Technical Addendum to the Joint Threat Assessment on the Iran's Nuclear and Missile Potential

A Technical Assessment of Iran's Ballistic Missile Program

by Theodore Postol*
Professor of Science, Technology, and International Security
Massachusetts Institute of Technology

* This addendum does not necessarily represent the views of the other members of the study group of experts that compiled the Joint Threat Assessment. For additional information about this addendum, please contact Ted Postol at postol@mit.edu

3. IRAN'S BALLISTIC MISSILE PROGRAM: A TECHNICAL ASSESSMENT[1]

3.1 The origins of the Iranian ballistic missile program go back to the Iran-Iraq war, in the course of which Iraq launched a large number of SCUD ballistic missiles against Iran. Iran has made considerable efforts to acquire ballistic missiles and related technologies from foreign sources and has started an ambitious indigenous missile program of its own.

3.2 Iran claims to have developed at least four different liquid-propellant ballistic missile systems, the Shahab-1, Shahab-2, Shahab-3, and the Ghadr-1 Kavoshgar (which is also called the Shahab-3M). Three of these missiles, the Shahab-1, Shahab-2, and Shahab-3, do not appear to be truly indigenous, as their flight characteristics are essentially identical to those of the North Korean SCUD-B, SCUD-C, and Nodong missiles respectively.

3.3 The Shahab-3 has been operationally deployed in small numbers since 2003, and Iran's efforts to improve its range and payload are exhibited in the Shahab-3M, which is derived from relatively modest modifications of the Shahab-3. Iran has also developed the Safir space launch vehicle (SLV), which was used to launch the Omid satellite into space on February 2, 2009. The Omid satellite weighs about 27 kg and was launched into a low-earth orbit with an apogee of about 320 km and a perigee of about 240 km. The Safir, which will be described and analyzed in greater detail later in this chapter, could eventually provide the basis for developing ballistic missiles of longer range and larger payload relative to those based solely on SCUD missile technologies. In this report we will refer to the missile that might be derived from the Safir SLV as the Safir missile.

3.4 There are many unconfirmed rumors and speculations about the Iranian ballistic missile program, including claims by the U.S. Missile Defense Agency, that Iran is developing a long-range solid-propellant missile called the Ashura, and an Intermediate Range Ballistic Missile based on the Russian submarine launched ballistic missile known in the West as the SS-N-6.[2] There is no good evidence at this time to support a technical analysis of Iran's solid propellant ballistic missile program, but we expect to add to, and perhaps modify, this report as new information becomes available. With regard to the SS-N-6, there is evidence that

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[1] We wish to thank Markus Schiller and Robert H. Schmucker of Schmucker Technologies, Munich, Germany, for generously providing us with extensive technical information and advice with regard to their analyses of Iran's ballistic missile program. We are attaching as an appendix to this section an invaluable briefing they provided to us on Iran's ballistic missile program . We also thank them for additional information and advice they provided to us via e-mails.

[2] This Russian submarine launched ballistic missile is described as an Iranian IRBM (Intermediate Range Ballisitc Missile) having an IOC (Initial Operational Capability) in 2008 or later. It can be found in "Missile Defense Program Update For The 6TH Annual Missile Defense Conference," Lt Gen Trey Obering, USAF, Director, Missile Defense Agency, 31 MAR 08, Slide 7.

Iran has utilized the turbopump and associated vernier rocket motors (not the main rocket motor) from the SS-N-6 in the second stage of the Safir missile. These vernier motors are of relatively low thrust, which places some limits on the weight of payloads that this upper stage can carry. The SS-N-6 vernier motors have a sufficiently high exhaust velocity relative to rocket motors based on SCUD technology to make it possible to launch a low-weight satellite into low-earth orbit. The introduction of more efficient engines that use more energetic propellants than those used by missiles based on SCUD technology is a potentially significant development and will be discussed later in this report.

3.5 Iran's indigenous long-range liquid-propellant ballistic missile program relies very heavily on rocket motors and other missile components first imported from North Korea in the late 1980s and early 1990s.[3] North Korea may have developed an indigenous capability to manufacture SCUD-Bs and SCUD-Cs, but the extent to which it has this capability is uncertain.[4] The assumption that best explains the sudden appearance and the observed limitations of the North Korean missile program is that North Korea has learned to use critical rocket components, like rocket motors, to fabricate its own missiles. These components might have been sold to North Korea by Russian groups or institutions that were operating in violation of Russian laws. North Korea probably does not have the industrial base and knowhow to improve on these components and it seems likely that they as well lack the ability to manufacture these components.

3.6 SCUD missile technology uses relatively low-energy propellants; engines with materials and designs that are very hard to upgrade to more energetic propellants; and primitive guidance systems. The fact that Iran and North Korea rely on imported technology and have not been able to develop their own rocket motors has extremely important implications for the future of Iran's and North Korea's ballistic missile programs.

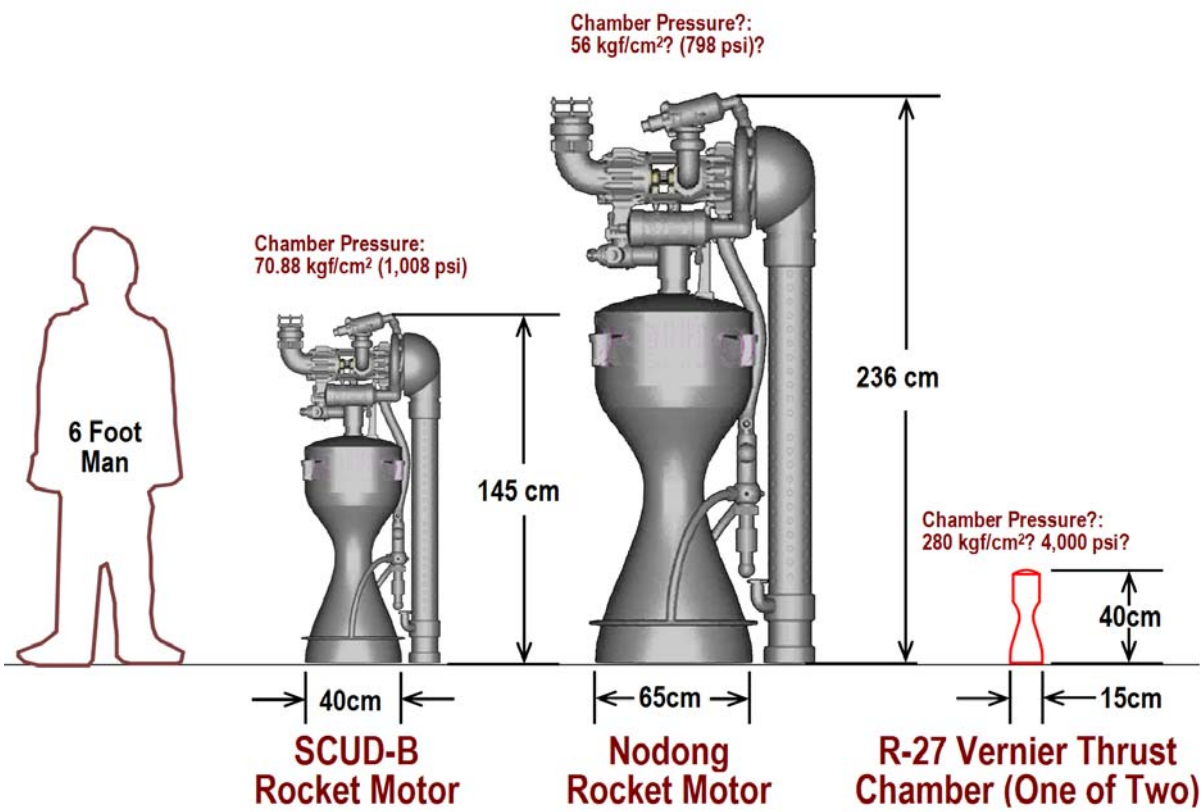
3.7 Iran and North Korea's liquid propellant rocket programs depend heavily on the use of two rocket motors. One is the motor from the SCUD-B ballistic missile; and the other is the motor used in the North Korean Nodong missile. Both rocket motors use the same "low-energy" rocket propellants (TM-185, a mixture of 20% gasoline and 80% kerosene, and an oxidizer known as AK27, which is a mix of

[3] Slide 23, Die nuklear bewaffneten Fernraketen des Iran (The Nuclear-Armed Long-Range Rockets of Iran), Robert H. Schmucker and Marcus Schiller, October 22, 2008. Also, for an excellent discussion of political factors that have shaped the North Korean ballistic missile program and a comprehensive review of articles published about that program, see "The North Korean Missile Programme," Daniel A. Pinkston, February 2008, Strategic Studies Institute, U.S. Army War College, Carlisle, Pennsylvania.

[4] Robert Schmucker has stated that he believes that North Korea's ballistic missile program may not have an indigenous capability to manufacture critical rocket components, but may instead be based on using Russian rocket components that may have been obtained at an earlier time from North Korea. All of the liquid propellant rocket motors that have been observed in photographs released by Iran of the Shahab series of missiles, and the first and second stages of the Safir SLV, strongly support this view.

27% N_2O_4 and 73% nitric acid). The Nodong has a bigger motor, which has more than twice the thrust of the SCUD-B motor.

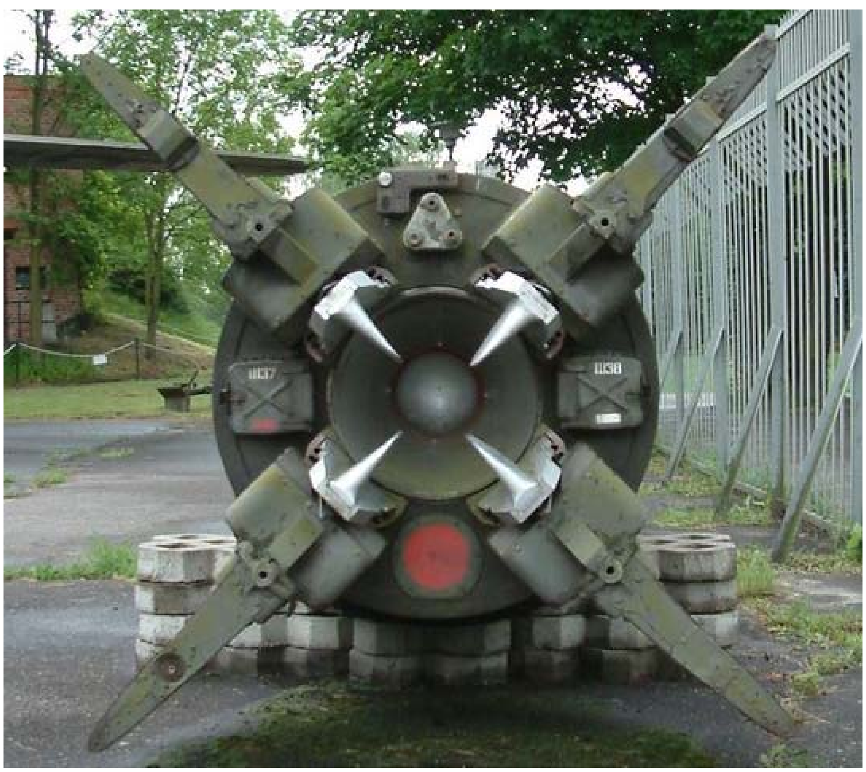
3.8 The Nodong rocket motor was first observed in North Korea in the late 1980s, and more recently Iran has released photographs of what appears to be a Nodong rocket motor (see photographs on the next page.) A drawing of what appears to be a device used in the manufacturing of that motor can be found in the Russian text book, "The Production Technology of Liquid Rocket Engines," by V. V. Vorobey and V. E. Loginov.5 If this identification is correct, the Nodong rocket motor is an example of 1950s Russian rocket technology, very similar to that used in the SCUD-B, which was first built and deployed during the same time-period. The Nodong motor uses the same fuel as the SCUD-B motor and its performance efficiency (exhaust velocity with altitude) is somewhat similar but lower than the Russian RD-214 engine used in the Soviet R-12 ballistic missile (known in the West as the SS-4 Sandal).6 The Nodong rocket motor has provided the enabling foundation for Iran's indigenous liquid-propellant ballistic missile program and for the Safir SLV.



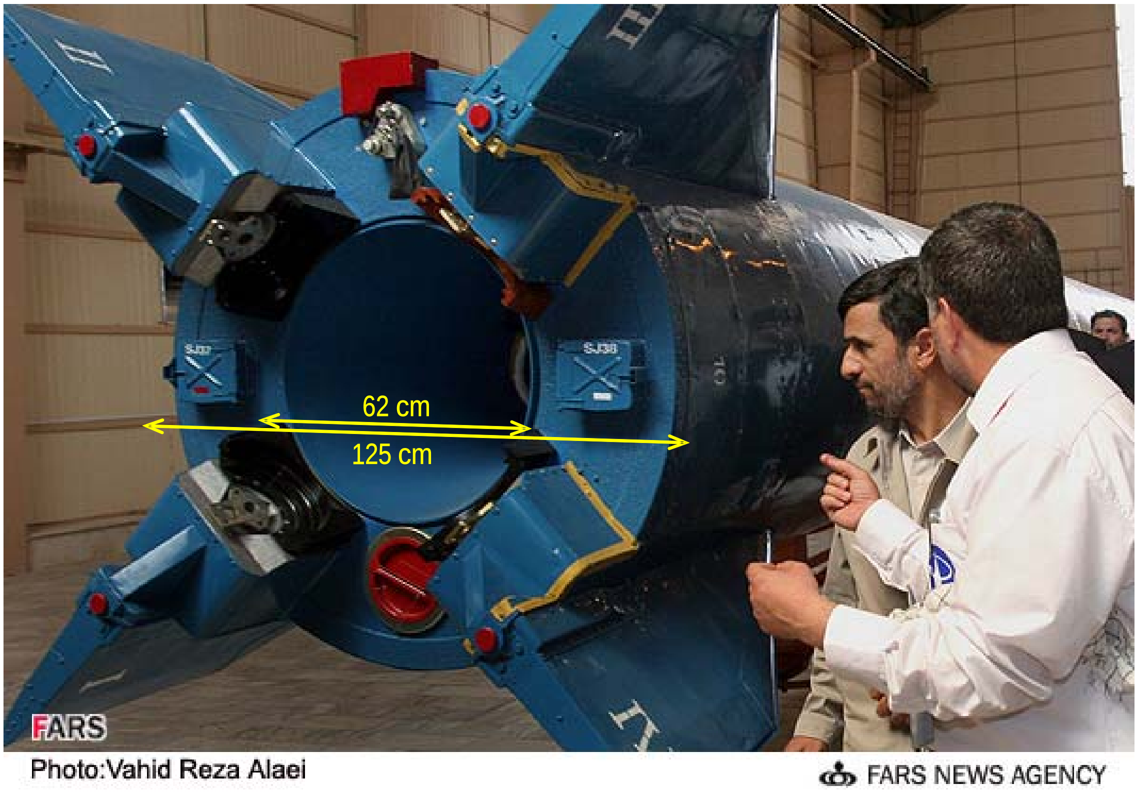
[5] Технология производства жидкостных ракетных двигателей, В. В. Воробей и В.Е. Логинов. The identification and drawing of this rocket motor can be found in slide 36 of Schiller and Schmucker's attached briefing.

[6] We thank Markus Schiller for providing information to us on the specific impulse of the Nodong engine at sea level and in vacuum. The RD-214 is completely different from the Nodong rocket motor. It has four thrust chambers that operate at lower pressure, uses the same propellant as the Nodong, but its specific impulse at sea level and in vacuum is essentially the same as that of the Nodong.

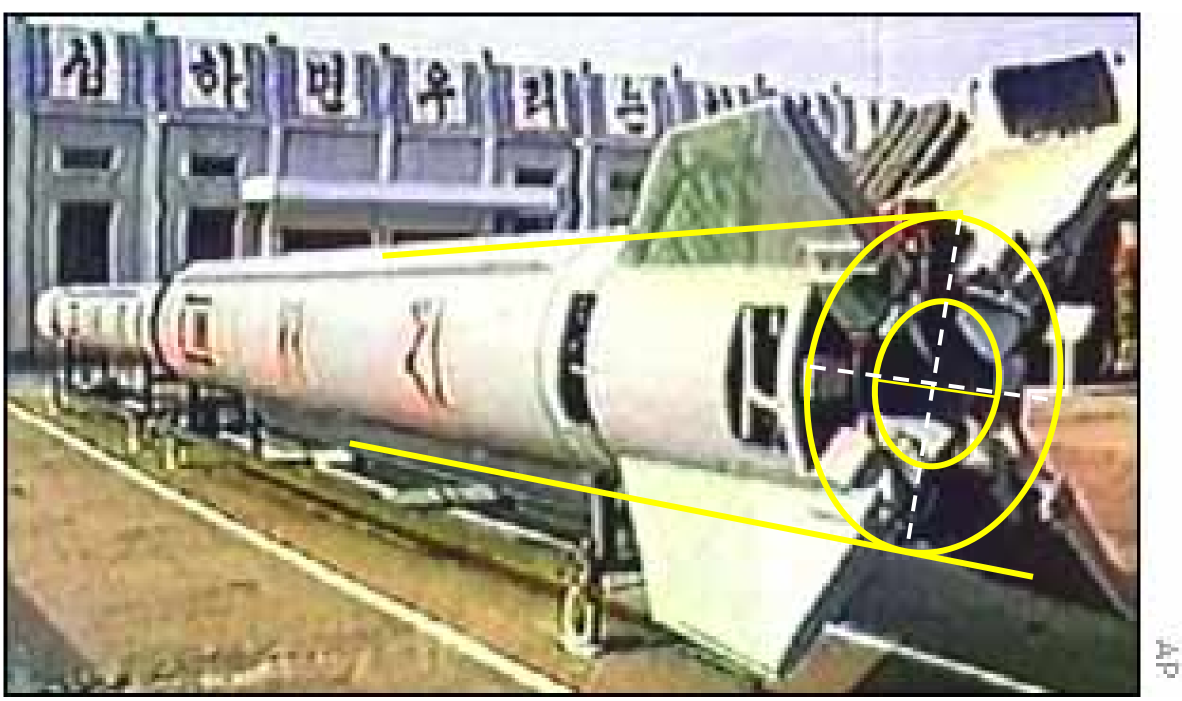
Above left, is a photograph released by the Iranian news agency of what is almost certainly the Nodong rocket motor. Above right, is a photograph released by UNMOVIC of a SCUD B. rocket motor obtained from Iraq. The size of both photographs has been adjusted so the physical scale for each motor is roughly the same.



The photograph above shows the rear end propulsion section of a SCUD-B ballistic missile. Note the four jet vanes that sit directly in the exit nozzle of the rocket motor. These jet vanes control the motion of the rocket by deflecting the exhaust from the motor while the rocket is in powered flight.



The photograph above shows the back end of the Iranian Shahab 3 ballistic missile. This photograph shows that in essentially all respects, the propulsion section of the Shahab 3 has the same design as that used in the SCUD-B. In this particular photograph, the jet vanes have been removed. The only obvious difference between the back end of the SCUD-B and the Shahab 3 is that the components of the Shahab 3 are larger than the same components on the SCUD-B by a factor of roughly 1.4.



This photographs of the rear section of the first stage of the Taepodong 1 reveals that it is simply a Nodong rocket that has been modified to be the first stage of the Taepodong 1. For all practical purposes, the Nodong and the Shahab 3 are the same missiles.

3.9 The Shahab-1 was first presented to the world by Iran as a new ballistic missile, but Marcus Schiller and Robert H. Schmucker have convincingly shown from analyses of publicly available videos of a Shahab-1 missile launch that the Shahab-1 is identical to the North Korean SCUD-B. They have also concluded that the Shahab-2 is identical to the North Korean SCUD-C, and the Shahab-3 to the North Korean Nodong. The Pakistani Ghauri-1 is also a Nodong missile purchased from North Korea. Hence the Shahab-1, Shahab-2, and Shahab-3 ballistic missiles were not developed indigenously by Iran.

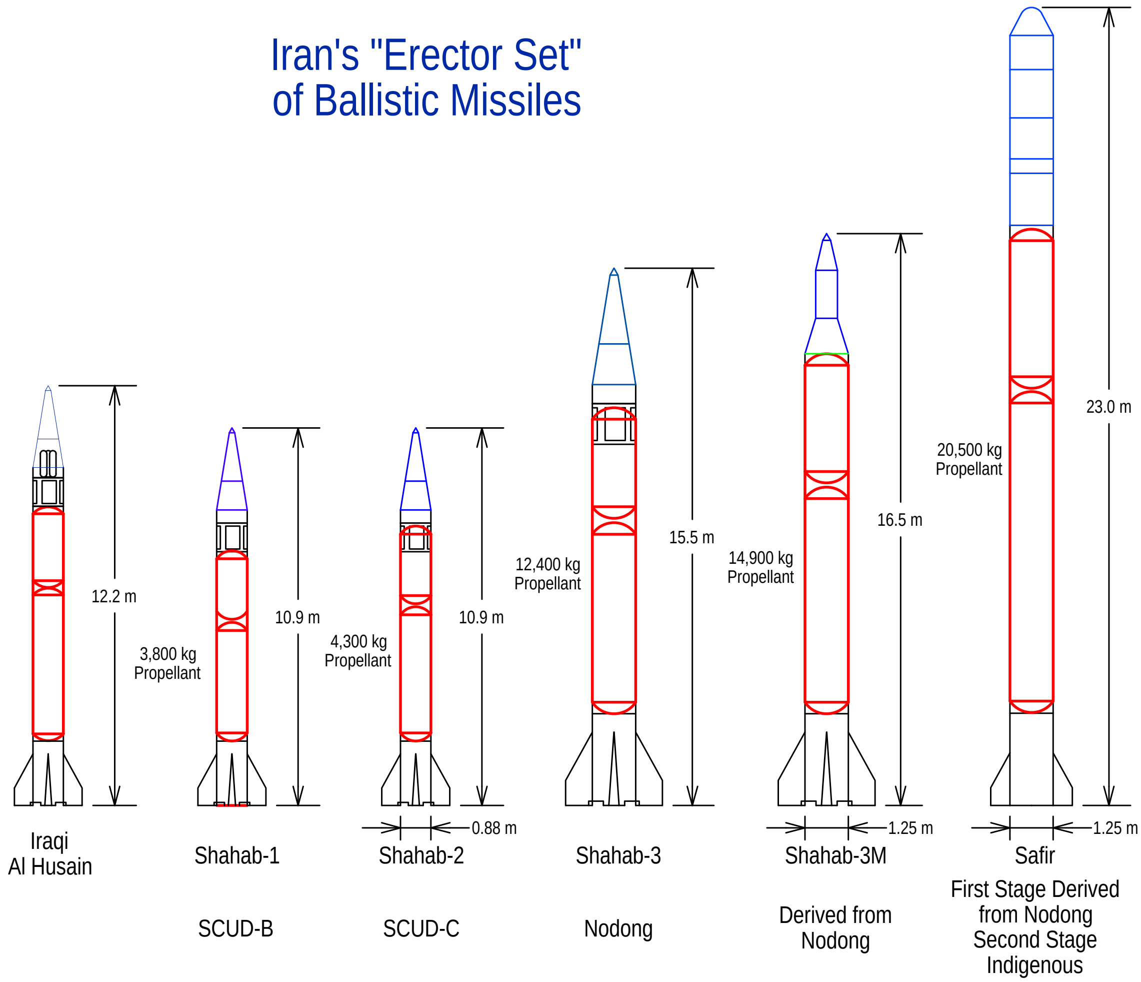


Figure 1

3.10 Figure 1 shows the evolution of the liquid propellant ballistic missiles that Iran describes as products of its indigenous ballistic missile programs. It also shows an “indigenous” Iraqi ballistic missile, the Al Husain, which has range and payload characteristics somewhat similar to that of the North Korean SCUD-C. The Al Husain is the first missile on the left. It is of interest because it is entirely fabricated from SCUD-B missile components and because the Iraqis used exactly the same strategy to extend its range as the Iranians are now using with the North Korean Nodong.

3.11 The analysis and findings of UNMOVIC[7] about Iraq's ballistic missile program may be instructive as a model for understanding Iran's and North Korea's ballistic missile programs. All of Iraq's indigenous liquid propellant rockets, including the 600 km range Al Husain (the equivalent of the North Korean SCUD-C), used rocket components scavenged from the SCUD-B missiles Iraq originally purchased in 1980 from the Soviet Union. The shorter-range (130 km) liquid propellant Al Samoud, which Iraq used in the Gulf War of 2003, was powered by rocket motors scavenged from Soviet SA-2 surface-to-air missiles. This shows that even when a country has substantial indigenous expertise to utilize rocket components to construct ballistic missiles, the difficulties inherent in reverse engineering and in manufacturing critical components present a giant obstacle to further advances.

3.12 The second to fourth missiles (Figure 1) from the left are the North Korean SCUD-B, SCUD-C, and Nodong missiles. As already noted, these missiles are identical to the Shahab-1, Shahab-2, and Shahab-3. The fifth missile is the Shahab-3M (the Ghadr-1 Kavoshgar). It is a variant of the Shahab-3 that carries more propellant in fuel tanks that have been slightly extended relative to those of the Shahab-3.

3.13 The last rocket vehicle in the diagram is the Safir Omid. This rocket uses a first stage derived from the Shahab-3 and a new indigenous upper rocket stage. The new upper rocket stage of the Safir is a clear step forward in the exploitation by Iran of non-indigenous rocket motor and airframe technologies relative to that utilized in the SCUD and Nodong missiles.

3.14 If the Safir had utilized only two rocket stages based on SCUD rocket technology, it would not be able to achieve a nearly high enough burnout speed to place a satellite into orbit. Such a SCUD-based vehicle would instead have required a small third stage solid-rocket motor, like that used by North Korea when it attempted to launch a small satellite with its Taepodong 1 rocket.

3.15 Photographs of the Safir upper stage released by Iran, and analysis of the orbital characteristics of the satellite launched by Iran, indicate that the Safir upper stage uses rocket motors that have exhaust velocities about 20 percent higher than those associated with the SCUD-B and Nodong engines. All other things being equal, such an increase in motor exhaust velocity results in a similar twenty percent increase in the overall velocity that could be achieved by the rocket stage. This higher exhaust velocity therefore results in an upper stage with significantly higher overall performance than that based on SCUD rocket motor technologies.

[7] Compendium of Iraq's Proscribed Weapons Programmes in the Chemical, Biological and Missile areas, The Missile Programme, Chapter IV.I Iraq's Missile Programme (The Beginnings), United Nations Monitoring, Verification And Inspection Commission, June 2007

3.16 A significant constraint associated with the Safir upper rocket stage is that it had to be relatively small and light, as the rocket motors that were used to accelerate the stage were of relatively low thrust. Our initial assessment leads us to believe that these relatively low-thrust but high efficiency rocket motors were probably salvaged vernier engines from Russian SS-N-6 submarine launched ballistic missiles that were reportedly sold by North Korea to Iran. If this is in fact the case, it underscores how access to improved rocket motor technologies can enable competent states with limited industrial capacities to advance their space and missile programs far beyond what they otherwise could do on their own.

3.17 The implications of the Safir being used as a ballistic missile, with its more advanced upper rocket stage, will be discussed in a later section of this chapter.

3.18 All of Iran's efforts to increase the range and payload of its liquid propellant ballistic missiles beyond that of the Shahab-3 take advantage of the higher thrust of the Nodong rocket motor. Since the Nodong rocket motor has sufficient excess thrust to lift missiles that are heavier than the original Nodong, Iran has followed a strategy of gradually increasing the length of the fuel and oxidizer tanks of the original Nodong so that it can carry more propellant. This strategy of increasing the fuel load is ultimately limited to rockets that weigh less than the thrust of the Nodong rocket motor. Since Iran's exploitation of the increased lift capability is now essentially at "the end of the line," further advances in its indigenous ability to produce rockets of greater range and payload will require new and major technological advances beyond those so far demonstrated by Iran.

3.19 In summary, Iran's indigenous long-range liquid propellant missile program is thus far based on the rocket motor used in the North Korean Nodong missile. Most recently, Iran has demonstrated the successful exploitation of low-thrust high-efficiency vernier rocket motors that appear to be salvaged from Russian SS-N-6 submarine launched ballistic missiles. Iran has not proved its ability to manufacture rocket motors of its own; nor has it demonstrated any capacity to design, develop, and build its own rocket motors. Iran has demonstrated that it is able to lengthen the fuel and oxidizer tanks of the Nodong to produce a variant of the Nodong it calls the Ghadr-1 Kavoshgar (Shahab 3). It has used the same techniques to produce the first stage of a two-stage rocket it calls the Safir. Iran has also demonstrated with the upper stage of the Safir, it is quite capable of innovatively using rocket technologies that become available to it. For now, the Safir is the "end-of-the-line" in Iran's liquid propellant ballistic program, as it uses a Nodong rocket motor in its first stage, which is at the absolute limit of its lift capability for a vehicle of the Safir's size and weight, and limited but effective SS-N-6 rocket technology in the small upper stage. If the Iranian ballistic missile program is to advance to longer range and higher payload liquid propellant ballistic missiles, it will next have to master wholly new and as yet not observed rocket technologies to be described later in this chapter. While Iran's accomplishments in rocketry are significant, they do not show a sophisticated and advanced command of liquid-propellant rocket technology. On the other hand, Iran is not working in isolation. It is obtaining technology and know-how from North Korea. As such, developments in either of these missile programs cannot be treated as unrelated.

Technical details of Iran's Ballistic Missiles

3.20 Table 1 shows qualitative estimates of the launch weights, empty and full body weights, payloads, residual fuel, and ranges of the Iranian missiles. Although these estimates are not exact, we believe that the performance assessments that are derived from these estimated missile characteristics are qualitatively correct. They could, however, be further refined if additional information about Iran's flight tests – ranges and times of flight, for example – were made public.

Missile Type	Launch Gross Weight (kg)	Empty Weight (kg) (Without Warhead)	Full Weight (kg) (Without Warhead)	Structure Factor	% Residual Fuel	Specific Impulse (sec) Sea Level / Vacuum	Range (km)	Warhead Weight for Quoted Range(kg)
Shahab 1	5900	1100	4900	0.23	0.05	230 / 253	315	1000
Shahab 2	6400	1100	5400	0.20	0.05	230 / 253	375	1000
Shahab-3	15200	1800	14200	0.13	0.04	220 / 247	930	1000
Shahab3M	17785	1885	16785	0.11	0.04	220 / 247	1100	1000

Table 1[8]

3.21 As already noted, the Shahab-1 ballistic missile is identical to the North Korean SCUD-B. The SCUD-B was originally designed by the Soviet Union as a short-range tactical ballistic missile. Its operational characteristics – range, payload, and powered flight profile – are essentially the same as the German V-2 rocket, first flown in 1942. The SCUD-B, however, has many significant technological features that were not used in the V-2. Its rocket motor uses the relatively "low-energy" storable liquid propellant TM-185 and AK27 while the V-2 used Alcohol and Liquid Oxygen. The SCUD-B rocket motor is far more efficient than that used in the V-2 and its airframe is far lighter. As a result, the SCUD-B has less than half the weight of the V-2 but can carry the same 1,000 kg payload to the same range.

3.22 The Shahab-2, or SCUD-C, is simply a SCUD-B with "stretched" fuel tanks that can carry a warhead weighing roughly 500 kg to a range of roughly 550 km

[8] We wish to thank Marcus Schiller and Robert Scmucker for sharing their estimates of the empty dry and wet weights of the Shahab 1, Shahab2, and Shahab3 missiles. Another source of the dry and wet weights of the SCUD-B we have used is from "Missile Exploitation Data (Section IV-A Through IV-D) (U)," Volume 4, July 1980, AMA-1060X-010-80-Vol-4 DIA, TASK NO. PT-PTX-01-01L, Classified by: DIA/DT, Review: 1 July 2000.

and a warhead weighing 300 kg to a range of about 650 km, roughly twice the range of the SCUD-B when it carries a 1,000 kg warhead. The North Korean SCUD-C uses exactly the same rocket motors, turbopumps, fuel and oxidizer lines, airframe, and guidance system as the SCUD-B, but its fuel and oxidizer tanks are stretched so that it can carry about 13-14% more fuel and oxidizer than the SCUD-B. Since the SCUD-C is designed to be as technologically close to the SCUD-B as possible, the warhead of the SCUD-C is lightened to about 300 to 500 kg in order to keep the overall weight of the system close to that of the original SCUD-B. A SCUD-B carrying a 300 kg warhead could reach a range of about 550 km.

3.23 The North Korean Nodong is essentially the same as the Pakistani Ghauri 1 and the Iranian Shahab-3. The body of the Nodong missile is a near exact replica of the SCUD-B, except that all its major structural components are scaled to a larger size.[9] The SCUD-B body diameter is 0.88 m, while the Nodong body diameter is close to 1.25 m. Thus the Nodong is larger than the SCUD-B in every dimension by a factor very close to 1.4 (we use the factor reported by Schiller and Schmucker of 1.25/0.88=1.42). The Ghauri 2 is also similar to the Nodong. The dimensions of this missile also appear to be scaled up by a factor of about 1.4, but its length-to-diameter ratio appears closer to that of the Iraqi Al Husain.

Figure 2

3.24 The evolution of the Shahab-3 to the Ghadr-1 Kavoshgar (Shahab 3M) follows exactly the evolution of the SCUD B to SCUD-C. The larger Nodong rocket motor associated with the Shahab-3 has sufficient "excess" thrust to lift the "stretched" and heavier Shahab-3M. The Shahab 3M (shown third from the left in the photograph below) has the same overall dimensions as the Shahab 3, except

[9] This was first pointed out by Robert Schmucker, see 3rd World Missile Development - A New Assessment Based on UNSCOM Field Experience and Data Evaluation, Robert H. Schmucker, 12th Multinational Conference on Theater Missile Defense: Responding to an Escalating Threat, June 1-4, 1999, Edinburgh, Scotland.

that the guidance section has been moved forward into the payload section. This change makes it possible to stretch the propellant tanks further without increasing the overall length of the missile or drastically changing the mass distribution. The resulting missile has increased range and payload relative to the Shahab 3.

3.25 Figure 2 shows photographs of the Ghauri 1, the Shahab 3, Shahab 3M (Ghadr-1 Kavoshgar), and Ghauri II missiles. Figure 3 below shows the same photographs overlaid by outlines of the same missiles and an outline of the Safir launch vehicle. The outlines show the estimated locations and relative lengths of the fuel and oxidizer tanks.

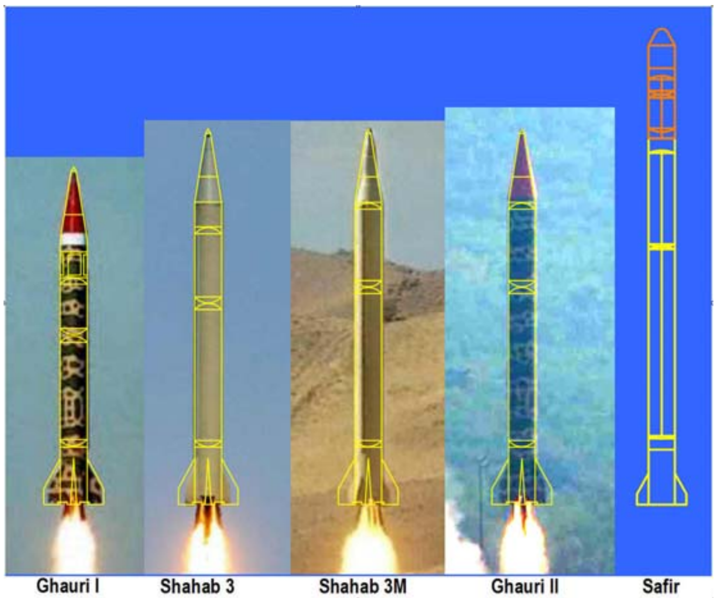


Figure 3

Sources of Disinformation about Iran's Ballistic Missiles

3.26 Iran releases numerous photographs of rocket components and videos of missile launches, and makes public statements about the results of flight tests. These statements, and the technical information that often accompanies them are highly unreliable, and in many cases appear to be designed to mislead outside observers about the extent and sophistication of Iran's indigenous ballistic missile capabilities.

3.27 The U.S. Missile Defense Agency, with the support of the U.S. State Department, has used Iranian statements in an extensive series of briefings to the governments of friends and allies of the United States. Our analysis of the Iranian ballistic missile program suggests that Iranian statements – and hence also the U.S. Missile Defense Agency and State Department briefings based on them – are misleading and present an inaccurate picture of Iran's ballistic missile program.

3.28 We therefore strongly recommend that the Obama Administration immediately order a review by the U.S. intelligence community of the claims made by Iran about the extent of its indigenous ballistic missile program. It would be useful if the Russian government were to do the same, and if both countries published technically informative unclassified versions of these reviews.

The Range and Payload Capabilities of Iran's Existing Ballistic Missiles

3.29 In this section we provide basic performance estimates of the capabilities of Iran's ballistic missiles. The estimates provided here could be refined if basic range and flight time data were made public by intelligence agencies.

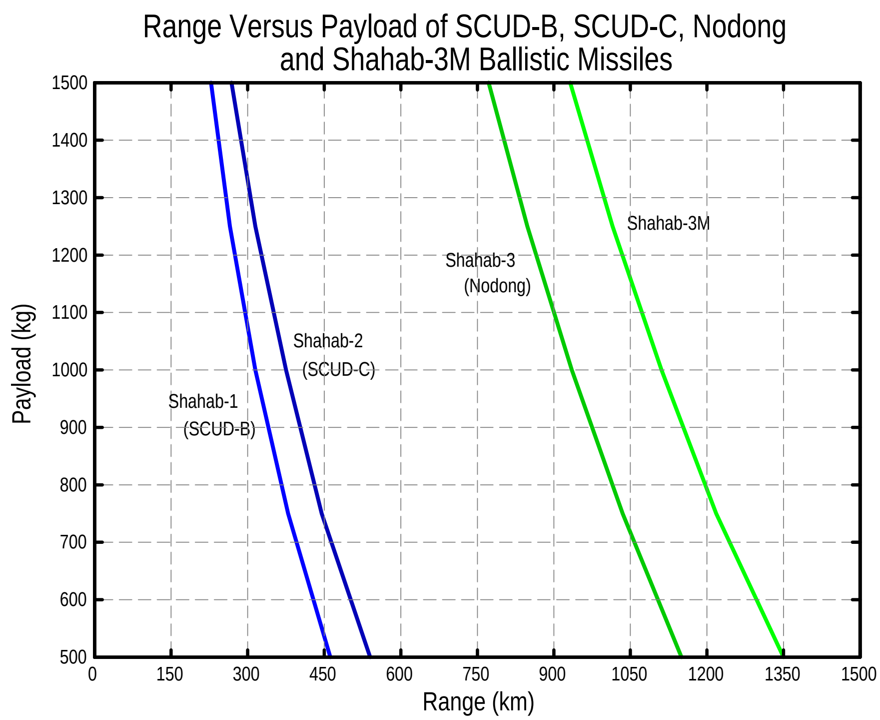


Figure 5

3.30 Figure 5 shows the estimated ranges and payloads of the Shahab 1, Shahab 2, Shahab 3, and Shahab-3M (Ghadr-1 Kavoshgar) ballistic missiles. Assuming a payload of 1,000 kg, the estimated ranges of the four missiles are about 315, 375, 930, and 1100 km. The ranges of the Shahab-1 and Shahab-2 increase to about 450 and 550 km respectively if the warhead weight is reduced from 1,000 kg to 500 kg. The range of the Shahab-3M (Ghadr-1 Kavoshgar) increases by slightly more than 200 km if the warhead is lightened from 1,000 kg to 500 kg.

3.31 Figure 6 shows three notional trajectories for the two-stage Safir missile, assuming payloads of 500, 1,000 and 1,500 kg, and that the rocket motors and airframe are based solely on SCUD ballistic missile technologies. The location of the missile during its powered and free flight is shown at 5-second intervals. The location during powered flight is shown with crosses and the location during free flight with circles. The estimated characteristics of stages one and two are described in text in the figure. As will be discussed in the next section, the second stage of the Safir does not use SCUD technology, and is not suitable for delivering nuclear warheads, which are much heavier than the satellite payload it carried into a low-earth orbit. Hence, the trajectories shown in figure 6 show what the Safir *could* achieve if Iran builds a second stage for the Safir based on SCUD technology and designed to carry the additional weight of a nuclear warhead.

3.32 Figure 7 shows the exhaust velocity with altitude, and the thrust levels at sea level and in vacuum of different Soviet rocket motors built in the 1950s. The Soviet rocket motor that most closely exhibits the exhaust velocity with altitude of the Nodong rocket motor is the RD-203, used in the Soviet R-5M rocket and known in the West as the SS-3 Shyster. The RD-203 engine burns alcohol and liquid Oxygen (LOX) and has a sea level thrust of about 44 tons, in contrast to the Nodong's sea level thrust, which appears to be around 30 to 31 tons. The Nodong rocket motor is less efficient per unit weight of fuel consumed than the engine used in the SCUD, but it has more than twice the 13.4 ton thrust of that motor.[10]

3.33 In order to provide a baseline estimate of the range and payload that could be achieved by the Safir if it is converted to be a ballistic missile, we assume that the high altitude performance of the *upper stage* rocket motor is close to that of the SCUD-B rocket motor at high altitudes. If the high-altitude motor performance of the *upper stage* rocket motor were instead close to that of the RD-214 motor, and the structure factor is assumed to be 0.15 (a reasonable number given the small size of the upper stage), one gets the same overall range-payload performance. If the structure factor remains 0.126, then the maximum range for a 500 kg payload would increase by about 400 km to about 3,250 km. We believe that the maximum range for the case of a 500 kg payload should be about 3,000 km

3.34 Figure 8 shows the estimated ranges for a notional two-stage Safir for payload weights between 500 and 1,500 kg. We emphasize that the range and payload curves for the Safir as a ballistic missile are for a *notional* missile that uses SCUD rocket technologies to implement a second stage. There is *no* evidence at this time that Iran has built such an upper stage. However, the production by Iran of such an upper stage based on SCUD technology is well within Iran's capabilities if a decision to proceed is made.

[10] We thank Marcus Schiller and Robert H. Schmucker for providing us with their estimates of the specific impulses at sea-level and in vacuum of the Nodong rocket motor.

Powered and Free Flight Profile of *Notional* Safir Missile

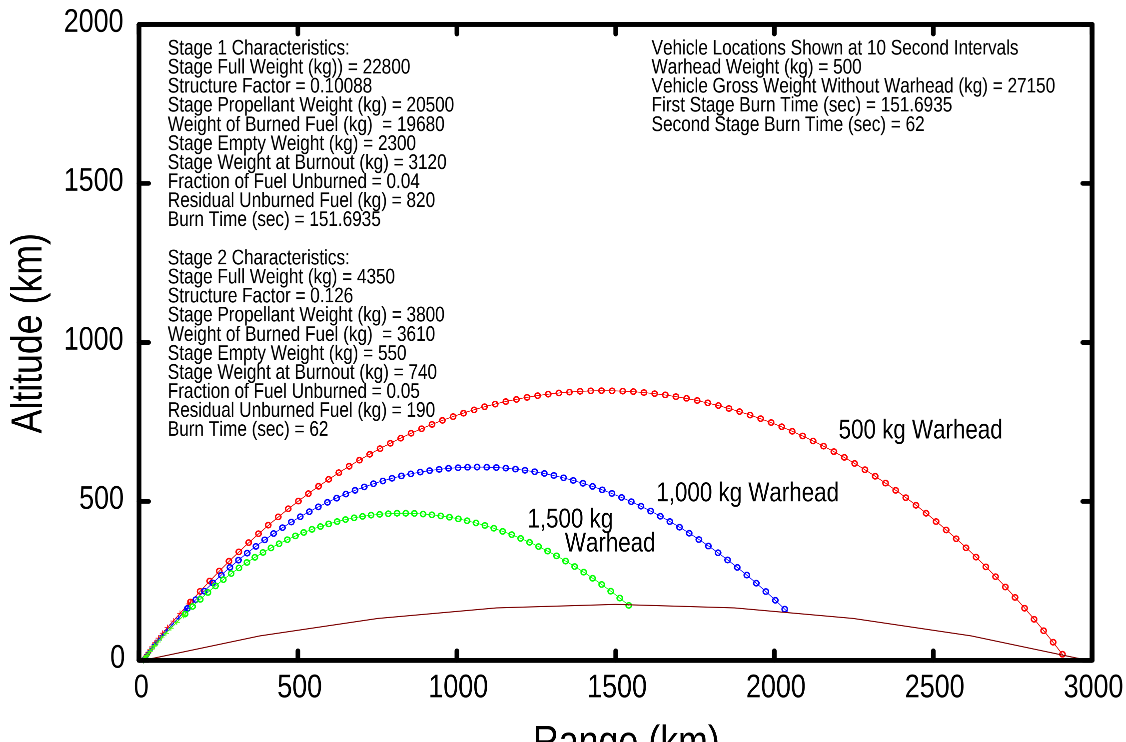
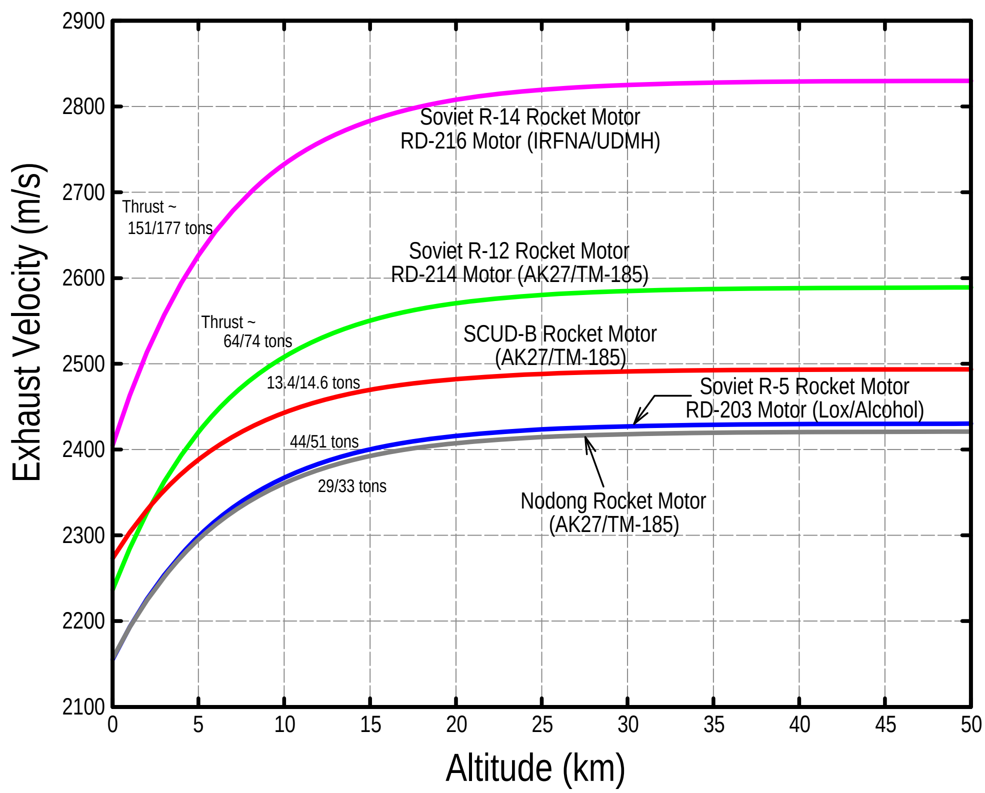
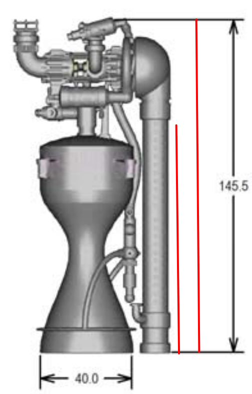


Figure 6

Exhaust Velocities vs Altitude of Early Liquid Propellant Rocket Motors





SCUD-B
Rocket Motor

Figure 7

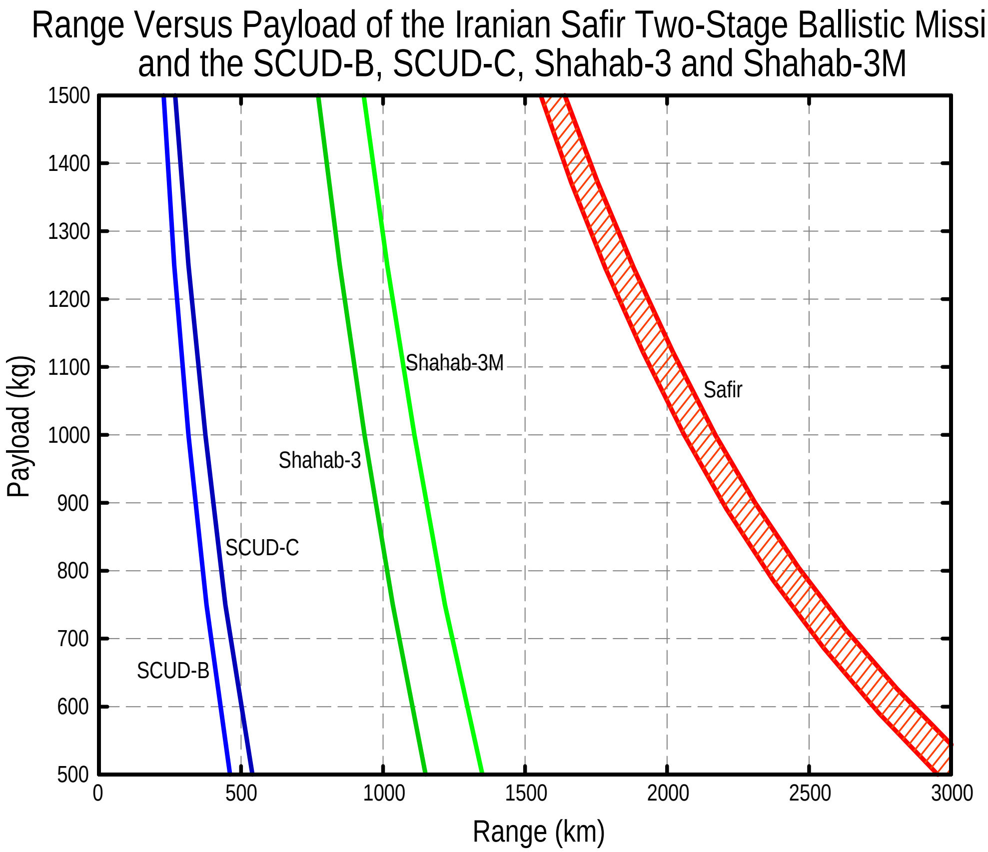


Figure 8

Insights about Iranian and North Korean Rocket Technologies and Ability to Innovate Gained from Satellite Launch Data

3.35 On August 31, 1998 North Korea attempted to launch a small satellite into low-earth orbit and in February of 2009 Iran successfully launched a 27 kg satellite into a low-earth orbit with an apogee of 380 km and the perigee of 245 km. These two satellite launch attempts contain a wealth of data and insights about the rocket technologies that are available to North Korea and Iran and the ability of the North Korean and Iranian missile programs to innovate with these technologies.

3.36 In the case of the North Korean satellite launch attempt the North Koreans used a three stage rocket. Data from the impact points of the first and second stages of the Taepodong 1 launcher, and statements issued by North Korea about the timing of events during the launch attempt are totally consistent. These data very strongly suggest that the first stage of the Taepodong 1 was derived from the Nodong missile. The second stage used the airframe from a SCUD-B and a variable thrust rocket motor salvaged from the SA-5 strategic long-range surface-to-air missile (SAM). The third stage solid-rocket motor was almost certainly from the SS-21 tactical ballistic missile. This indicates a very high level of innovation on the part of North Korean missile designers.

3.37 In the case of the Iranian satellite launch, the Iranians chose to use a two-stage missile. The first stage of their launch vehicle was implemented by substantially extending the length of a Shahab 3 ballistic missile (the Shahab 3 is the same missile as the North Korean Nodong). This resulted in a first stage that carried about 60% more propellant than the missile it was derived from. The second stage of the Iranian launch vehicle used the low-thrust directional control rocket motor salvaged from the SS-N-6 Russian submarine launched ballistic missile. This engine, which has a single turbopump that feeds two thrust chambers, generates a thrust of about 3 tons. The engines use a very energetic fuel, nitrogen tetra oxide and UDMH, which results in a very high exhaust velocity relative to that of the Nodong rocket motor – which is used in the first stage. In addition, it appears that the airframe of the upper rocket stage was constructed from high-strength light-weight aluminum alloys. Hence, by adapting new low thrust but very high efficiency rocket motors to a much lighter weight airframe, the Iranians were able to successfully launch a small satellite into a low earth orbit.

3.38 These distinctly different choices by both Iran and North Korea show a high degree of innovation with regard to the use of available rocket components. This suggests that future developments in Iranian and North Korean rocketry will likely be limited to the innovative use of available rocket components.

The Safir Satellite Launch

3.39 On February 2, 2009 Iran launched a satellite weighing 27 kilograms using the Safir Omid two-stage rocket. Iran describes the Safir as a space-launch vehicle. Photographs of the Safir upper rocket stage used to inject the satellite into orbit suggest that the Safir could not be used as a ballistic missile to carry nuclear warheads to significant ranges (see figure 9). The rocket motors used in this upper stage do not have enough thrust to efficiently offset the additional gravitational force that would act on the upper stage when it carries a heavy warhead payload (in this case, payloads of 500 to 1000 kg, rather than 27 kg). The inability of the upper stage's low-thrust rocket motors to offset gravitational forces and the very light construction of the stage, would likely limit the ability to accelerate the upper rocket stage and its heavier payload to the higher speeds needed to achieve significant range increases over a one-stage vehicle. However, as noted earlier in this chapter, Iran has demonstrated that it could develop a new or modified upper rocket stage based on SCUD rocket technology that would make it possible for the Safir to deliver a 1000 kg warhead to ranges of about 2000 km.

3.40 The first stage of the Safir launch vehicle is derived from the Shahab 3 airframe. The first stage fuel and oxidizer tanks are extended to increase the fuel load of the first stage by about 60 percent relative to that of the Shahab 3. Photographs released by Iran of the second stage propulsion section (see figure 9) shows what appears to be two vernier rocket engines and a turbopump exhaust nozzle that look like they have been salvaged from a dismantled Russian SS-N-6 submarine-launched ballistic missile.[11] These photographs suggest that the upper stage of the Safir uses a powerful and energetic fuel combination, N_2O_4 and UDMH (Nitogen Tetroxide and Unsymmetrical Dimethyl Hydrazine), which allows for rocket motors with high exhaust velocities relative to those based on SCUD technology. Information derived from Iran's successful launch of a satellite weighing 27 kg makes it possible to estimate possible performance characteristics of this upper stage.

Left Photo: Mock up of the Safir upper rocket stage on a gurney and (Right Photo) view of its propulsion section

Figure 9

Figures 10 and 11 below show photographs of the 27 kg Omid satellite. The satellite is cube-shaped and is 40 cm on a side.

3.41 Additional photographs published by the Iranian Space Agency show that the satellite was powered by three banks of 15 standard D-sized batteries. It also had an onboard computer module, separate UHF transmitter and receiver modules, and other circuitry, all of which appear to have been constructed from electronic components manufactured by Western companies. For example, two Dallas Semiconductor Corporation 64 kb static random access memory chips (SRAM) and microwave signal splitting devices from the Mini-Circuits company can be readily identified from the photographs (see figure 11). This satellite is therefore derived from commonly available commercial electronic components, none of which could possibly be manufactured by Iran. A very rough estimate of the weights of these different components leads to the conclusion that the satellite might well weigh the 27 kg reported by Iran.

[11] Attached Schmucker and Schiller briefing, Slide 50.

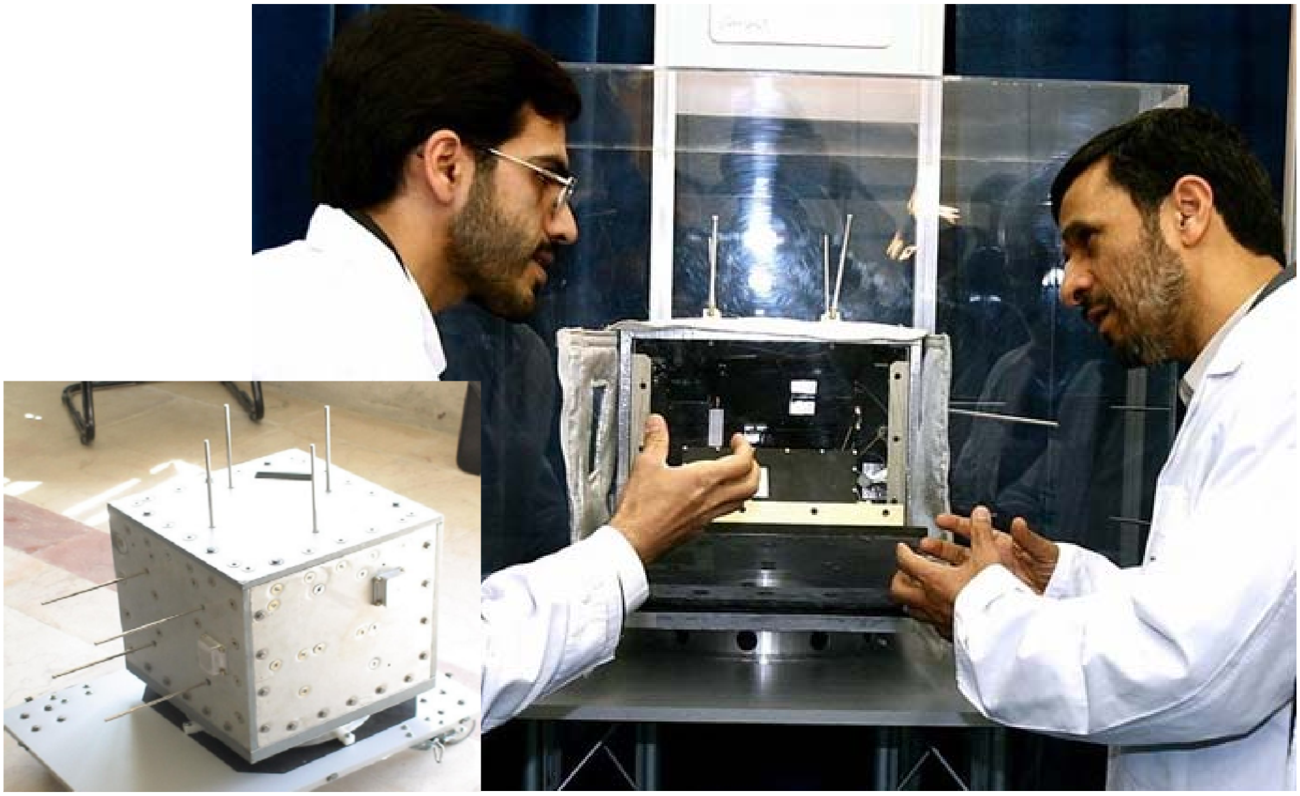


Figure 10

One of three battery assemblies used in the Omid satellite. These power packs are fabricated with standard D-sized batteries. Each pack should weigh about 3kg.

Analog to Digital Converter System

Section of the On-Board Computer (OBC) used in the Omid satellite shows widely available integrated circuits produced by companies based in the United States.

Figure 11

3.42 Figure 12 shows the location of the satellite launch and its first two orbits, which spans a time-period of roughly 3 hours. The tick marks on the trajectory show the location of the satellite at five minute intervals.

3.43 The trajectory shown in figure 12 was derived from "two line elements" that were published by NORAD after there were enough sightings of the satellite and the trailing upper rocket stage to make it possible for the orbit to be characterized. The satellite orbit that was achieved had an apogee of about 380 km and a perigee of about 245 km.

Figure 12

3.44 The information that makes it possible to estimate the performance characteristics of the upper rocket stage are as follows:

3.45 We have reasonable estimates of the performance characteristics of the first rocket stage, which is basically derived from the technologies used to build the Nodong missile and its variants (like, for example, the Shahab-3M). The first stage carries a heavy payload during its powered flight (the fully fueled second stage and the satellite) and burns out at a relatively low altitude and velocity (about 2.1 km/s at an altitude of 68 km). As a result, the exact performance characteristics of the first stage do not strongly affect the overall ability of the two-stage rocket to place the satellite into orbit (the required orbital speed for the satellite is roughly 7.7 km/s). If the rocket can place the satellite into orbit, almost all of the velocity needed to achieve this result must come from the second stage. Hence, the information about the orbital characteristics of the Omid satellite makes it possible to estimate the total velocity capability of the second stage. This then makes it possible to estimate the performance characteristics of the upper rocket stage. These estimates can then be used to determine the possible range and payload of this rocket, or its variants, if it is employed as a ballistic missile.

Estimated Performance Characteristics of the Safir Missile Rocket Stages

Stage	Full Weight (kg)	Empty Weight (kg)	Burnout Weight (kg)	Structure Factor	% Residual Fuel	Specific Impulse (sec)	Burn Time (sec)
Stage 1 (SCUD Technology)	22,300	2230	3032	0.10	0.04	220 (SL) 247 (Vac)	137
Stage -2 (SS-N-6 Technology)	3100	279	465	0.09	0.03	300	274

Table 2

3.46 At this time, there is still considerable uncertainty about the configuration of the second stage of the Safir and the actual engineering components that were used in it. In 2005[12] Iran reportedly bought 18 disassembled SS-N-6 (R-27) Soviet submarine launched ballistic missiles from North Korea. The R-27 utilizes Soviet rocket technologies that were first developed in the 1960s.[13] The propulsion system of the R-27 uses a single rocket motor that generates a thrust of 23 tons and two steering rocket thrust chambers that together generate 3 tons of thrust. The powered flight-time of the R-27 is about 120 seconds. The two steering rocket thrust chambers are fed by a single turbopump and the fuel used by the R-27s rocket motors is Nitrogen Tetroxide and Unsymmetrical Dimethylhydrazine (N_2O_4 and UDMH). This propellant is much more powerful than that used by missiles based on SCUD technology. The R-27 airframe is also constructed from high-strength Aluminum alloys, which have a density almost one third that of steel.

3.47 The photographs (see figure 9) of the propulsion section of the Safir upper stage suggest that the propulsion system is derived from the two thrust chambers and turbopump used for steering the R-27 missile. These thrust chambers do not deliver enough thrust to lift the more than three ton fully fueled upper rocket stage, but the thrust is enough to take advantage of the upward and downrange velocity imparted to the upper stage by the first stage. Many of the detailed characteristics of the upper stage are also uncertain. For example, an analysis of the amount of

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12 "Iran acquires ballistic missiles from DPRK," Alon Ben-David, Jane's Defense Weekly, December 29, 2005.
13 An authoritative though brief discussion of the technology used in the R-27 missile can be found in "Russian Strategic Nuclear Forces," edited by Pavel Podvig, The MIT Press, 2001.

propellant that could potentially be carried within the volume that appears to be used for fuel tanks suggests that the upper stage could weigh more than 4000 kg. However, detailed analyses of the performance of such a 4000 or more kilograms second stage indicates that there is no performance advantage to be gained with such a heavy stage. This is because the thrust of the rocket motors is not large enough to offset the gravitational forces that would also be acting on the vehicle. Our analysis of the launch dynamics suggests that a stage weighing about 3100 kg is consistent with what is known about the launch trajectory and achieved orbit of the satellite and upper stage. The assumption that the upper stage carries about 2800 kg of propellant and has a thrust of 3 tons is consistent with assuming that the fuel and oxidizer are in separate tanks, each of which has two end-caps. An alternative fuel-tank configuration would be a single tank with a common wall separating the fuel and oxidizer, but this tank-configuration would carry 15 percent more propellant, leading to a stage that is too heavy relative for the low-thrust generated by the stage's rocket motors. Since the upper stage rocket motor should consume roughly 10 tons per second, these considerations lead to an estimated burn time of about 274 seconds. Of course, if radar tracking data from intelligence sources were made available to the public, the uncertainties associated with our estimates could be considerably reduced.

3.48 Assuming the photographs of the Safir upper stage are not misleading, the motor would have to operate for about 274 seconds, roughly two and a half times longer than the time it is supposed to operate when used as part of the R-27. Calculations also indicate that if the Safir upper stage is capable of launching a satellite, it must have a very low empty-weight. Such a low empty-weight would almost certainly require that the stage's airframe be constructed from light-weight high-strength aluminum alloy rather than from heavy steel. The R-27 is constructed using these same materials. Such a light aluminum airframe would likely only be able to support a very light-weight payload. In addition, if payloads of hundreds of kilograms or more could be mounted on this upper stage, the low-thrust of the rocket motors could not initially offset the pull of the Earth's gravity on the vehicle, and it would continuously lose vertical velocity during the early part of its powered flight. These observations lead to the conclusion that the current Safir upper rocket stage is not readily adaptable to carrying a warhead of a thousand, or even hundreds of kilograms. Thus, if our observations about the Safir upper stage are correct, the upper rocket stage used to launch the Omid satellite is only useful for launching a very light satellite into a low-earth orbit. Any further advances towards launching heavier satellites to low-earth orbits, or lighter satellites to higher orbits, will require an entirely new rocket with first and second stages that are considerably larger than those used by the Safir.

3.49 Figure 11 shows the estimated launch trajectory of the Omid satellite by the Safir rocket for an upper stage that weighs 3100 kg and with rocket motors that produce 3 tons of thrust over 274 seconds. The launch trajectory predicts that the first stage burns out at a loft angle of 47 degrees, a speed of over 2.1 km/s, and an altitude of 68 km. Thus, the first stage "throws" the second stage upward and downrange relative to the direction of the earth's gravitational pull. The second stage rocket motors are then reoriented within the first 25 seconds of second-stage powered flight to fire at 10 degrees relative to local horizontal, and remain at 10 degrees, until rocket motor shutdown roughly 250 seconds later. This simple flight profile achieves the altitude and speed for injection into an orbit at about 240 km altitude.

3.50 As we will see, the North Koreans used a three stage rocket in their attempt to launch a satellite. In order to solve the problem of maintaining the orientation of the second stage during the long transit time to orbital injection, the North Koreans used a variable thrust rocket motor salvaged from the SA-5. Thus, in the case of the Iranian satellite launch directional control motors from the SS-N-6 missile were adapted for use in the second stage, and in the case of the North Korean satellite launch, the variable thrust rocket motor from the SA-5 strategic long-range surface to air missile was used instead. This second stage rocket motor is far less efficient (it has a much lower exhaust velocity) then the rocket motor from the SS-N-6, so the North Koreans used a third stage rocket motor derived from the SS-21 tactical ballistic missile for orbital injection.

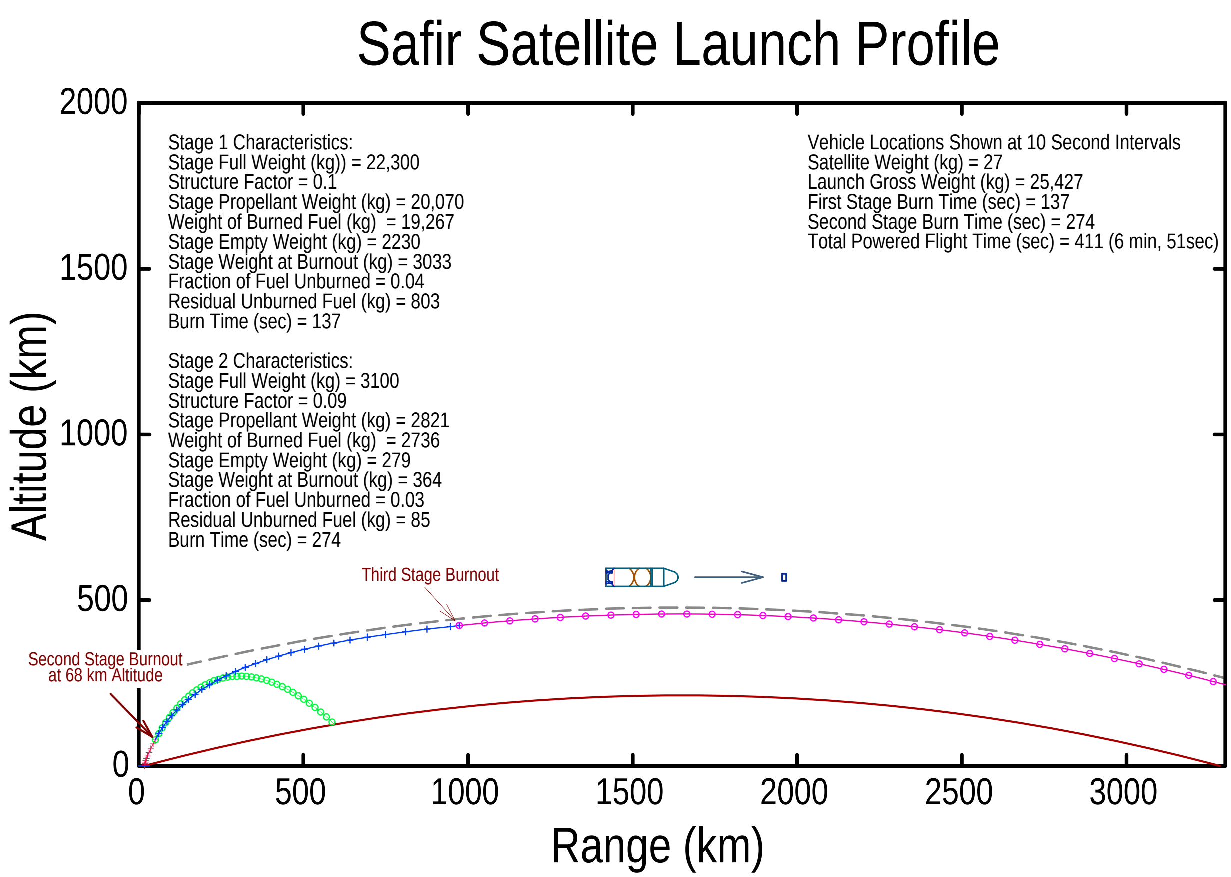


Figure 11

The Safir as a Ballistic Missile

3.51 We emphasize that the current upper rocket stage of the Safir is not suitable for carrying a nuclear warhead of roughly 1000 kg weight, as its structure may not have the strength to support such a heavy payload during accelerated flight and the thrust of the upper stage motors would be too-low to offset the pull of gravity until very late in its powered flight.

3.52 However, Iran has demonstrated a command of SCUD rocket motor technology and could eventually build a second stage based on that technology.

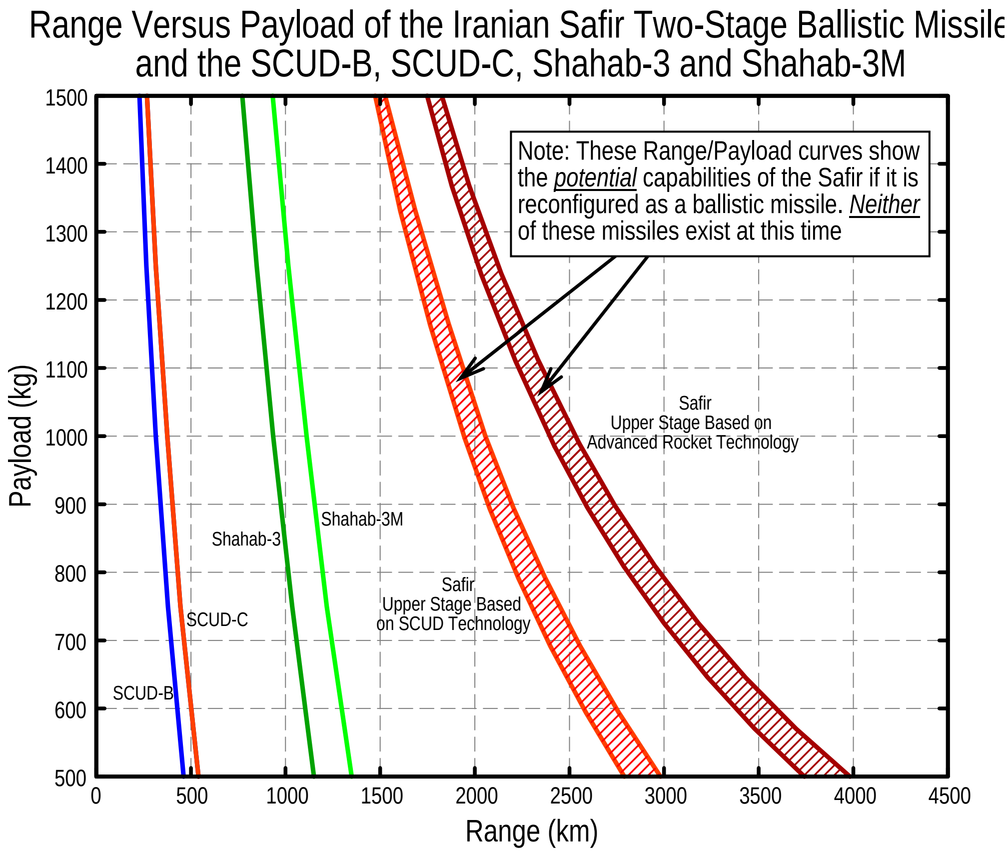


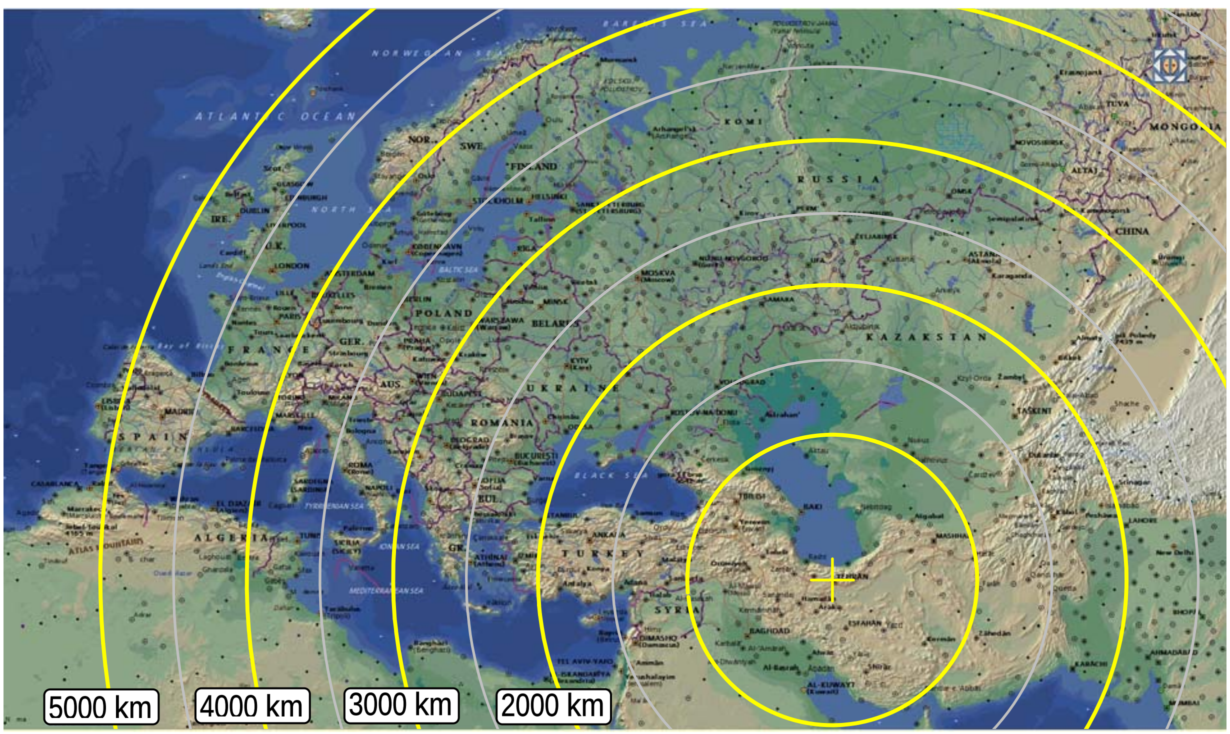
Figure 12

3.53 In order to establish the baseline performance of a Safir that uses purely SCUD ballistic missile technologies, we assume that the upper rocket stage motors perform in vacuum with about the same efficiency of the SCUD-B rocket motor, and that the upper rocket stage has a structural factor of about 0.14 and a residual fuel ratio roughly the same as that of the SCUD-B (about 0.05). These assumptions are reasonable since they account for the extra residual propellant and weight associated with a large thrust rocket motor and the strengthening of the upper stage airframe to carry a heavy payload while under acceleration. Based on these assumptions, we estimate that the Safir could carry a 1,000 kg payload to about 2,000 km, a 750 kg payload to about 2,500 km, and a 500 kg payload to perhaps 2,900 km (see figure 12). Since an Iranian first-generation advanced implosion type nuclear weapon would likely result in a ballistic missile warhead that weighs more than 1,000 kg, the working range of the SCUD-based Safir would be about 2,000 km or less.

3.54 An alternative upper rocket stage design might try to use multiple vernier rocket motors or even the main engine from the R-27 missile. If we assume that the main rocket motor from the R-27 is used in the upper stage, the structural weight and residual propellant numbers for that stage would be similar to those associated with the SCUD technology upper stage just discussed.

3.55 In both these cases, the acceleration of the upper rocket stage with a 1000 kg payload could easily be 10 to 12 G's, requiring an airframe that can carry these loads without breaking up.

3.56 Thus, if the Safir is eventually modified for use as a ballistic missile it would be able to carry a nominal 1000 kg warhead to between 2000 and 2500 km depending on whether Iran proceeded by building an upper rocket stage based on either SCUD or R-27 rocket technologies.



The North Korean Taepodong 1 Satellite Launch Attempt

3.57 As already noted, the North Korean and Iranian liquid propellant ballistic missile programs are tied together with North Korea supplying missile components and technical support to Iran, and Iran providing financial support, and possibly technical information, to North Korea. Both of these programs show considerable innovation in the use of rocket components salvaged from missiles that were built for varied purposes. Iran appears to have launched a satellite by constructing an upper stage with rocket components salvaged from the Soviet R-27 submarine launched ballistic missile. North Korea also attempted to launch a small satellite in 1998 using the Taepodong 1, a vehicle that is in the same class, in terms of potential range and payload capabilities. However, the technical choices made by North Korea to implement a small-satellite launch capability with the Taepodong 1 are distinctly different from those made by Iran in the Safir launch vehicle. These different choices can potentially provide important insight into ways that both North Korea and Iran might in the future exploit existing rocket components in their ballistic missile development programs.

3.58 Figure 13 shows speculations about the characteristics of some of the missile components that might have been used in the Taepodong 1. We do not claim that these speculations are exact. But we do believe that they are consistent with publicly available information and that they illustrate how North Korea and Iran have fabricated ballistic missiles by using rocket components designed for other systems.

3.59 The first stage of the Taepodong 1 is derived from a slightly stretched Nodong, and the second stage airframe appears to be derived from the SCUD-B airframe. We have no way of knowing for sure from publicly available information whether the rocket motor in the second stage is actually the SCUD-B motor, nor do we have any way of knowing the exact size and propulsion characteristics of the small third stage, which was supposed to inject a satellite payload into orbit. However, we can show that it is almost certain that the rocket motor used in the second stage is derived from the SA-5 strategic surface to air missile and that the third stage rocket motor could well be the solid-propellant booster motor from the SS-21, a short-range tactical ballistic missile.

3.60 If the second stage of the launch vehicle uses the SCUD-B rocket motor, the second stage would burn at roughly constant thrust for about 60 to 80 seconds. The payload would then have to coast to apogee for another 60 to 90 seconds before the solid rocket motor could inject the payload into orbit.

3.61 During the time the upper stage is coasting, it would likely tumble due to unintended lateral forces imparted to the vehicle during the last seconds of powered flight. The tumbling of the second stage would have serious and catastrophic consequences for the launch attempt as the third stage rocket motor would then not be properly oriented for it to inject itself into orbit.

3.62 Robert Schmucker[14] has suggested that the rocket motor used for the Taepodong second stage is not from the SCUD-B, but may instead be from the Soviet SA-5 long-range ballistic missile. This speculation is almost certainly correct, as it perfectly fits with essentially all of the publicly available data on the Taepodong 1 launch.

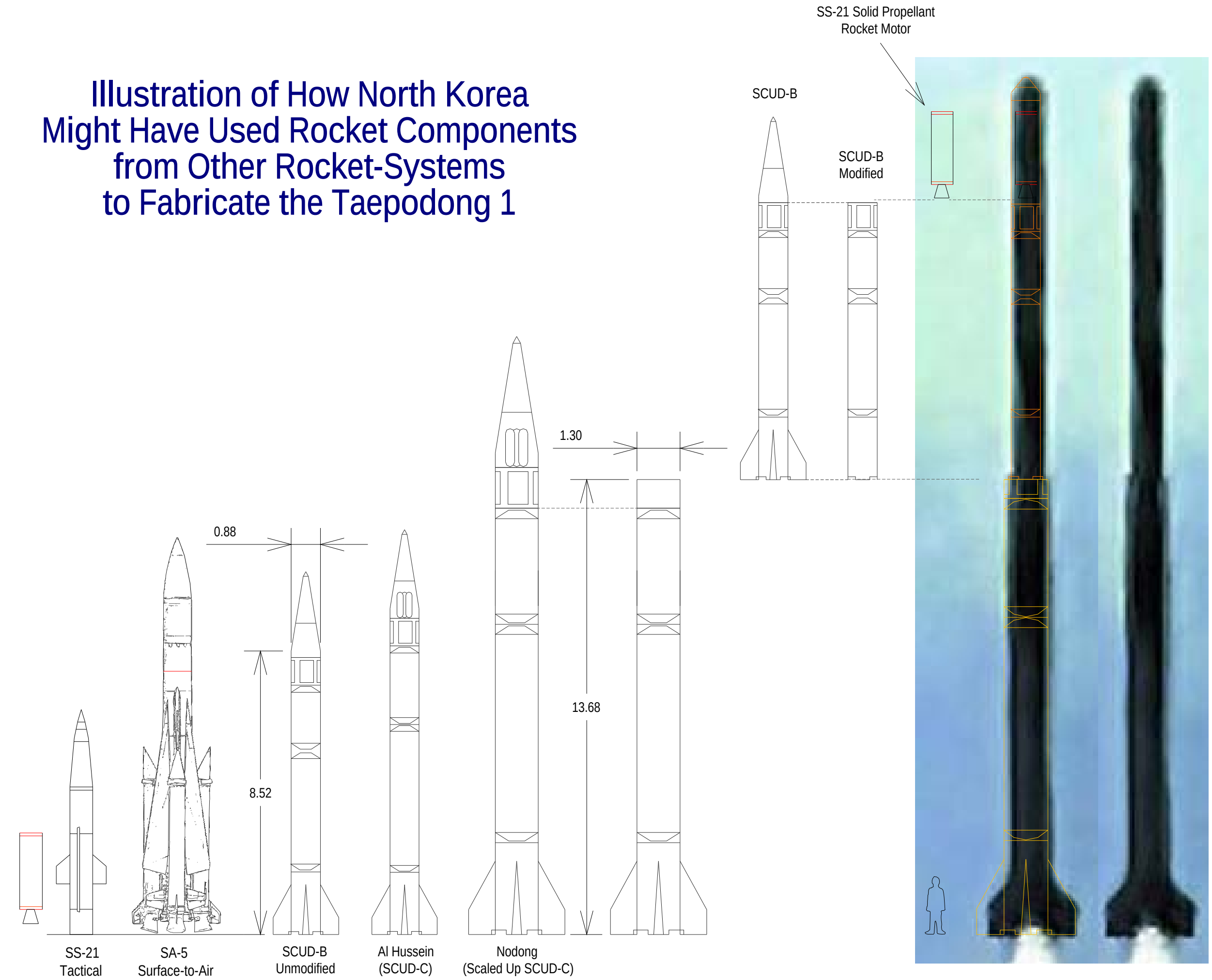


Figure 13

3.63 Figure 14 shows a rough side by side comparison of the Iranian Safir and North Korean Taepodong 1 small-satellite launch vehicles. The first stages of both the Iranian Safir and the North Korean Taepodong missiles are derived from the Nodong ballistic missile. The fuel tanks of the Iranian Safir first stage have been stretched to carry roughly 20,000 kg of propellant, while the first stage of the Taepodong 1 carries about 16,000 to 17,000 kg of propellant. Since the

[14] 3rd World Missile Development - A New Assessment Based on UNSCOM Field Experience and Data Evaluation, Robert H. Schmucker, 12th Multinational Conference on Theater Missile Defense: Responding to an Escalating Threat, June 1-4, 1999, Edinburgh, Scotland.

Taepodong 1 design uses a lighter first stage, it can lift the heavier total weight of a second and third stage relative to that of the Safir.

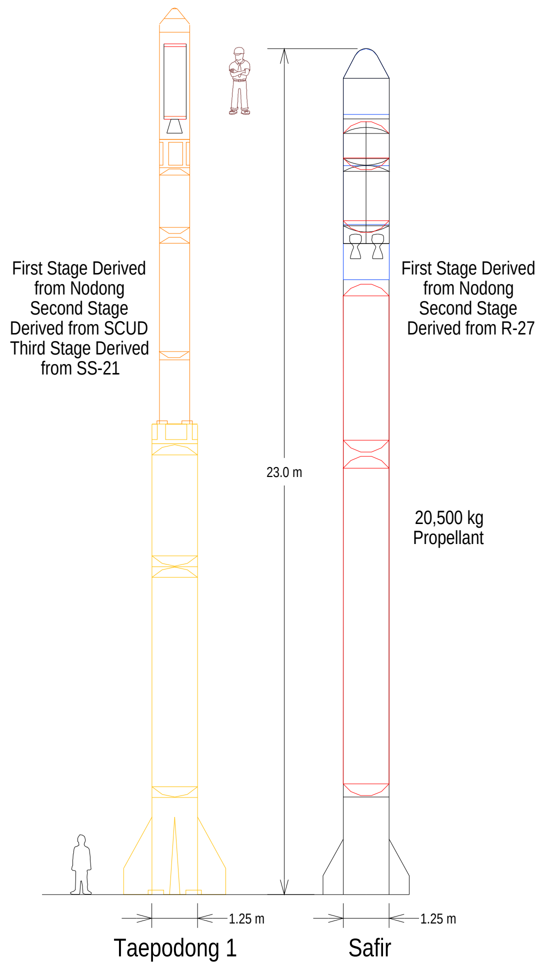


Figure 14

3.64 If the second stage uses the liquid rocket motor from the Soviet SA-5 (known in Russia as the S-200) surface-to-air missile, the propellant in that stage would have to be TG-02, a propellant mixture of 50% xylidine and 50% triethylamine, and the oxidizer AK-27P, which is only very slightly different from that used in the SCUD-B. The volume ratio of propellant to oxidizer used in the SCUD-B (TG-185 and AK27) is essentially the same as the volume ratio of propellant to oxidizer used by the SA-5 engine (TG-02 and AK27P). The diameter of the exhaust nozzle of the SA-5 motor is also the same as that of the SCUD-B motor and the overall lengths of both motors are nearly the same. An extremely important difference between the SCUD-B and SA-5 motors is that the SCUD-B motor operates at a single thrust of 13,390 kg F, while the thrust of the SA-2 engine can be operated at a maximum thrust of 10,000 kg F and a minimum thrust of 3200 kg F. This makes it possible to run the engine at different thrust levels throughout the powered flight of the second stage so the orientation of the third stage can be controlled until the third stage ignites to inject the satellite into orbit.

3.65 Figure 15 shows an estimation of a launch profile that is compatible with publicly available information on the Taepodong 1 launch. Figure 16 shows a diagram published by the Japanese Self-Defense Forces that shows where the first and second stages of the Taepodong 1 fell. Referring to figure 15, the first stage propels the vehicle at a high loft angle until it burns out about 95 seconds after launch. The second stage fires at high thrust (10,000 kg F) for about 55 seconds and then fires at low thrust for about 120 seconds until it reaches an apogee of over 200 km, where the third stage motor was to be ignited. For unknown reasons, the third stage failed, but the vehicle appears to have worked properly until this time. At about 40 seconds after the third stage was supposed to ignite (320 seconds after launch), the first stage impacts at about 185 km from the launch site. About 280 to

300 seconds later, the second stage falls at a range of about 1100 km from the launch site, off the east coast of Japan.

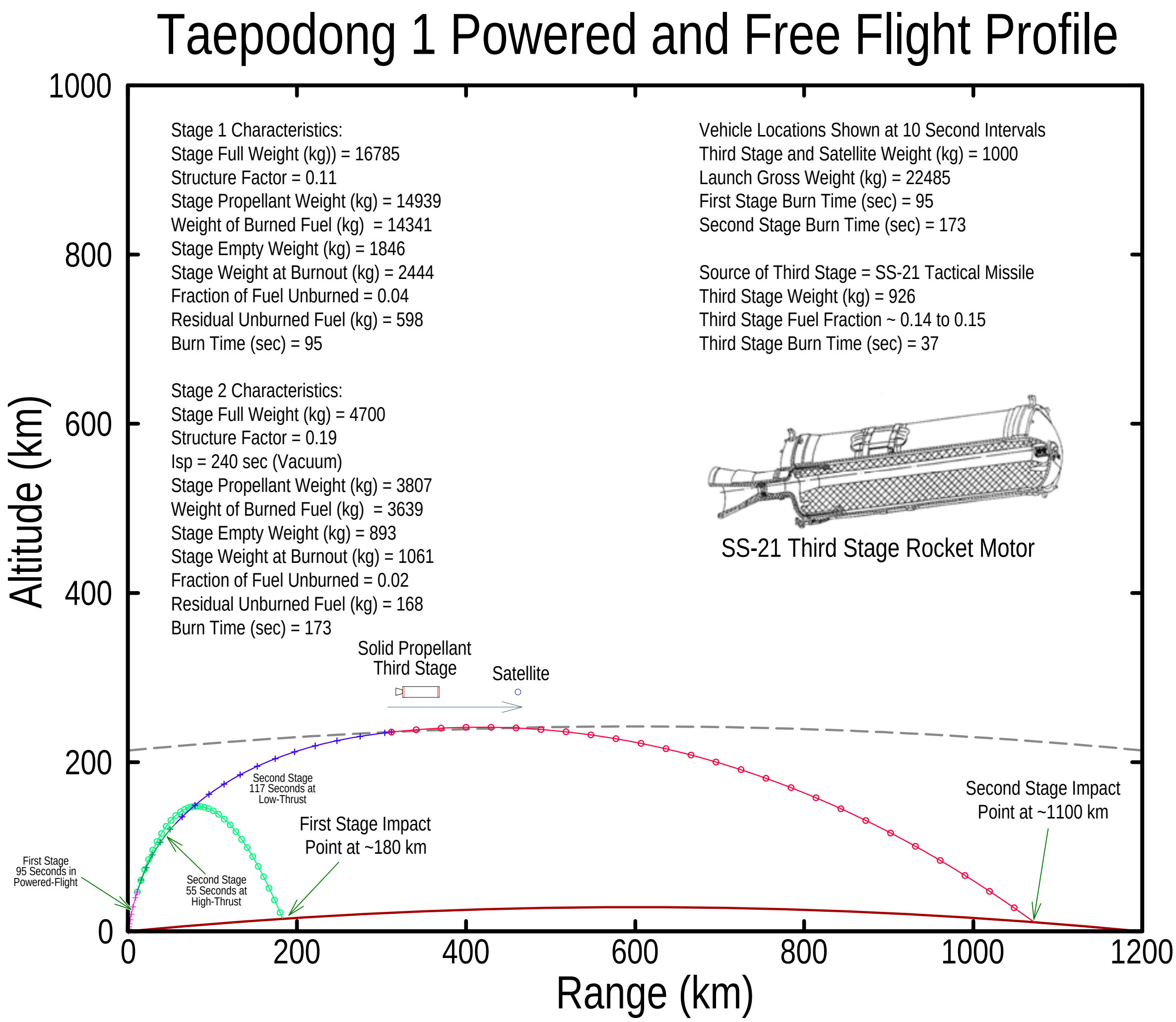


Figure 15

3.66 Tables 3 and 4 show the extraordinary consistency in all the observed and publicly issued data about the launch. The burn times, injection altitudes, impact distances of the first and second stage, and characteristics of the rocket motors assumed for each of the stages are all perfectly consistent. The sources used for this information include Russian technical discussions of the characteristics of the motors used in all three stages, information from Japan about the impact points of the first and second stage, and information about the the injection altitude, and burn times of the all three rocket stages. The consistency of all this data almost certainly indicates that the second stage did in fact use the SA-5 rocket motor. The true identity of the third stage rocket motor was not demonstrated in-flight, but its weight, and the 27 second burn time reported by North Korea, very strongly suggest that the third stage is an SS-21 rocket motor.

Diagram 6-6 Status of the Flight Trajectory of the North Korean Missile and the Area of Its Descent

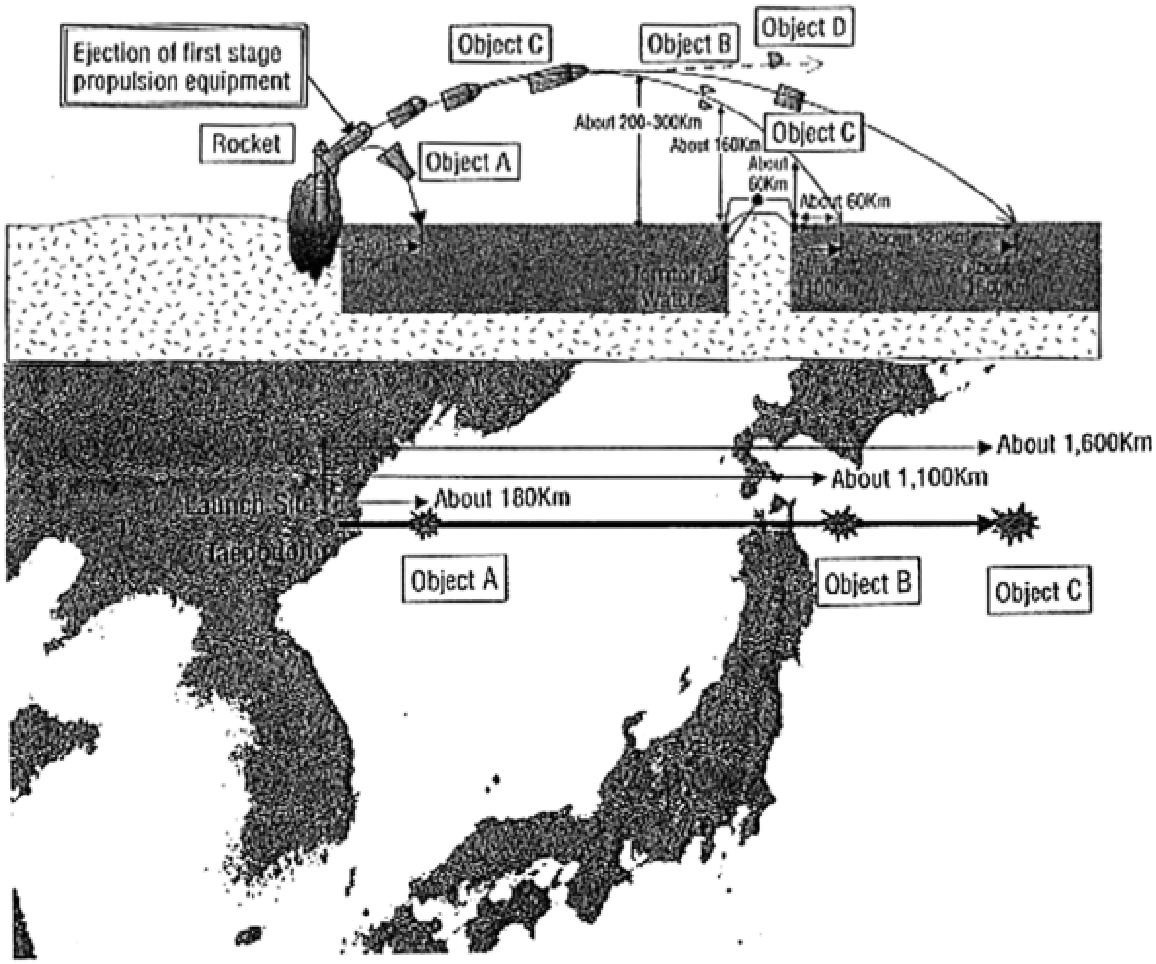


Diagram released by Japanese Self-Defense Forces

Figure 16

3.67 Shortly after the North Korean Taepodong 1 launch, North Korea claimed that the satellite had been successfully launched into an orbital with a perigee of 218 km and an apogee of 6,978 km. To achieve such an orbit, the satellite would have had to be injected at about 8.9 km/sec. The solid rocket motor would have had a vacuum specific impulse of 265 seconds, and a fuel fraction of 0.10. The satellite would have weighed about 4 to 5 kg. These rocket motor characteristics appear somewhat optimistic relative to those associated with the SS-21 rocket motor.

3.68 Thus, it appears that both the North Korean and Iranian missile programs designed different launch vehicles from salvaged components from different missiles. In all, rocket components may have been used from the Nodong, R-27, SA-5, and SS-21 ballistic missiles. The first missile is likely from an early mid-1950's rocket that was developed as a tactical ballistic missile, the second from an early generation submarine launched ballistic missile, the third from an early strategic surface-to-air missile, and the last from a short range solid rocket ground-to-ground tactical missile.

3.69 At this time, none of these components appear to have been manufactured by Iran or North Korea. However, both North Korea and Iran have demonstrated that they can innovatively use relatively primitive rocket technologies. These observations are likely to have implications for future developments in rocketry by these countries.

Numbers Assumed in and Derived from Calculations

First Stage Burn Time (seconds)	95
Second Stage Burn (seconds)	173.6
Time Second Stage Works at High Thrust (seconds)	55
Time Second Stage Works at Low-Thrust (seconds)	118.6
Total First and Second Stage Powered Flight Time (seconds)	267.6
Injection Altitude (kilometers)	214
Impact Range of First Stage (kilometers)	185
Impact Range of Second Stage (kilometers)	1076

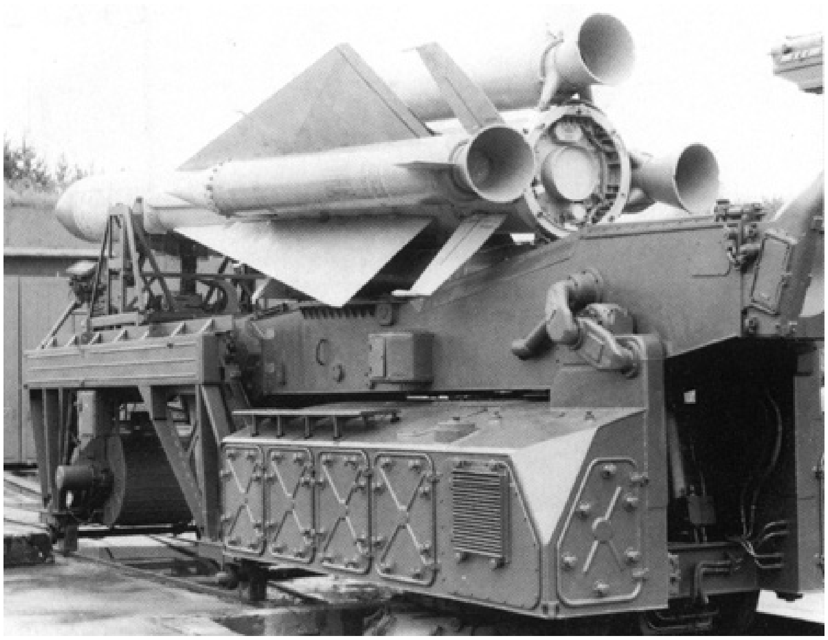
Table 3

Numbers Reported by the North Korean Government

First Stage Burn Time (seconds)	95
Second Stage Burn (seconds)	171
Third Stage Burn (seconds)	27
Total First and Second Stage Powered Flight Time (seconds)	266
Injection Altitude (kilometers)	218

Table 4

SA-5 Rocket Motor Characteristics

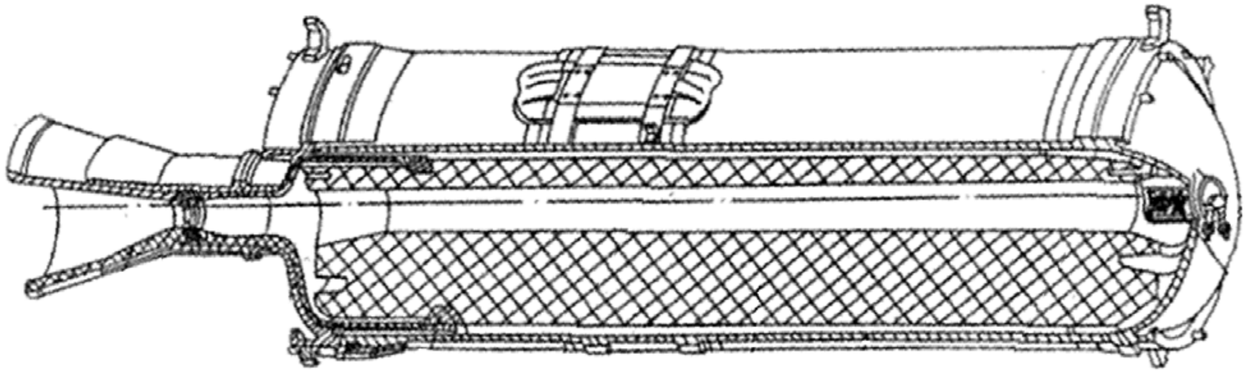


Comparison of
SCUD-B and SA-5 Rocket Motors

SA-5 Variable Thrust Rocket Motor

Fuel: TG-02 and Nitric Acid
TG-02 Samin (50% xylidine and 50% triethylamine
Volume Ratio of Oxidizer to Propellant: 2:1
(Same as TM-185 and Nitric Acid)
Engine Weight = 119 kg
High-Thrust Mode: 10,000±300 kgf
Low-Thrust Mode: 3200±180 kgf
Time Interval in High Thrust:
Variable Between 0.2 and 50.8 seconds
Probable Vacuum Specific Impulse ~ 240 to 250 sec

SS-21 Rocket Motor Characteristics



Weight of Rocket Motor and Armor Coating (kg)	926
Weight of Armor Coating (kg)	17
Nominal Thrust kgF	9788
Specific Thrust (m/s)	236
Mean Chamber Pressure (kgf/cm^2)	69
Engine Operating Time (s)	18.4-28
Propellant: Ammonium Perchlorate and Aluminum	

Technical Assessment of the Unha-2 Satellite Launch Attempt of April 4/5, 2009

3.70 The North Korean launch on April 4/5, 2009 of a large three stage rocket, weighing about 90 tons, has provided a flood of data on both North Korean and Iranian ballistic missile programs. This data includes detailed photographs of the North Korean rocket, information on the splashdown points for the first and second stages of the rocket, satellite images of the rocket contrail that indicates the early trajectory of the rocket, verification of a wealth of earlier information derived from other analyses on the use of rocket components by Iran from its launch of the Omid satellite on February 2, 2009, and information that further supports analytical findings associated with North Korea's attempt to launch a satellite using the Taepodong 1 rocket in 1998. All the information described above is completely self-consistent and can be explained and reproduced in an internally consistent technical analysis of all these events. This powerful self consistency in the data and analysis very strongly suggests that the estimates provided in this preliminary analysis are likely to be reliable.

3.71 We find that the North Korean Unha-2 represents a very significant advance in rocket technology by North Korea. The first two stages of this vehicle functioned in the flight test. The third stage, which apparently failed to operate in the North Korean flight tests, has most probably already successfully been flown as the second stage of Iran's Safir SLV. The successful operation of the first stage indicates that North Korea has the enabling technology to build rockets that can deliver much higher payloads to much longer ranges. The successful functioning of the second stage demonstrates that North Korea has found a way to obtain a high-performance second stage by adapting an available rocket, the SS-N-6 Submarine Launched Ballistic Missile, for the second stage of the Unha-2 By using the SS-N-6 as the second stage of the Unha-2, North Korea has, in effect, obtained a second rocket stage that has an airframe that is constructed from light high-strength aluminum alloy combined with high performance rocket motors.

3.72 Figure 17 shows a video frame extracted from a television video of the Unha-2 launch attempt. Figure 18 shows a blowup of the Unha-2 with a carefully drawn overlay showing the detailed geometric features of the vehicle. In order to facilitate an inspection of the accuracy of the outline by the reader, the right side of figure 18 is the photograph of the Unha-2 with the overlay and the left side of the figure is the photograph. Figure 19 shows detailed drawings, based on the Unha-2 shape-outline derived from the photograph and guesses about the various components associated with the Unha-2 vehicle.

3.73 The first stage is assessed to carry about 68,000 to 69,000 kg of propellant and to have a total weight of about 74,000 to 75,000 kg. The estimate of the weight of propellant is based on the assumption that the fuel tanks have end-caps that have the same ratio of height to width as those used in the SCUD-B ballistic missile. The fuel used by the first stage is assumed to be TG-185 and AK-27. This fuel combination is used in the SCUD-B, SCUD-C, SCUD-D, and the Nodong missile. The first stage is assumed to use a cluster of four Nodong rocket motors each of which generate about 30 tons of thrust. Estimates from the video of the Unha-2 launch indicate an acceleration rate at launch of roughly 0.3 Gs. The rocket motors therefore have a thrust of roughly 1.3 times the launch gross weight of the vehicle. If the launch gross weight of the vehicle is about 90 tons, then the thrust of the rocket motors in the first stage is roughly 120 tons.

3.74 Also shown in figure 19 are drawings and images of the SS-N-6 (Russian R-27) submarine launched ballistic missile. This missile has a full-length of 9.65 m with the original attached warhead and 7.1 m with the warhead removed. Its diameter is 1.5 m. When the silhouette of the SS-N-6 is placed over the second stage of the Unha-2 there is perfect geometric agreement. The upper frustum on the SS-N-6 has exactly the same dimensions and taper angle as that of the interstage between the second and third stages on the Unha-2. The rear end of the SS-N-6 extends slightly into the interstage between the first and second stages.

3.75 Figure 20 shows a blowup of the cutaway image of the SS-N-6 shown earlier in figure 19. The cutaway reveals many novel engineering features of this missile. The main rocket motor, including its turbopumps, is immersed within the fuel tank of the missile. This novel design was chosen so the missile could carry the maximum amount of propellant and still fit within the restricted volume of a submarine launch-tube. Similar design features can be found in US submarine launched ballistic missiles – although US submarine launched ballistic missiles use solid propellant rocket motors rather than liquid.

3.76 Figure 21 is a blowup of the propulsion section of the SS-N-6. The image shows the position of one of the two vernier motors. These motors are about 0.72 m apart. Also shown is the pre-burner that generates gas to drive the main-engine turbopump, the fuel inlet oxidizer line that runs to the oxidizer tank above the fuel tank, the fuel intake line that siphons fuel from the bottom of the fuel tank, the main engine thrust chamber, and the frustum shaped wall of the lower fuel tank.

3.77 Figure 22 shows a video frame from a video very recently released by Iran. The video frame shows the rear propulsion section of the Safir upper rocket stage. The two vernier motors are partially immersed in the frustum shaped wall of the Safir fuel tank. The motors are also partially immersed in the fuel tank as is the case with the SS-N-6. The motors are separated by 0.72 m (this has been determined by analysis of other photos released by Iran of the propulsion section), essentially the same separation distance of the vernier's in the SS-N-6. The opening at the center of the end-cap of the frustum shaped fuel tank wall shows the exhaust manifold of the turbopump from the SS-N-6 that is used to drive the vernier rocket motors. Figure 23 shows the placement of the vernier turbopump within the fuel tank and what appears to be a partially completed frustum-shaped wall for the fuel tank. The turbopump for the two vernier rocket motors is in the center of the open-ended cylinder that is attached to the bottom of the wall. Figure 24 simply repeats the earlier photograph from Figure 22 of the back end of the propulsion section so the reader can readily see the wall and associated motor components from both sides. It is therefore appears that the propulsion section of the Safir second stage is derived from a competent and innovative adaptation of components from the SS-N-6 submarine launched ballistic missile. Figures 25 and 26 show photographs of the front end of the stage with and without the payload shroud, and figure 27 shows the unfolded payload shroud itself. Figure 28 shows a photograph of an early mockup of the propulsion section of the upper stage (on the right) and a Nodong rocket motor (on the left). The dramatic differences between the propulsion capabilities of the first and third stages can be appreciated by noting that the first stage uses a cluster of four Nodong rocket motors while the third stage uses two small vernier motors, only one of which is mounted on the displayed mockup of the third stage propulsion section.

3.78 Figure 29 shows the estimated actual and intended parts of the trajectory associated with the Unha-2 satellite launch attempt. Figure 30 shows a satellite photograph of the contrail from the first stage rocket motor assembly during the first 50 to 60 seconds of flight[15] and figure 31 shows range-safety impact zones for the first and second stage as declared by the North Korean government. Since the launch direction is known to be close to due East, it indicates that the initial flight path at this time during powered flight of the first stage had a loft angle close to a 50 to 60 degrees. Our trajectory calculations suggest that the burnout altitude of the first stage was roughly around 50 km and had a loft angle of about 40 degrees. This results in the first stage impacting at more than 500 km downrange, within the safety keep out zone declared by the North Koreans.

3.79 The second stage burns for about 122 seconds until it reaches an altitude of about 230 km with a loft angle of about 24degrees. For the assumptions used in this calculation, this results in the second stage falling at about 3200 km from the launch site and within the second stage safety keep out zone declared by the North Koreans.

3.80 If the third stage had properly ignited, its vernier rocket motors would consume about 10 kg per second for roughly 275 seconds (in our calculations we assume 274 seconds). This would then result in a satellite injection altitude at about 490 km, which is the altitude declared by the North Koreans. The North Koreans also declared that the powered flight time of the Unha-2 was nine minutes and 2 seconds (543 seconds). Our model, without adjustments, predicts a flight time of 533 seconds. Very minor adjustments in our assumptions could be made to get exactly the powered flight time declared by North Korea, but these differences in powered flight time have no implications for our performance estimate.

[15] Special thanks to Dr. Geoffrey Forden, a colleague in our research group at MIT who pointed out the importance of this photograph.

3.81 Applying our performance estimate to the questions of how the Unha-2 could perform as an IRBM or an ICBM leads to the following conclusions:

1. If all three stages of the current Unha-2 function as intended, the Unha-2 could deliver somewhat less than 1000 kg to 10,000 km range. This relatively limited lift capability is largely due to the low-thrust of the vernier rocket motors from the SS-N-6 used in the current third stage. It appears that the upper stage of the Unha-2 could be the same stage as that used in the Safir SLV. If this is the case, the upper stage is almost certainly a vehicle derived from the SS-N-6.
2. If the Unha-2 is used only with its first and second stages, both of which successfully flew in the satellite launch attempt, it could deliver 1000 to 2000 kg to 5000 to 6000 km range.

3.82 We believe these conclusions are robust with regard to the uncertainties in our estimation procedures.

3.83 These numbers indicate that the Unha-2 is on the verge of providing an intercontinental ballistic delivery capability if the third stage is upgraded by using rocket engine components that can generate the higher thrust needed to place heavier payloads onto ballistic trajectories. It also indicates that if a two-stage variant of the Unha-2 were made available to Iran, Iran would have the ability to deliver payloads of roughly 2000 kg to all parts of western and northern Europe.

3.84 An extremely important caveat associated with this emerging capability is that the assembly and fueling of this missile takes many days and possibly even weeks. The two-and three stage variants of the vehicle are very large and heavy, weighing roughly 90 tons. If either Iran or North Korea were foolish enough to threaten either the United States or Europe with such a vehicle, they would be inviting a preemptive attack of the vehicle on its launch pad. This fact, of course, does not negate any psycho-political advantages for North Korea and Iran that might accompany this development, but it does point out that any attempt to threaten the US and its allies with this missile would be fraught with danger and uncertainty for both Iran and North Korea.

Unha-2 on Launch Pad Seconds Prior to Launch

Figure 17

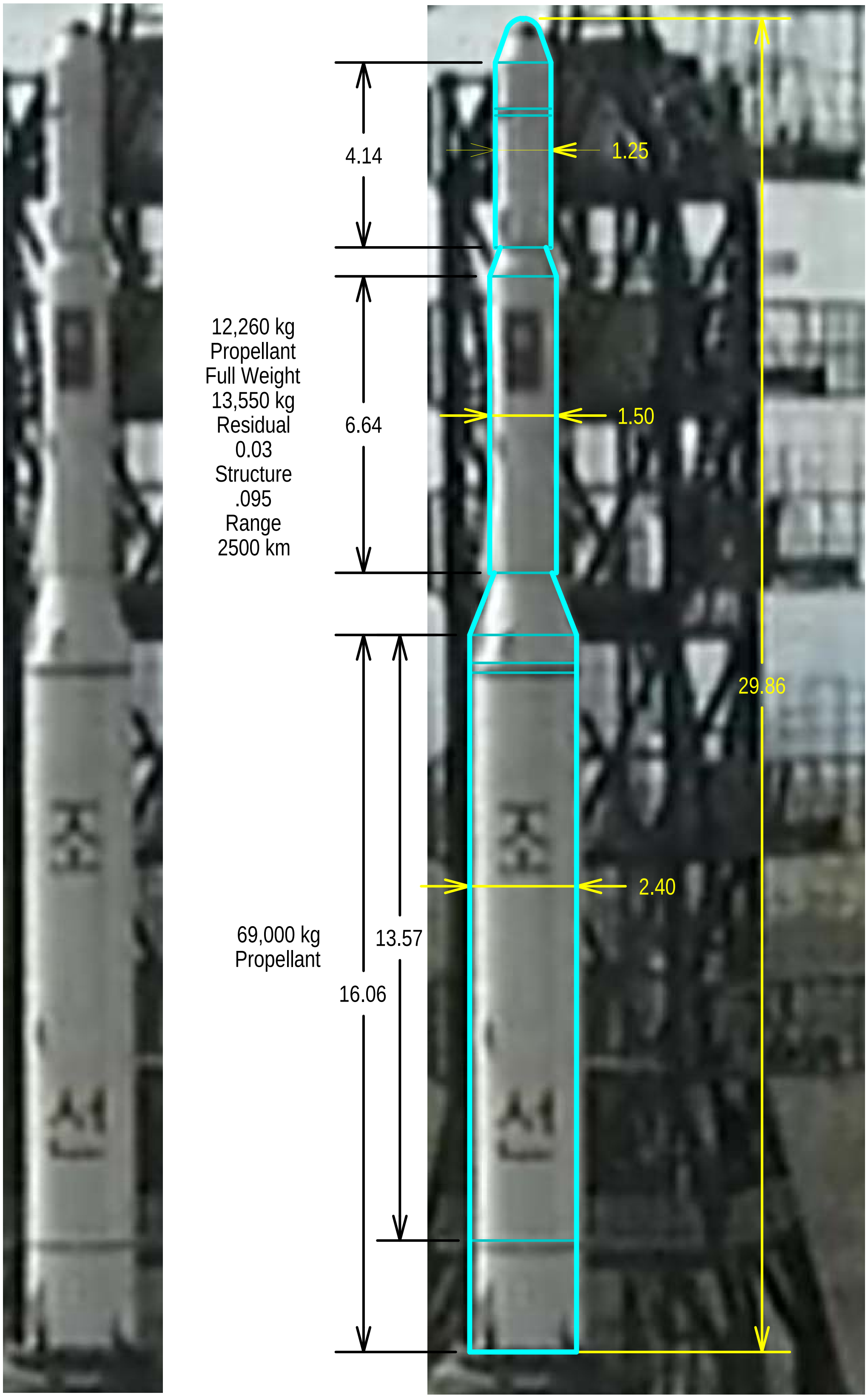

4.14
1.25
12,260 kg
Propellant
Full Weight
13,550 kg
Residual
0.03
Structure
.095
Range
2500 km
6.64
1.50
29.86
2.40
69,000 kg
Propellant
13.57
16.06

Figure 18

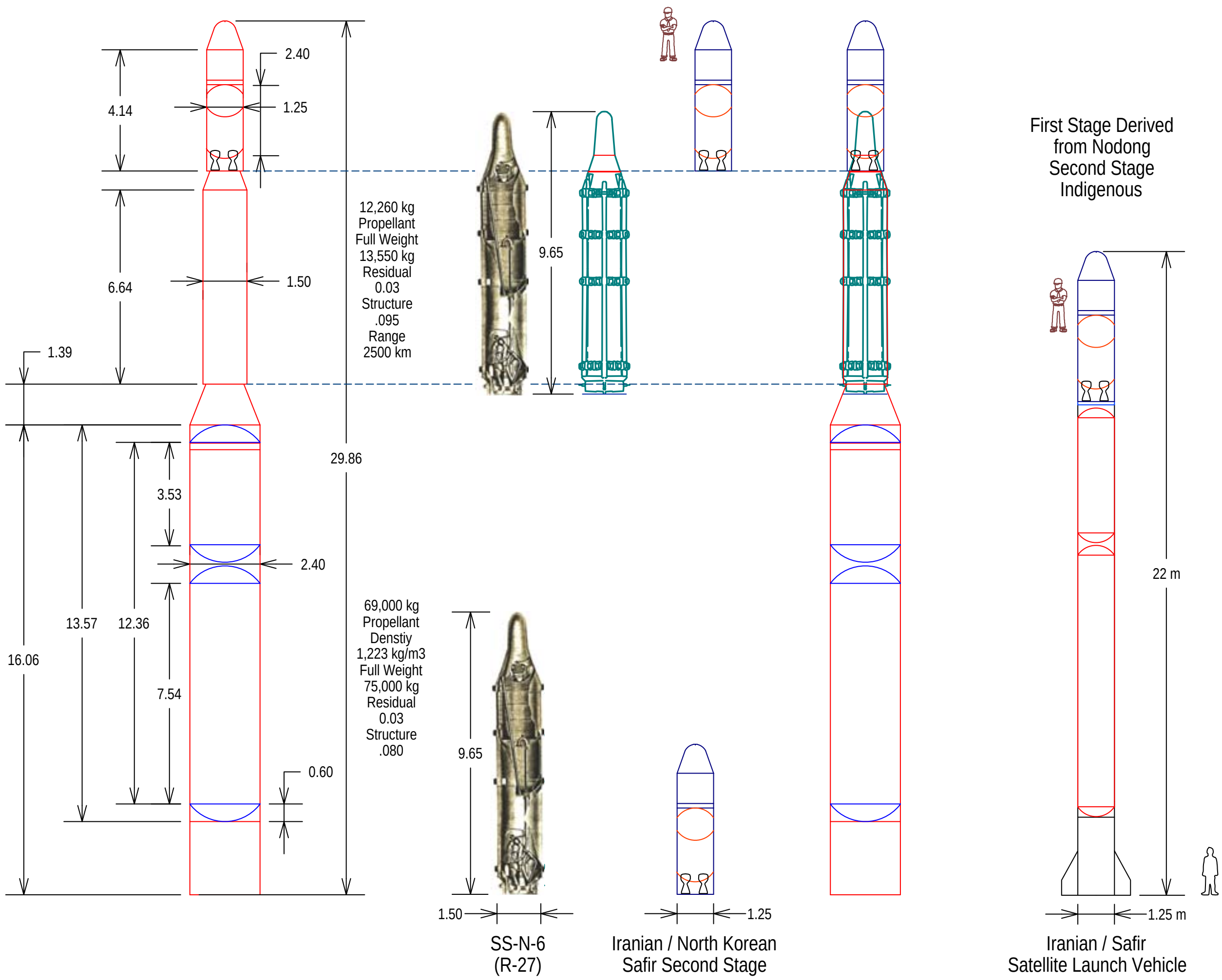

2.40
4.14
1.25
6.64
1.50
1.39
12,260 kg
Propellant
Full Weight
13,550 kg
Residual
0.03
Structure
.095
Range
2500 km
9.65
First Stage Derived
from Nodong
Second Stage
Indigenous
29.86
3.53
2.40
13.57
12.36
16.06
7.54
0.60
69,000 kg
Propellant
Denstiy
1,223 kg/m3
Full Weight
75,000 kg
Residual
0.03
Structure
.080
9.65
22 m
1.50
1.25
1.25 m
SS-N-6
(R-27)
Iranian / North Korean
Safir Second Stage
Iranian / Safir
Satellite Launch Vehicle

Figure 19

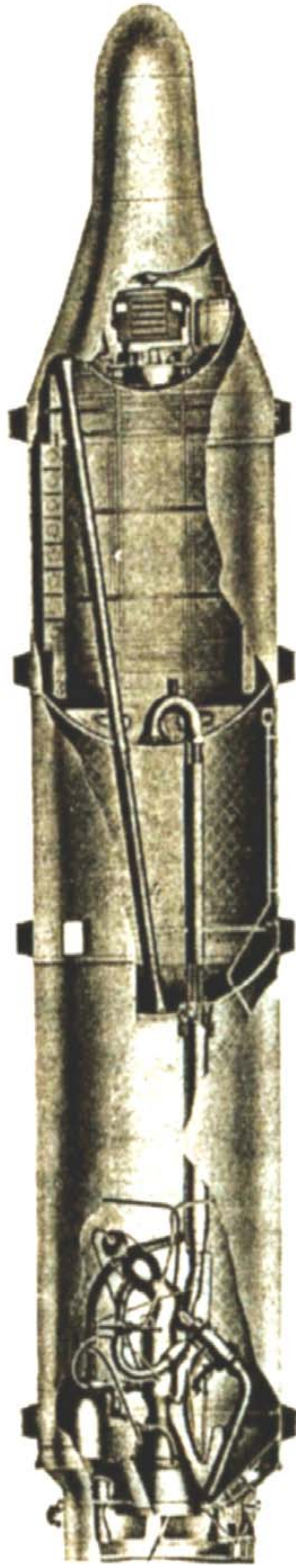


Figure 20

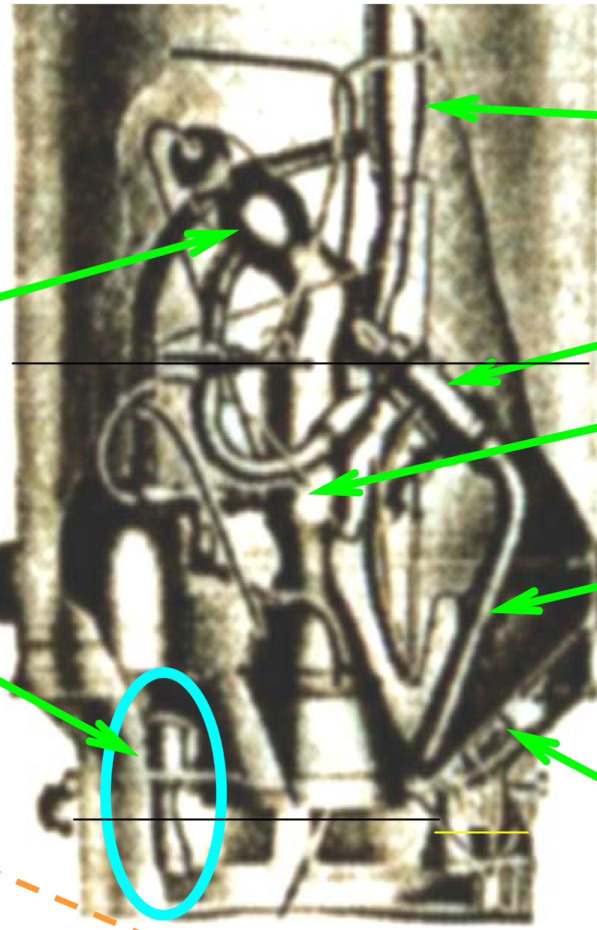


Figure 21

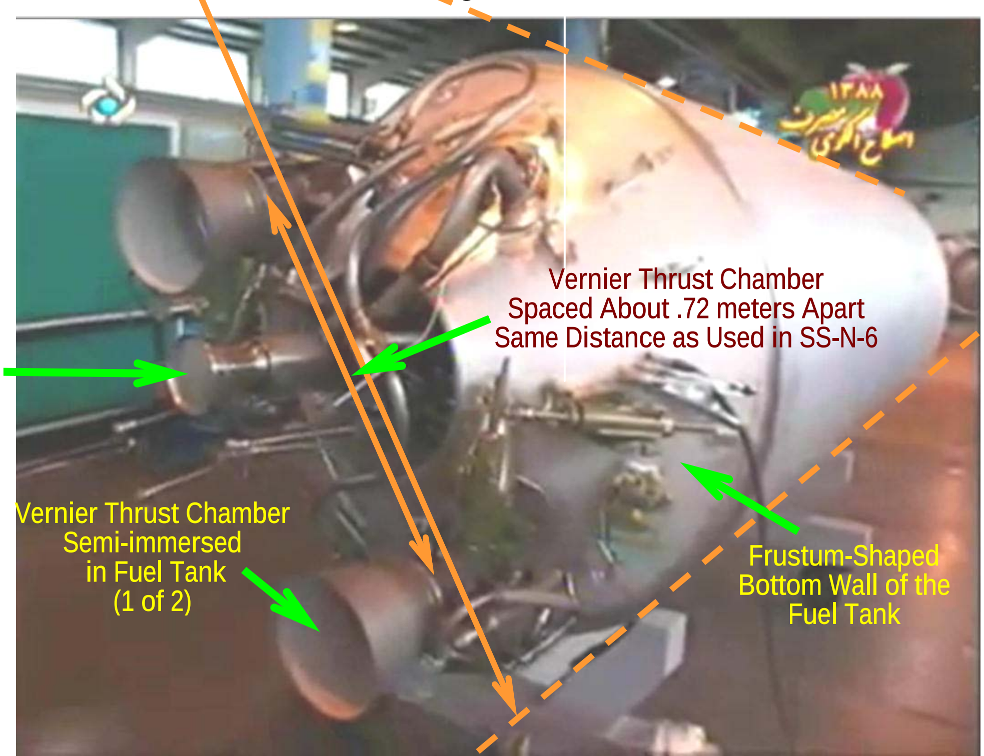


Figure 22

Figure 23

Figure 24

Figure 25

Figure 26

Figure 27

Figure 28

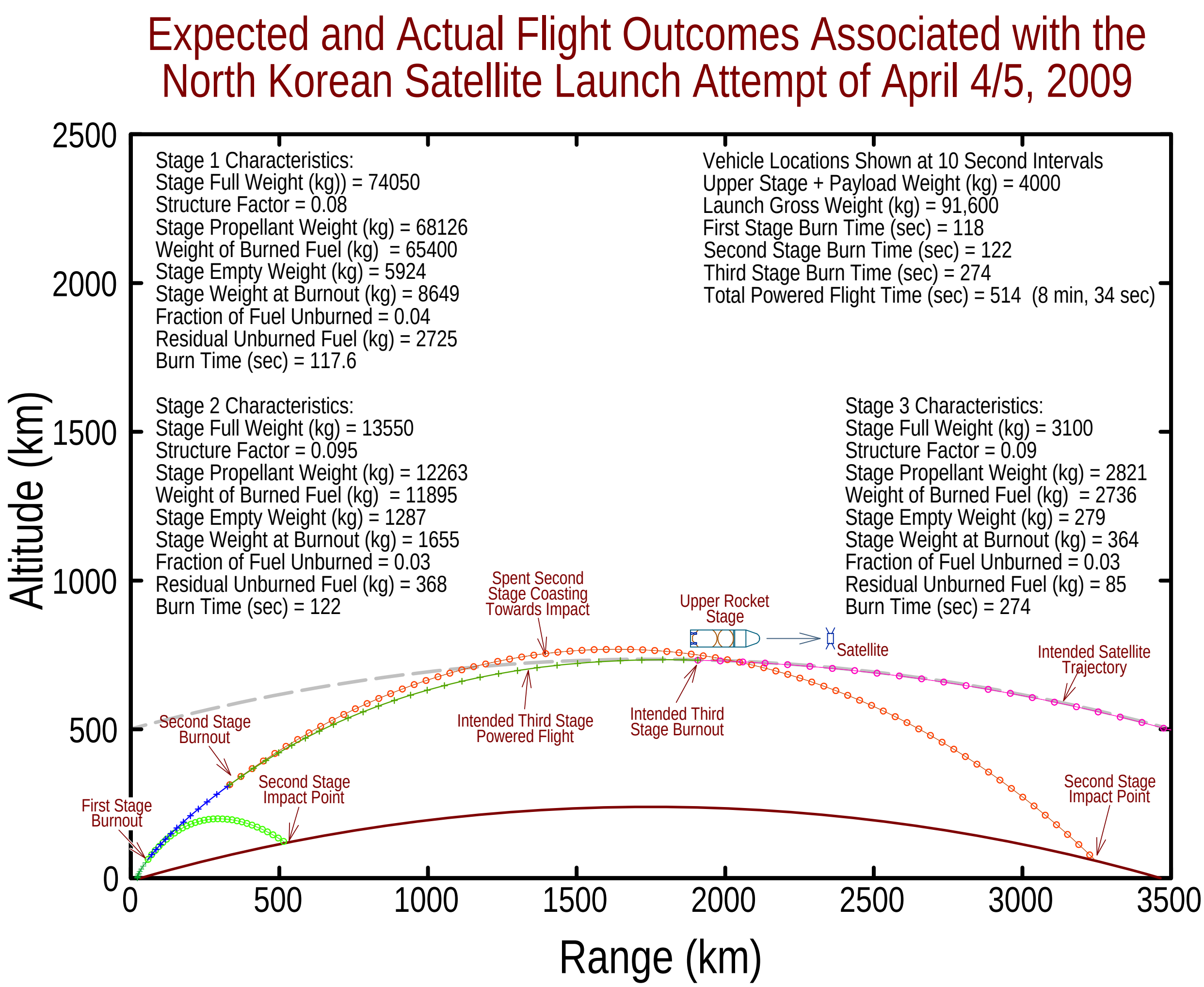
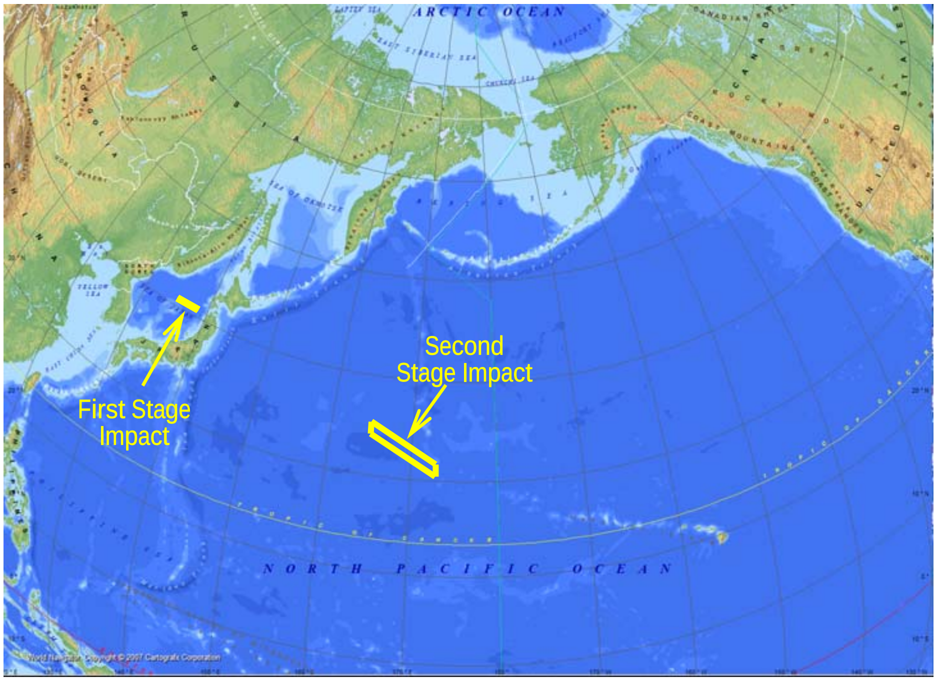

Expected and Actual Flight Outcomes Associated with the
North Korean Satellite Launch Attempt of April 4/5, 2009
Stage 1 Characteristics:
Stage Full Weight (kg)) = 74050
Structure Factor = 0.08
Stage Propellant Weight (kg) = 68126
Weight of Burned Fuel (kg) = 65400
Stage Empty Weight (kg) = 5924
Stage Weight at Burnout (kg) = 8649
Fraction of Fuel Unburned = 0.04
Residual Unburned Fuel (kg) = 2725
Burn Time (sec) = 117.6
Stage 2 Characteristics:
Stage Full Weight (kg) = 13550
Structure Factor = 0.095
Stage Propellant Weight (kg) = 12263
Weight of Burned Fuel (kg) = 11895
Stage Empty Weight (kg) = 1287
Stage Weight at Burnout (kg) = 1655
Fraction of Fuel Unburned = 0.03
Residual Unburned Fuel (kg) = 368
Burn Time (sec) = 122
Vehicle Locations Shown at 10 Second Intervals
Upper Stage + Payload Weight (kg) = 4000
Launch Gross Weight (kg) = 91,600
First Stage Burn Time (sec) = 118
Second Stage Burn Time (sec) = 122
Third Stage Burn Time (sec) = 274
Total Powered Flight Time (sec) = 514 (8 min, 34 sec)
Stage 3 Characteristics:
Stage Full Weight (kg) = 3100
Structure Factor = 0.09
Stage Propellant Weight (kg) = 2821
Weight of Burned Fuel (kg) = 2736
Stage Empty Weight (kg) = 279
Stage Weight at Burnout (kg) = 364
Fraction of Fuel Unburned = 0.03
Residual Unburned Fuel (kg) = 85
Burn Time (sec) = 274
Spent Second Stage Coasting Towards Impact
Upper Rocket Stage
Satellite
Intended Satellite Trajectory
Second Stage Burnout
Intended Third Stage Powered Flight
Intended Third Stage Burnout
First Stage Burnout
Second Stage Impact Point
Second Stage Impact Point
Altitude (km)
Range (km)
0
500
1000
1500
2000
2500
3000
3500

Figure 29



First Stage Impact Range = 500 to 700 km
Second Stage Impact Range = 3,150 to 4,000 km

Figure 30

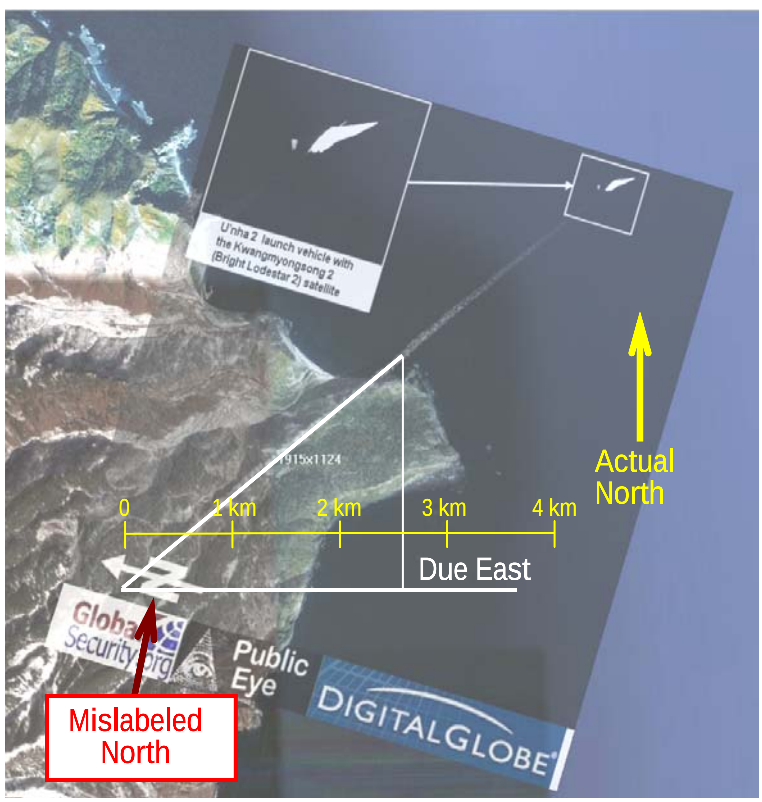


Figure 31

Digital Globe satellite image shows that the initial flight path angle of the first stage, which has a loft angle of about 45 degrees. The first stage impacted within 500 km of the launch point, providing further confirmation of launch trajectory calculations provided herein.

Conclusions, Relevant Uncertainties, and Needs for Further Analysis

3.89 Figure 32 below illustrates the extensive innovations displayed by both the Iranian and North Korean ballistic missile programs. In the case of the Iranian Safir satellite launch vehicle, the excess thrust of the Nodong rocket motor was exploited to build a first stage with highly extended fuel tanks. The second stage utilized the vernier rocket motors from the SS-N-6 submarine launched ballistic missile. In the case of the Taepodong 1, the first stage was essentially a modified Nodong missile, and the second stage used a SCUD B airframe with the SA-5 rocket motor substituted for the SCUD B. rocket motor. This change also required a new fuel combination, TG-02 and AK-27P. The third stage of the Taepodong 1 utilized the solid rocket motor from the SS-21 tactical ballistic missile. Thus, figure 32 illustrates a high degree of competence and innovation in both the Iranian and North Korean missile programs – limited by the availability of rocket components.

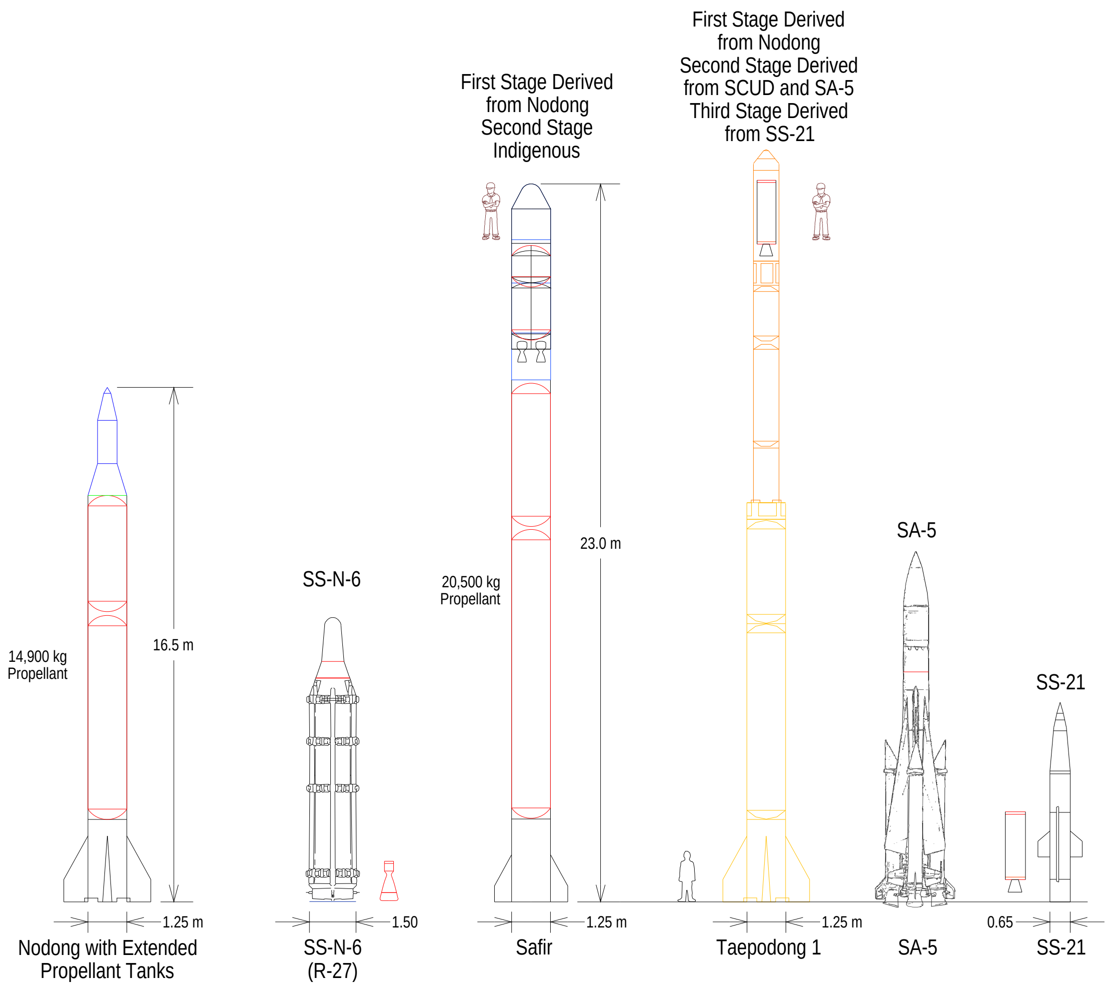


Figure 32

3.90 Figure 33 further illustrates continuing innovations that have been demonstrated by the North Korean's in the development of the Uhna-2. In the case of the Unha-2, a first stage weighing nearly 75 tons was fabricated into a monocoque structure that was powered by a cluster of four Nodong rocket motors. The second stage was adapted from the Russian SS-N-6 submarine launched ballistic missile. This innovation took advantage of the fact that the SS-N-6 has a very light and high strength airframe that is constructed from aluminum alloy and a high exhaust velocity (high specific impulse) rocket motor. This second stage uses a high-energy fuel combination of nitrogen tetroxide and unsymmetrical dimethylhydrazine. As a result, it seems likely that the Unha-2 that was launched on April 4/5, 2009 has been significantly improved by North Korea over the earlier generation variant that failed 42 seconds into flight in July of 2006.

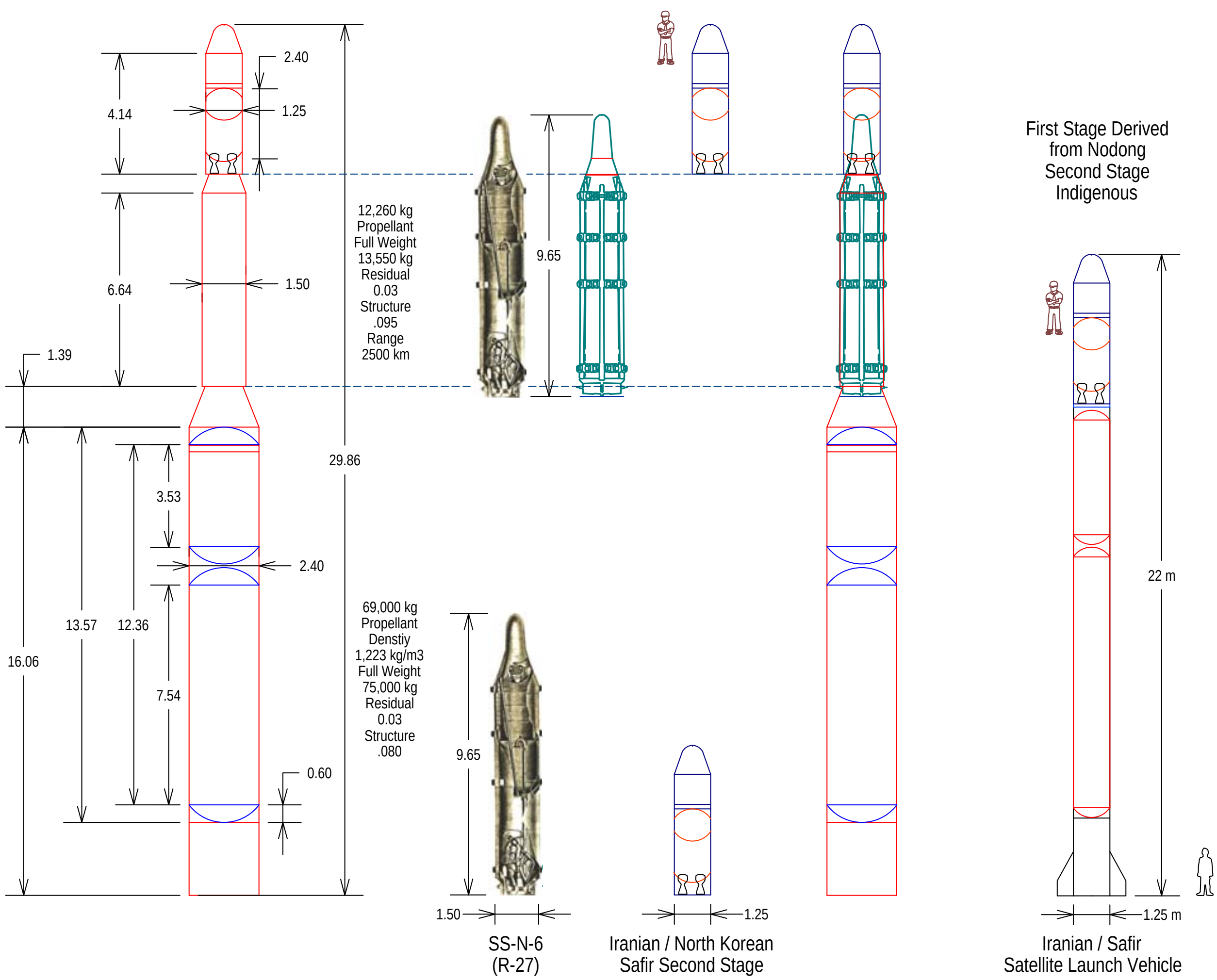


Figure 33

3.91 Table 3 below summarizes the characteristics of the baseline model of the Unha-2 missile that we are using for our estimates of performance. We do not claim that the characteristics of our model missile are exactly those of the North Korean Unha-2, however, we believe that in spite of uncertainties in the details of our model, the predictions of range and payload we will present with regard to the

Unha-2 are reasonably accurate. Our guess is that our estimates of the Unha-2 payload at any given range is accurate to about ±10%. As the reader will see from the results presented later in this section, such uncertainties would not affect conclusions that are relevant for the formulation of national policy.

Characteristics We Assume for Our Baseline Model of the Unha-2 Launch Vehicle

Stage	Full Weight (kg)	Empty Weight (kg)	Burnout Weight (kg)	Structure Factor	% Residual Fuel	Specific Impulse (sec)	Burn Time (sec)
Stage 1 (SCUD Technology)	74,050	5924	8649	0.08	0.04	220 (SL) 247 (Vac)	118
Stage -2 (SS-N-6 Technology)	13550	279	1287	0.095	0.03	300	122
Stage -3 (Derived from SS-N-6)	3100	279	465	0.09	0.03	300	274
Stage -3 (Derived from SA-5/SCUD-B	3100	372	454	0.12	0.03	253/255	65/48

Table 3

3.92 Figure 34 shows the range payload estimates we have derived for two-stage and three stage variants of the Unha-2. The two-stage variant simply assumes a vehicle that uses first and second stages with the properties listed in table 3. As can be seen from an inspection of the graph and the figure, the two-stage variant of the Unha-2 can potentially deliver 1800 kg to 5000 km range and 1600 kg to 6000 km range. At ranges of 8000 and 9000 km respectively, it can potentially deliver 1150 and 1000 kg payloads.

3.93 There are somewhat greater uncertainties associated with estimating the potential range of a three stage ballistic missile variant of the Unha-2. A third stage could be based on the use of the current upper stage. This would almost certainly require that the stage be built of a much stronger airframe in order to accommodate the larger weight of a warhead. Such a stage might be workable but it appears that it would be better to build a stage that uses a higher thrust rocket motor and burns a much shorter time. One possibility would be to build a stage based on the SCUD rocket motor, or on the rocket motor from the SA-5 long-range strategic surface to air missile. Both of these rocket motors have been used by North Korea and have a demonstrated reliability. The drawback associated with using these rocket motors is that they are relatively inefficient compared to the high-performance rocket motors used in the second stage of the Unha-2. However the second stage rocket motors in the Unha-2 are more than twice the thrust and would cause extreme acceleration stresses on a third stage that uses this motor.

3.94 We assume a third stage rocket motor that uses either the rocket motor from the SCUD-B ballistic missile (thrust equal to 13,390 kgf, and vacuum specific impulse of 253 seconds) or the rocket motor from the SA-5 (thrust equal to 10,000 kg force and vacuum specific impulse in high thrust mode of 255 seconds). The general characteristics of this third stage, based on either a SCUD-B or SA-5 rocket motors, are shown in row 4 of table 3.

3.94 An inspection of the graph in figure 34 shows that such a missile could potentially deliver more than 1400 kg to 8000 km range and about 1150 kg to 10,000 km range.

Range Versus Payload of Two and Three Stage Taepodong-2 Ballistic Missiles and the SCUD-B, SCUD-C, Shahab-3 and Shahab-3M, and Safir

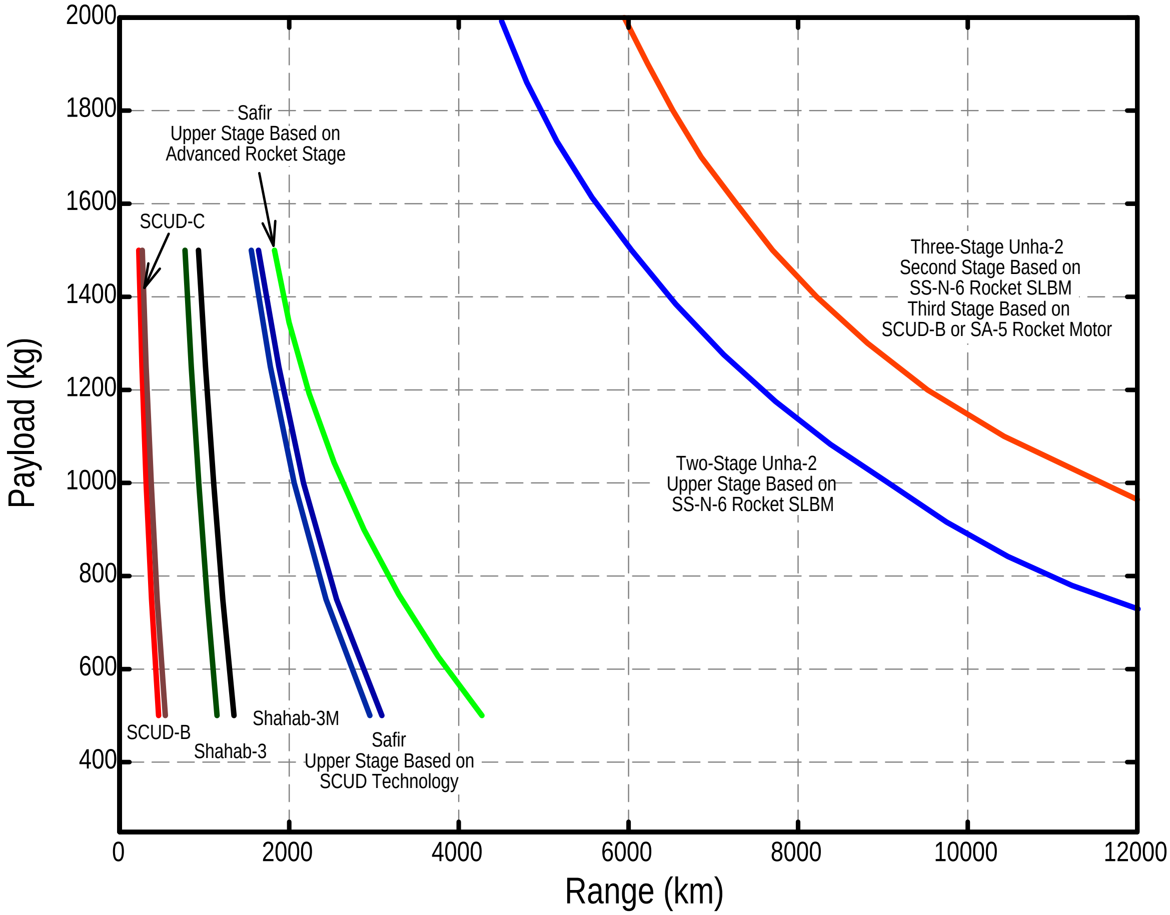


Figure 34

3.95 Figures 35A and 35B show the relevance of ranges between 8000 and 10,000 km assuming launches from either Iran or North Korea against the United States. An inspection of figure 35A shows that for Iran to deliver a payload of 1000 kg or more with such a missile, the missile will have to fly a distance of roughly 10,000 km. In the case of North Korea, ranges of 8000, 9000, and 10,000 km cover increasingly larger areas of the United States.

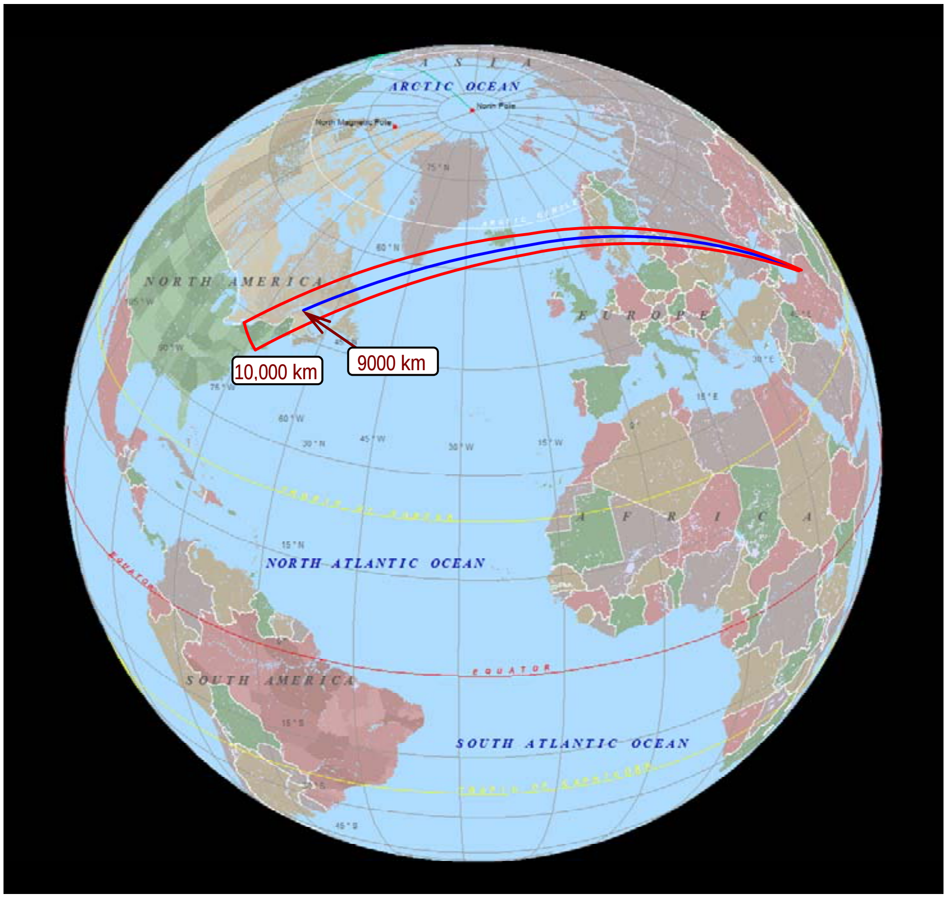


Figure 35 A

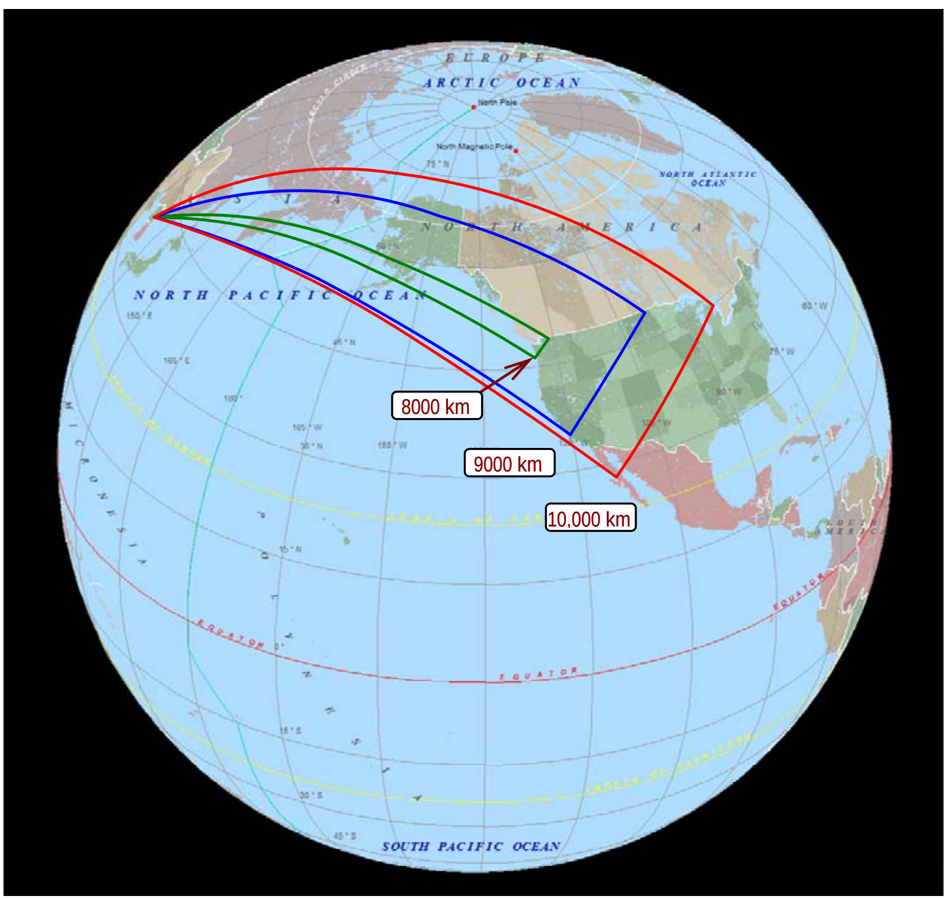


Figure 35 B

3.96 Our estimates therefore indicate that future variants of the Unha-2 could potentially deliver payloads in excess of 1000 kg to large areas of the United States. As noted earlier in this appendix, such a missile would be highly vulnerable to a preemptive attack by the United States if there were any attempt to prepare such a missile for launch.

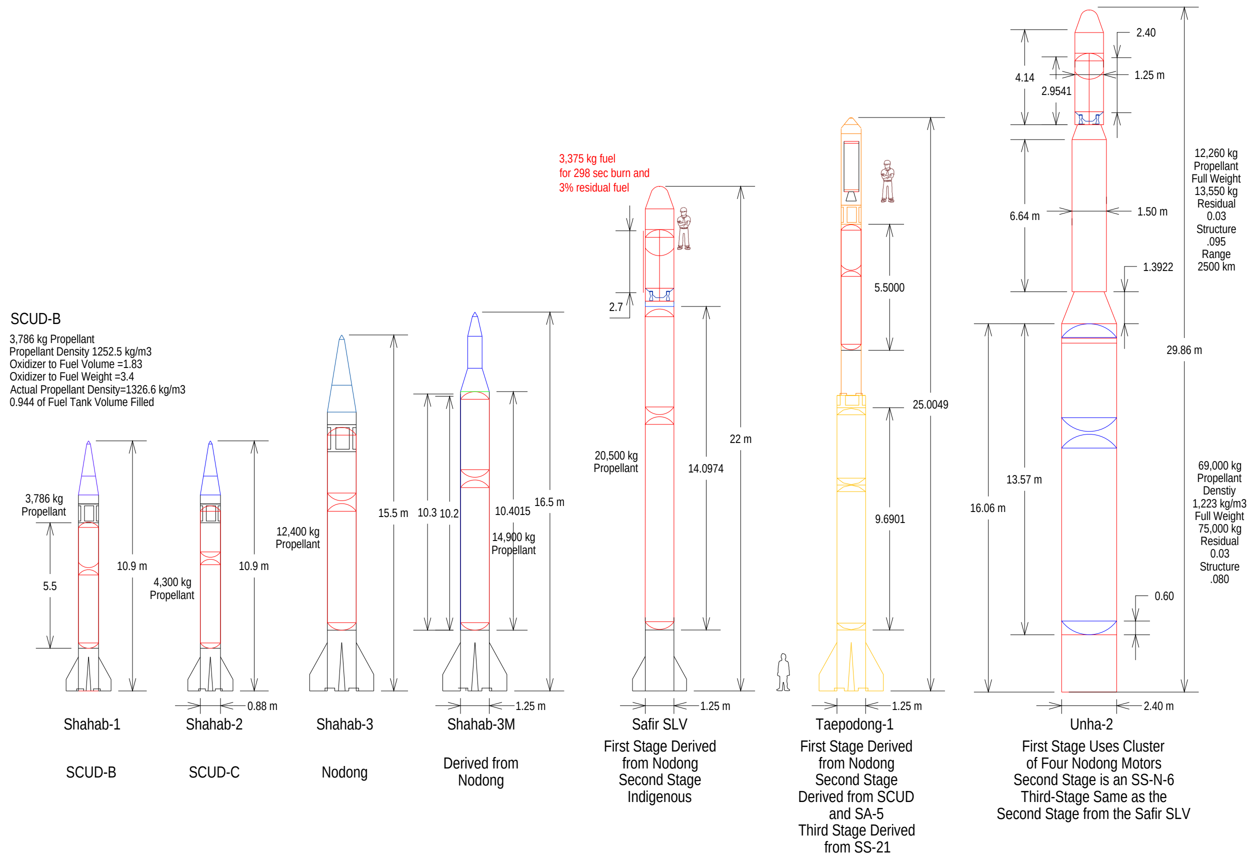


Figure 35

Figure 35 illustrates the range of ballistic missile technologies that have been developed by both Iran and North Korea over the last roughly 20 years. All of these rockets depend on the use of rocket components that were built for other vehicles. This suggests that stronger controls of the export of rocket components may provide an important opportunity for limiting further advances in Iran's and North Korea's rocket programs. So far, the only rockets that Iran and North Korea could use to try to pose threats to the West and its allies are large and cumbersome and highly vulnerable. To erect such a missile in the hope of threatening the West would be an invitation to preemptive attack that could lead to a disaster for the country attempting to use such missiles as a threat. Depending on how much equipment is already in the hands of Iran and North Korea, it may well be possible to severely limit further advances, and possibly to even roll back their capabilities to build large ballistic missiles.

Figure 33

Figure 34

Figure 35

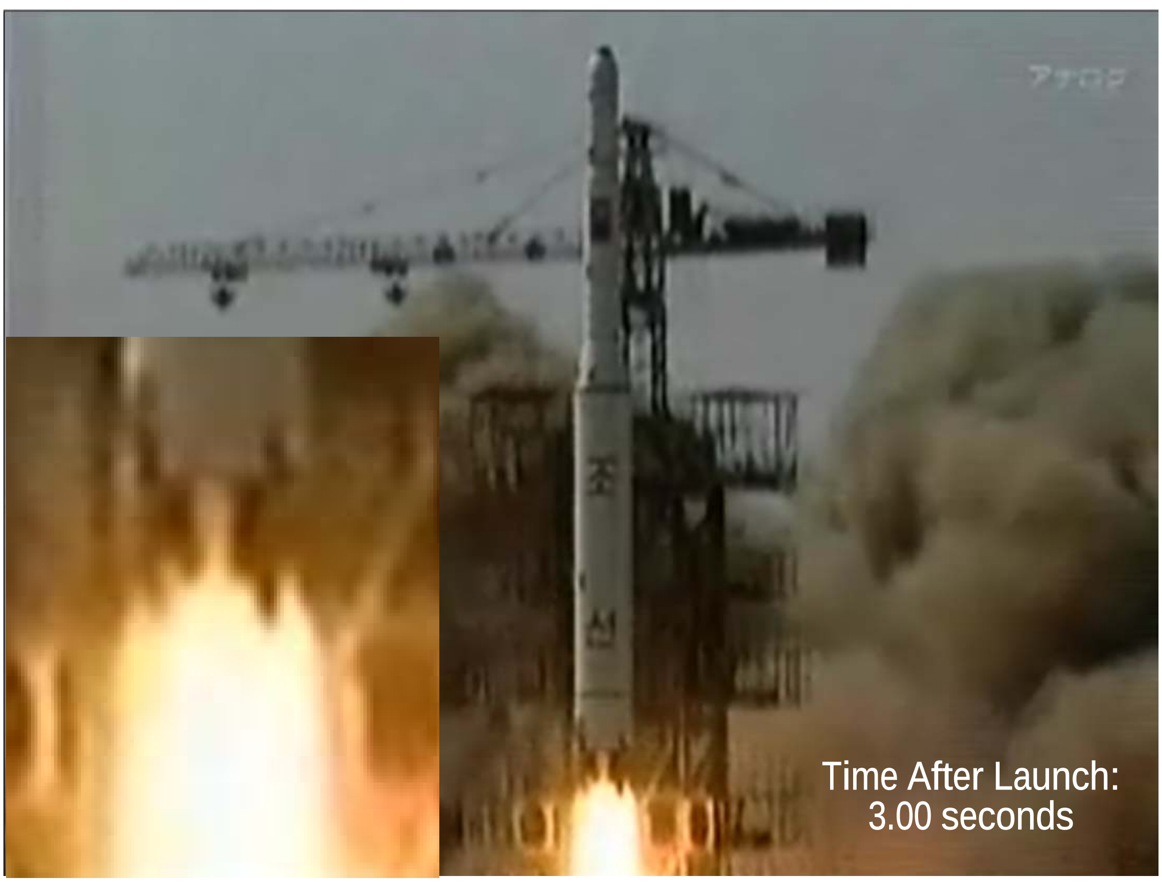


Figure 36

Rocket Altitudes versus Time Based on Acceleration Rates Observed in Videos of Rocket Launches