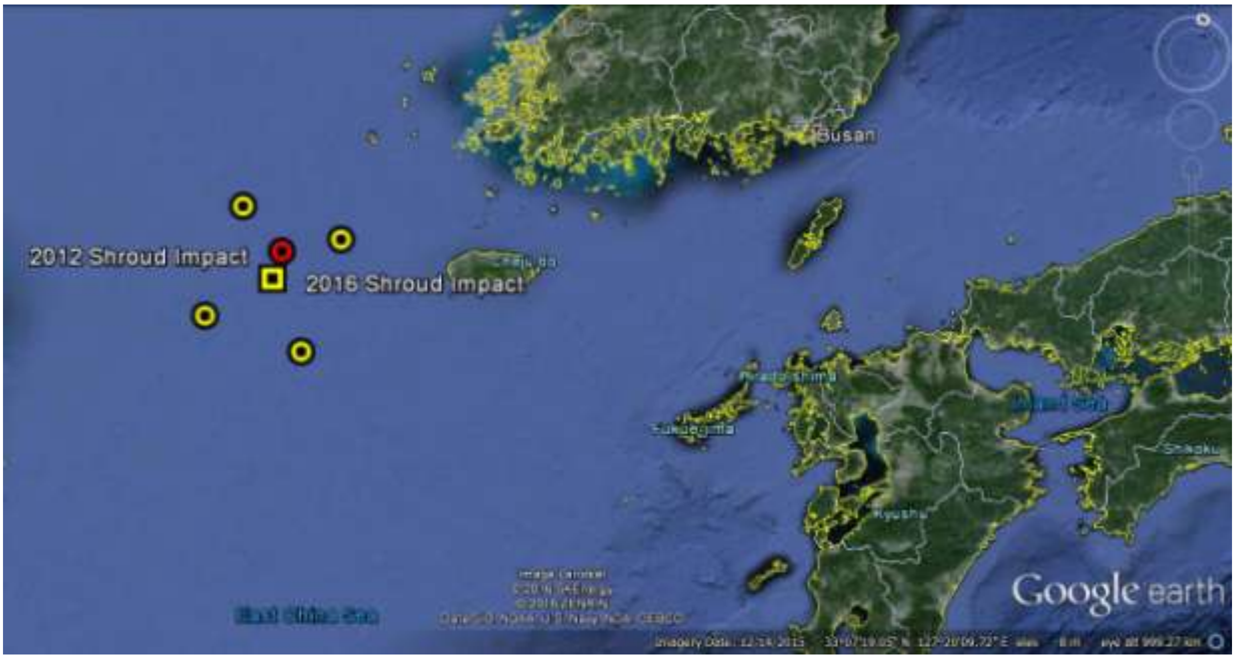


**Figure 2: Comparison Shroud Impact for December 2012 (Red) and February 2016 (Yellow) Launch**

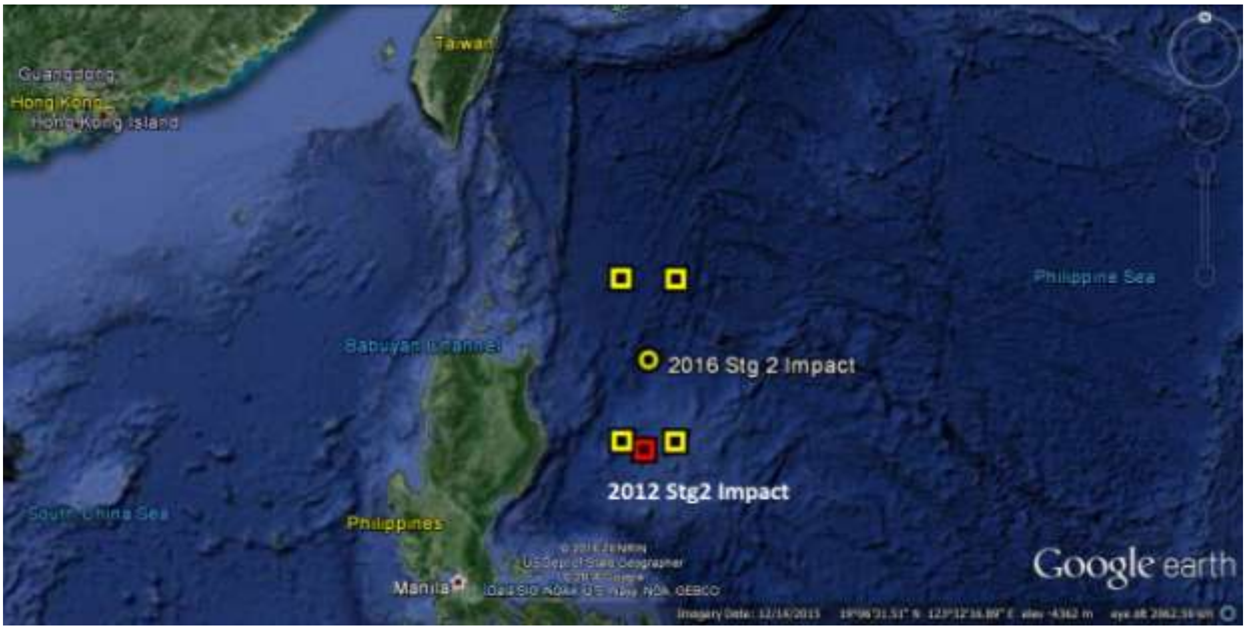


**Figure 3: Comparison for Second Stage Impact for December 2012 (Red) and February 2016 (Yellow) Launch**

The differences in the nominal impact points of the first and second stages for the December 2012 and the February 2016 launches could be due to two reasons. It is possible that North Korea was planning to put a slightly heavier satellite into orbit as compared to the 100 Kg satellite that it put into orbit in December 2012. The other reason could be that the North Koreans decided to load more propellant in the third stage of the launcher.

## North Korea's *Unha*-3 Launch Vehicle

North Korea has used the *Unha*-3 launch vehicle for the December 2012 and the February 2016 launches. ISSSP, NIAS had carried out an analysis of the vehicle used in the December 2012 successful *Unha*-3 launch.[10]

The *Unha*-3 is a three-stage launch vehicle. The first stage comprises of four *NoDong* Engines as depicted in **Figure 4** below.[11] There are also four Vernier engines for control purposes. The integration of these components into a unified stage with autonomous control is a significant improvement over the graphite jet vane control systems used in the earlier launchers.

The second stage interestingly does not use a NoDong engine. North Korea designed a new engine for the satellite mission. This engine uses a UDMH/RFNA fuel and oxidizer mix which provides the much lower thrust that is needed for a satellite launch.

[10] S. Chandrashekar, N. Ramani, Rajaram Nagappa and Soma Perumal, "North Korea's Successful Space Launch", Report No. R20-2013, April 2013, Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, available at http://isssp.in/north-koreas-successful-space-launch/

[11] Norbert Brügge, "North Korea's impressive space launch vehicle 'Unha-2'," available at http://www.b14643.de/Spacerockets/Diverse/Unha-2/

The third stage uses an advanced propellant oxidizer combination of UDMH and Nitrogen Tetroxide. The realization of this stage is also a significant departure from the earlier Scud based technology used by North Korea.

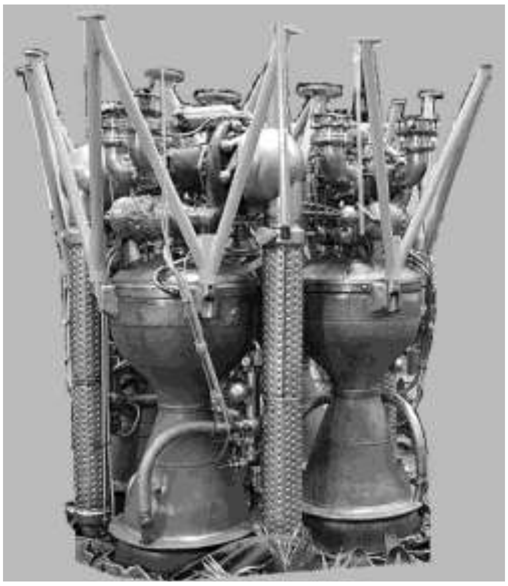

**Figure 4: Four NoDong engines used in *Unha* Launch Vehicle**

## Choosing the Baseline Configuration for Analysis of the 2016 Launch

Analysis of the images and the video put out by the DPRK as well as the performance of the vehicle establishes the point that the *Unha*-3 launch vehicle used in the February 2016 space launch was very similar to the vehicle which put the satellite into orbit in December 2012.[12] The images of the December 2012 and the February 2016 *Unha*-3 vehicles are shown in **Figure 5.**

**Figure 5: Launch of *Unha*3 Dec 2012 (Left) and February 2016 (Right)**

[12]" Kim Jong Un guides Satellite launch! [FULL VIDEO] Kwangmyongsong-4", *You Tube*, February 10, 2016, available at https://www.youtube.com/watch?v=Oe1h37V5NC0&feature=youtu.be

Given the similarities between the two launches we decided to largely retain the same parameters of the three stages of the *Unha*-3 that we had arrived at in our analysis of the December 2012 North Korean launch.[13] However given the changes in the nominal impact points for the first and second stages that suggests a slightly heavier third stage we did decide to make some changes to the third stage parameters to arrive at a baseline configuration for investigations into the February 2016 launch.

The overall mass of the satellite third stage combination was increased by 100 Kg. In the first instance this increase was in the propellant mass carried by the third stage. It was based on the assumption that if needed this could be transferred to the satellite if the trajectory simulation results warranted such a change. A comparison of the parameters used as the baseline for the 2016 launch with the parameters arrived after the analyses of the 2012 launch are in **Table 3**.

**Table 3: Baseline Configuration of the *Unha* Launcher based on the 2012 Launch**

| *Unha* 3 Parameters | 2012 Final Value | 2016 Assumed Value |
|---|---|---|
| **Stage 1 parameters** | | |
| Propellant Mass Stage 1 (kg) | 55287 | 55287 |
| Inert Mass Stage 1 (kg) | 10531 | 10531 |
| Stage Mass | 65818 | 65818 |
| Fuel Fraction | 0.84 | 0.84 |
| Thrust Sea Level (Newtons) | 1254957 | 1254957 |
| ISP Sea Level (seconds) | 229 | 229 |
| Burn time Computed (seconds) | 98.935 | 98.935 |
| Area of Cross Section ($m^2$) | 4.52 | 4.52 |
| **Stage 2 parameters** | | |
| Propellant Mass Stage 2 (kg) | 8866 | 8866 |
| Inert Mass Stage 2 (kg) | 2217 | 2217 |
| Stage Mass | 11083 | 11083 |
| Fuel Fraction | 0.80 | 0.80 |
| Thrust (Newtons) | 150000 | 150000 |
| ISP Vacuum (seconds) | 269 | 269 |
| Burn time Computed (seconds) | 155.92 | 155.92 |
| Area of Cross Section ($m^2$) | 1.52 | 1.52 |
| **Stage 3 Parameters** | | |
| Propellant Mass Stage 3 (kg) | 1800 | 1900 |
| Inert Mass Stage 3 (kg) | 294 | 294 |
| Stage Mass | 2094 | 2194 |
| Fuel Fraction | 0.86 | 0.87 |

[13] S. Chandrashekar, N. Ramani, Rajaram Nagappa and Soma Perumal, "North Korea's Successful Space Launch", Report No. R20-2013, April 2013, Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, available at http://isssp.in/north-koreas-successful-space-launch/

| *Unha* 3 Parameters | 2012 Final Value | 2016 Assumed Value |
|---|---|---|
| Thrust (Newtons) | 93000 | 93000 |
| ISP Vacuum (seconds) | 288 | 288 |
| Burn time Computed (seconds) | 54.66 | 54.66 |
| Area of Cross Section ($m^2$) | 1.02 | 1.02 |
| Payload Mass (kg) | 100 | 100 |
| Shroud Mass (kg) | 300 | 300 |
| Lift Off Weight (kg) | **79395** | **79495** |

**Details of the February 2016 North Korean Space Launch**

The statement released by the DPRK's National Aerospace Development Administration (NADA) following the February 2016 launch, claimed that the satellite was put into a Sun Synchronous Orbit with a period of 94 minutes and 24 seconds. The statement claimed that the satellite had a perigee of 494.6 km, an apogee of 500 Km with an inclination of 97.4 degrees.[14]

The NORAD data put out after the satellite was put into orbit showed significant differences from the DPRK data. The NORAD data mentions a perigee of 472.6 Km, an apogee of 508.5km with an inclination of 97.5280 degrees.[15] **Table 4** provides a comparison of the data put out by these agencies.

**Table 4: Comparison of Orbit Parameters**

| Orbital Parameters Feb 2016 launch | NADA Statement | NORAD Statement |
|---|---|---|
| Perigee Altitude (Km) | 494.6 km | 472.6 km |
| Apogee (Km) | 500 km | 508.5 km |
| Inclination (degrees) | $97.4^o$ | $97.5280^o$ |
| Period (minutes) | 94.40 | 94.30 |

Following the December 2012 launch, South Korea had recovered the first stage debris of the *Unha*-3 and publicly released their evaluation of the launcher. In order to prevent South Korea from recovering and analyzing the first stage debris, DPRK destroyed the first stage just before it impacted into the sea.[16] Dr. Jeffrey Lewis shared images **(Figure 6 below)**

[14] "DPRK National Aerospace Development Administration Releases Report on Satellite Launch", *KCNA Watch*, February 7, 2016, available at http://www.kcnawatch.co/newstream/1454827398-615795121/dprk-national-aerospace-development-administration-releases-report-on-satellite-launch
[15] "Kwangmyongsong-4 Orbital Elements", *N2YO Website*, available at http://www.n2yo.com/satellite/?s=41332 (as on February 9, 2016)
[16] "N. Korea launches long-range rocket", *Yonhap News*, February 7, 2016, http://english.yonhapnews.co.kr/news/2016/02/07/0200000000AEN20160207000952315.html

comparing the recovered first stages following the December 2012 and the February 2016 launches depicting the greater damage suffered by the recovered stage in the later launch.[17]

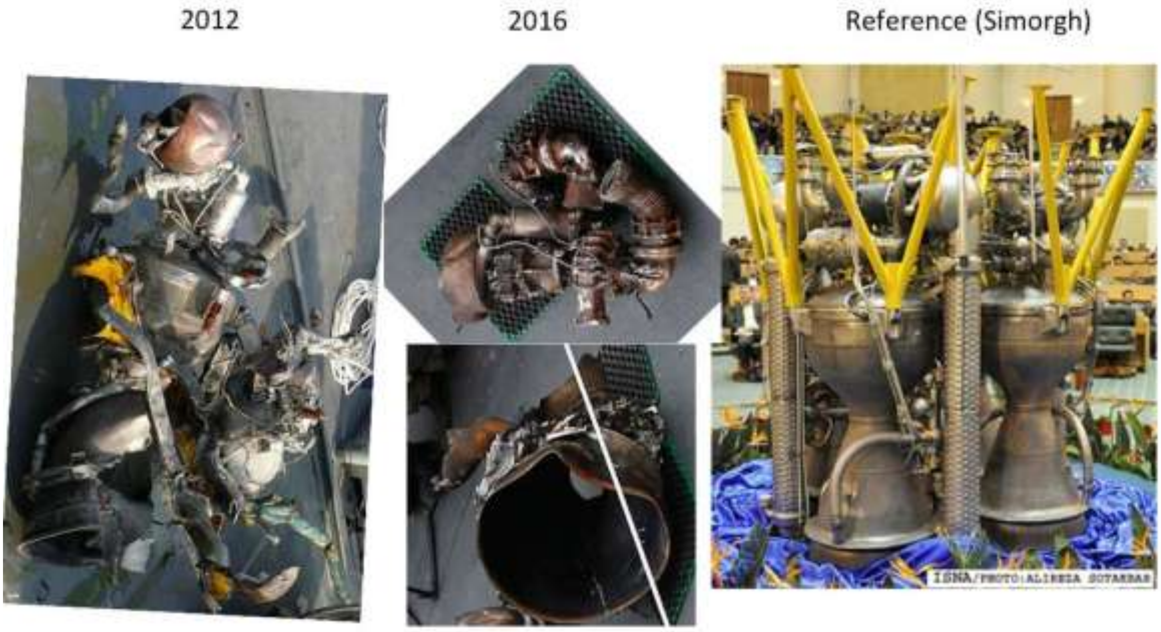


**Figure 6: Comparison of recovered 2012 and 2016 *Unha*-3 First stages**

## Analysis of the 2016 North Korean Launch

The analysis was carried out using the *Quo Vadis* trajectory software developed at the National Institute of Advanced Studies (NIAS), Bangalore. The parameters of the baseline *Unha*-3 launch vehicle configuration (**see Table 3**) were fed into to the software.

Using an iterative trial and error process involving changes in the various launch vehicle parameters very similar to those used in our analysis of the 2012 launch we attempted to arrive at a trajectory in which the impact points of the first stage, second stage and shroud are closely matched with the nominal impact points put out by North Korea. Along with this we also introduced needed maneuvers to the first, second and third stages for realizing an orbit that matched well with the NORAD orbital data. The results of the trajectory reconstruction exercise are provided below.

The U.S. Strategic Command mentions that the *Unha* rocket lifted off at 0:29 UTC on Sunday, February 7, 2016 at 8:59 a.m. local time. The safety zone for the first stage impact was located 450 Kilometers from the launch site, a little over 100 Kilometers from the South Korean coast line and 250km south west of Seoul.[18] The NIAS *Quo Vadis* trajectory simulation of the launch shows that the first stage impacted at a distance of 444.5 Km from

[17] Jeffrey Lewis, Twitter Arms Control Wonk Timeline, February 16, 2016 available at https://twitter.com/ArmsControlWonk/status/699720019186352128

[18] "Controversial Rocket Launch: North Korea successfully places Satellite into Orbit", *Spaceflight101.com*, February 7, 2016, available at, http://spaceflight101.com/north-korea-kms-4-launch-success/

the launch site after a flight time of 466.41 seconds or 7 minutes and 46 seconds after launch.

South Korean and Japanese tracking information shared by Spaceflight101 website mention that the first stage impacted in the Yellow Sea at 0:37 UTC. The impact time from the NIAS *Quo Vadis* trajectory simulation is 0:36:46 UTC. This matches well with the 0:37 UTC impact time put out by the South Korean and Japanese sources. The impact point of the first stage from the NIAS trajectory simulation is 35.66 N, 124.81 E which is close to the nominal impact point of 35.69 N and 124.70 E put out by North Korea. The impact point of the First Stage using the NIAS Quo Vadis trajectory simulation exercise is therefore consistent with the data put out.

According to tracking information put out at the website Spaceflight101.com, the payload fairing impacted at 0:39 UTC in the designated zone to the south-west of Jeju island after separating from the launch vehicle shortly into the second stage burn. The fairing impact zone was located 750 Kilometers due south of the launch site in the East China Sea.[19] Our results show that the Shroud impact point is 760 Km due south of the launch site after a flight time of 663.35 seconds – 10 minutes and 3 seconds after launch or 0:39:03 UTC. The impact point 32.83 N and 124.82 E is also very close to the notified midpoint of the impact zone – 32.813 N and 124.663 E. It is also located south west of Jeju island in the East China sea. The location and timing of the shroud impact point is also consistent with the tracking data put out.

It was expected that the second stage of the Unha-3, once it separated from the third stage, would continue on a ballistic path, would re-enter the atmosphere and impact in a remote area of the Philippine Sea, away from populated land masses and fishing areas. The Japanese military tracked the launch vehicle as it overflew Okinawa and the second stage impact was detected at 0:45 UTC. The time of impact for second stage as calculated by the NIAS *Quo Vadis* trajectory run is 892 seconds which is 14 minutes and 52 seconds after launch. As per our trajectory, the second stage impact happened at about 0:44 UTC.

There is a difference of about one minute between our simulation of the trajectory and the actual flight time of the second stage.

Our impact point of the second stage at 18.45 N, 124.58 E is also slightly above the nominal impact point of 18.37 N, 124.35 E indicating a marginal underperformance of the second stage in our trajectory simulation exercise. In spite of this limitation our results are quite consistent with the published data on the impact locations of the various stages of the *Unha* launcher.

While we could do some minor tinkering with the second stage parameters to provide a better match given the uncertainties associated with some of our estimates and assumptions, such an effort does not make technical sense. The match is good enough for

[19] "Controversial Rocket Launch: North Korea successfully places Satellite into Orbit", *Spaceflight101.com*, February 7, 2016, available at, http://spaceflight101.com/north-korea-kms-4-launch-success/

us to state that our modeling of the *Unha* 3 vehicle and its February 2016 trajectory is close to the actual performance. **Table 5** provides a comparison between the orbital elements derived from our trajectory model with the orbital parameters of the North Korean satellite put out by NORAD immediately after the launch.

**Table 5: Comparison of NORAD and Trajectory Simulation Orbital Parameters**

| Orbital Elements Feb 2016 launch | Trajectory Reconstruction (NIAS Quo Vadis) | NORAD Data |
|---|---|---|
| Perigee Altitude (Km) | 470.5 | 472.6 km |
| Apogee (Km) | 515.6 | 508.5 km |
| Inclination (degrees) | 97.54 | 97.5280° |
| Semi Major Axis | 6864 | 6861 |
| Eccentricity | 0.003 | 0.0026202 |
| Period (minutes) | 94.30 | 94.3 |

As we can see from the above Table there is also a good fit between our simulation of the February 2016 launch and the orbital parameters put out by NORAD. Our reconstruction of the trajectory also enables us to estimate the Equatorial Crossing time of the North Korean remote sensing satellite. This is another parameter that helps us validate the results of our trajectory simulation.

Our trajectory simulation exercise gives a local equatorial crossing time of 08:38:44 which is also very close to the Equatorial Crossing Time of 08:39 put out.[20] Reports on the launch also state that the total flight time from lift off to injection for the February 2016 launch was 9 minutes and 46 seconds or 586 seconds. Our trajectory results show that the third stage satellite combination entered orbit at 527 seconds or 8 minutes and 47 seconds after launch. There is a difference of about 60 seconds between our trajectory reconstruction and the actual flight time.

After the third stage satellite combination is injected into orbit there is normally some delay before the satellite is separated from the upper stage. This could account for some of the differences between our reconstruction and the actual flight time. Our results also suggest that the second stage performance in our model, results in a marginal underperformance of this stage. It is possible that the second stage has a slightly higher specific impulse and this could account for some of the time difference.

On the whole, in spite of these differences, (most of which can be accounted for) our trajectory reconstruction is reasonably close to the parameters of the *Unha* 3 and the trajectory flown on February 7 2016.

[20] "Kwangmyongsong 4 Mission Summary: North Korea," *Zarya Website*, February 7, 2016, available at http://www.zarya.info/Diaries/NKorea/Kwangmyongsong4.php

Our assessment of North Korea's capabilities in launcher and satellite technologies based on this and earlier reconstructions of space launch trajectories is provided next section.

**North Korea's Space Launch Capabilities – Updated Assessment**

**Table 6** compares the *Unha* 3 vehicle parameters derived from our trajectory reconstructions of the December 2012 and February 2016 launches.

**Table 6: Comparison of the 2012 & 2016 *Unha*3 Parameters**

| *Unha* 3 Parameters | 2012 Final Values | 2016 Final Values |
|---|---|---|
| **Stage 1 parameters** | | |
| Propellant Mass Stage 1 (kg) | 55287 | 55287 |
| Inert Mass Stage 1 (kg) | 10531 | 10531 |
| Stage Mass | 65818 | 65818 |
| Fuel Fraction | 0.84 | 0.84 |
| Thrust Sea Level (Newtons) | 1254957 | 1260000 |
| ISP Sea Level (seconds) | 229 | 228 |
| Burn time Computed (seconds) | 98.935 | 98.109 |
| Area of Cross Section ($m^2$) | 4.52 | 4.52 |
| **Stage 2 parameters** | | |
| Propellant Mass Stage 2 (kg) | 8866 | 8866 |
| Inert Mass Stage 2 (kg) | 2217 | 2217 |
| Stage Mass | 11083 | 11083 |
| Fuel Fraction | 0.80 | 0.80 |
| Thrust (Newtons) | 150000 | 150000 |
| ISP Vacuum (seconds) | 269 | 264 |
| Burn time Computed (seconds) | 155.92 | 153.02 |
| Area of Cross Section ($m^2$) | 1.52 | 1.52 |
| **Stage 3 Parameters** | | |
| Propellant Mass Stage 3 (kg) | 1800 | 1900 |
| Inert Mass Stage 3 (kg) | 294 | 294 |
| Stage Mass | 2094 | 2194 |
| Fuel Fraction | 0.86 | 0.87 |
| Thrust (Newtons) | 93000 | 93000 |
| ISP Vacuum (seconds) | 288 | 291 |
| Burn time Computed (seconds) | 54.66 | 58.30 |
| Area of Cross Section ($m^2$) | 1.02 | 1.02 |
| Payload Mass (kg) | 100 | 100 |
| Shroud Mass (kg) | 300 | 300 |
| Lift off weight (kg) | **79395** | **79495** |

As we can see from this comparison, except for a marginal increase of the thrust of the first stage and a one-second decrease in the specific impulse, the two results match. The achievement of a clustered first stage with NoDong engines and integrating it with the Vernier engines required for attitude and trajectory control represents a substantial capability for North Korea. This stage uses RFNA and Kerosene as oxidizer and fuel.

The second stage comparison for the two trajectory reconstructs show that the specific impulse of the second stage in the 2016 reconstruction is only 264 seconds as compared to the 269 seconds needed for the 2012 launch. The second stage pitch down maneuver using the thrust vectoring of the second stage was only for about 25 seconds after second stage ignition in the 2012 reconstruction of the trajectory. For the recent launch the maneuver takes place gradually over a longer duration of 100 seconds after second stage ignition. This reconstruction provides a more realistic representation of the actual trajectory.

Both reconstructions however validate the development of a low thrust second stage designed specifically for a satellite launch application by North Korea. This stage uses UDMH and RFNA as fuel and oxidizer. It has a thrust of about 15 tonnes with a specific impulse of 264 seconds.

For the third stage there is a fair degree of match between the two reconstructions. The 2016 launcher carried a little bit more propellant than the 2012 launch. It also has a slightly higher performance third stage engine most probably based on a UDMH and Nitrogen tetroxide fuel and oxidizer combination. This has a thrust of about nine tonnes and a specific impulse of about 290 seconds. **Table 7** compares the achieved orbits of the December 2012 and January 2016 satellite launchings.

**Table 7: Comparison of Orbit Parameters – 2012 & 2016 Launches**

| Orbit Parameters | NORAD Data 2012 Launch | NORAD Data 2016 Launch |
|---|---|---|
| Perigee (Km) | 494 km | 472.6 km |
| Apogee (Km) | 588 Km | 508.5 km |
| Inclination (degrees) | $97.407^o$ | $97.528^o$ |
| Semi Major Axis (Km) | 6918.4 | 6861 |
| Eccentricity | 0.0061309 | 0.0026202 |
| Period (minutes) | 95.54 | 94.3 |

The available evidence suggests that North Korea wanted to achieve a 500 Km sun synchronous orbit in both cases. The orbital parameters show that the 2016 orbit represents an improvement over the orbit achieved in 2012. Whether this happened by accident or by intent is still debatable.

One difference between the two launches has to do with the injection of the satellite. In the 2012 case the injection point was close to the 494 Km perigee of the satellite. However because the final injection attitude could not be controlled precisely the apogee reached 588 Km far above the required 500 Km.

For the 2016 launch, the injection point happened close to the apogee of 508 Km. Though the control over the attitude during injection appears to be better the perigee point reached was only 473 Km which is less than the 500 Km needed for achieving the desired orbit. This would suggest that though it has made significant progress North Korea may still need to improve its capabilities in the final maneuvering of the third stage satellite combination to achieve a more precise orbit insertion.

With two successful satellite launches, North Korea has indicated its capability to indigenously design, develop, test and integrate advanced technologies like a new engine for its launch vehicle. More importantly, the two launches have highlighted the North Korean capability to bring together the hard technologies with the softer parts of the launch like mission planning and management.

For placing the satellite into a sun synchronous orbit, North Korea has to carry out maneuvers after liftoff, pitch down the second stage after the first stage separation and also carry out a yaw maneuver of the third stage before injection of the satellite into orbit.

Successful mastery of these difficult technologies and a complex mission indicates the progress in rocket and missile technology that the North Koreans have achieved since their first failed launch in April 2012. The launch trajectory and the initial orbits of the February 2016 launch of the *Unha*-3 as computed by the Quo Vadis software is depicted in **Figure** 7 below.

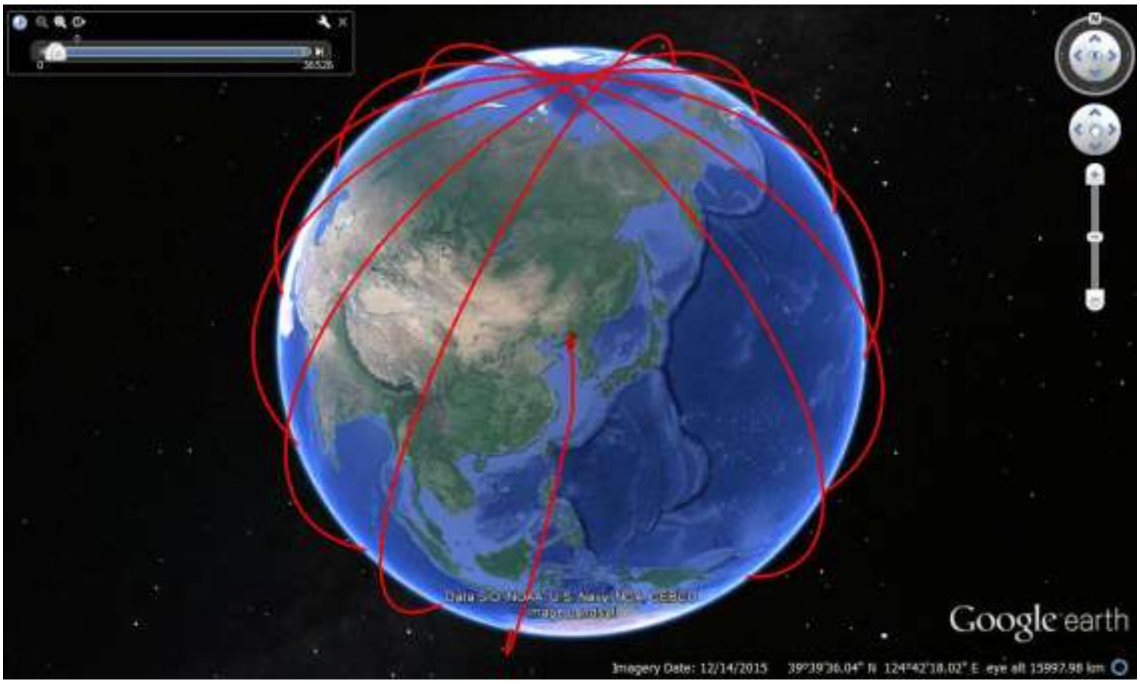


**Figure 7: *Unha*-3 Feb 2016 Launch Trajectory**

**Annexure 1 (Table 8)** provides a detailed time line of the major events taking place during the February 2016 launch of the *Unha* 3

### *Unha*-3 as a Long-Range Ballistic Missile

North Korea conducted four nuclear tests with the latest test in January 2016. In addition it has successfully put a satellite into orbit twice - in December 2012 and February 2016. With these capabilities, North Korea is moving towards the capability to minaturise its nuclear warhead and delivering them on long range missiles.

Though the *Unha*-3 is primarily designed for a space mission, it can be modified into a long range ballistic missile. Trajectory analysis using the NIAS trajectory modeling software – *Quo Vadis* – shows that a due North East launch ($25^{o}$ azimuth) of the *Unha* from a suitable location with a 1000kg payload (sufficient to carry a nuclear warhead) can reach all of Alaska and some parts of northern Canada. As indicated in an earlier ISSSP, NIAS report, if North Korea manages to reduce the payload mass to 800kg it will be able to successfully deliver a nuclear warhead on parts of western coast of the continental United States including the states of Washington, Oregon and northern parts of California.[21] **Figure 8** provides a visual representation of the range of the *Unha* 3 launcher if it is deployed as a long range missile.


**Figure 8: Range of Unha-3 as a long range Ballistic Missile**

[21]ArunVishwanathan, S. Chandrashekar, L.V. Krishnan and LalithaSundaresan. North Korea's 2016 Nuclear Test: An Analysis. ISSSP Report No. 1-2016. Bangalore: International Strategic and Security Studies Programme, National Institute of Advanced Studies, January 10, 2016 available at http://isssp.in/north-koreas-2016-nuclear-test-an-analysis/

# Annexure 1

## Table 8: Timeline of Major Events *Unha* February 2016 Satellite Launch

| Time (seconds) | Event | Altitude (Km) | Range (Km) | Velocity (Km / sec) |
|---|---|---|---|---|
| 0 sec | Vertical Lift off | 0 | 0 | 0 |
| 8 sec | Pitch Down 87.9, Azimuth 174.5 | 0.20 | 0 | 52.13 |
| 98.11 sec | Stage 1 Burnout | 54.34 | 30.99 | 1.927 |
| 98.11 sec | Stage 2 ignition | 54.34 | 30.99 | 1.927 |
| 99 sec | Pitch down stage 2 | 55.71 | 32.02 | 1.930 |
| 153 sec | Shroud release | 137.48 | 105.78 | 2.225 |
| 200 sec | Stage 2 Pitch down completed | 194.87 | 208.41 | 2.759 |
| 251 sec | Stage 2 Burnout | 291.36 | 332.55 | 3.832 |
| 251 sec | Stage 3 Coast Start | 291.36 | 332.55 | 3.832 |
| 472 sec | Stage 3 Coast end | 510.59 | 1022.55 | 3.303 |
| 472 sec | Yaw maneuver start | 510.59 | 1022.55 | 3.303 |
| 482 sec | Yaw Maneuver end | 512.53 | 1052.75 | 3.298 |
| 482 sec | Orbit insertion firing | 512.53 | 1052.75 | 3.298 |
| 526 sec | 3rd stage Satellite in Orbit | 515.56 | 1250.50 | 7.676 |
| 980 sec | Equatorial crossing north to south | 513.59 | 4458.65 | 7.682 |

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