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An Analysis of the Pakistani Ghauri Missile Test of April 6, 1998

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On April 6, 1998 Pakistan announced that it had tested a new ballistic missile, called the Ghauri. The reports attracted considerable attention, especially in South Asia. This report is an analysis of the limited information that has been reported about the Ghauri test, based in part on my understanding of the North Korean Nodong missile.

To better understand what might be behind the press reports of the Ghauri test, I have looked at whether the information given in press reports is consistent with a test of the type reported. Since some reports have claimed that the Ghauri missile is based on North Korean technology, I have also calculated what one would expect from a missile based on this technology and having the characteristics described in the press reports.

DESCRIPTION OF THE GHAURI MISSILE

Pakistani press reports about the Ghauri flight test typically mention a maximum range of 1,500 kilometers (km) for the missile, but the range of the test is usually given as 1,100 km with a flight time of 9 minutes and 58 seconds.[1] Many reports mention that the missile rose to an altitude of 350 km. This appears to refer to the apogee (the point of maximum altitude) of the trajectory, which occurs midway through the missile's flight.

The total mass of the Ghauri missile is generally reported to be 16 tonnes and the payload 700 kilograms (kg),[2] although one report gives the total mass as 15 tonnes.[3] Fuel masses of both 13 and 14 tonnes have been reported.[4] However, assuming the missile has one stage, a total mass of 16 tonnes and a fuel mass of 14 tonnes would give a fuel fraction[5] for the booster of 91.5 percent and a total mass of 15 tonnes and fuel mass of 13 tonnes would give a fuel

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fraction of 91 percent. These fuel fractions appear unrealistically high unless the missile was constructed of very lightweight materials, which seems unlikely. On the other hand, a total mass of 16 tonnes and a fuel mass of 13 tonnes would give a fuel fraction of 85 percent, which appears to be a reasonable value assuming the missile body is made of aluminum, rather than steel (which Scuds are made of).[6] Thus, for this analysis I assume the missile has a total mass of 16 tonnes and a fuel mass of 13 tonnes.

The missile can reportedly be fired from a mobile launcher[7] although one report said that the test was fired from a temporary launch pad.[8] There have been numerous reports in recent years of North Korea building transporter-erector-launchers (TELs) for the Nodong missile, which appears to be roughly the same size as the Ghauri, suggesting that reports of TELs for the Ghauri may be credible.

At least one report stated that the Ghauri is three-stage, but this appears to be a misinterpretation of Pakistani reports that "the missile will formally be tested in three stages..."[9] If the missile is liquid-fueled, it very likely single-stage, as described below.

A TEST TO A RANGE OF 1,100 KILOMETERS

Press reports have given the launch site of the test either as Malute, near the city of Jelum,[10] or as near the Kahuta nuclear research lab.[11] Reports of several impact locations have appeared. One of these stated that the missile landed "near Dasht, an area on the coast of Makran,"[12] which would be consistent with a test of 1,100 km from either of the launch sites.

The standard minimum-energy trajectory for a range of 1,100 km would give an apogee of about 300 km and a flight time of about 9.6 minutes. However, if a missile of this range was flown on a slightly lofted trajectory, it could still reach 1,100 km range but with an apogee of 350 km and a flight time of just over 10 minutes, which would agree with the press reports.

Is a missile of this range and payload consistent with one based on Nodong technology? The Nodong is a one-stage, liquid-fuel missile powered by four Scud-B engines.[13] My calculations show that a missile powered by four Scud engines and having a total mass of 16 tonnes (which includes the 700 kg payload) with 13 tonnes of fuel would indeed have a maximum range of about 1,100 km.[14]

It is interesting to note that if the payload of such a missile were reduced from 700 to 200 kg, the range would increase to roughly 1,400 km, which is near what is reported to be the maximum range. A payload of 200 kg might be roughly the smallest possible since it could represent the structural mass of the nose section without a warhead.

A missile of the type described here would have a range of 1,000 km with a one-tonne payload and a range of about 850 km with a 1.5 tonne payload.

If the mass figures reported for the Ghauri are correct, the missile appears to be somewhat smaller than the North Korean Nodong missile. The Nodong mass (about 15 tonnes of fuel and 18.5 tonnes total mass if the body is made of aluminum)[15] is estimated to be a couple of tonnes larger than the reported Ghauri values. The Nodong with a similar fuel fraction (85 percent) would give a longer range than the Ghauri for the same payload—1200 to 1250 km for a 700-kg payload.

Similarly, from the photos of the Ghauri launch that were released by Pakistani television, one can get a very rough estimate of the size of the missile based on the trucks in the background.[16] From this, the missile appears to be very roughly the same size as, though possibly smaller than, the Nodong, which is reported to be 15.2 meters long and 1.2 meters in diameter.[17]

Thus, the available information appears to be consistent with a missile that uses technology and a configuration similar to the Nodong, but which is somewhat smaller than a Nodong.

Clustering simple liquid-fueled engines is relatively straightforward. The assumption here is that North Korea and Pakistan would have followed the Chinese method of having a small fuel pump associated with each engine, rather than the Russian method of using a single large pump to feed multiple combusion chambers. The engines are fed from a single pair of oxidizer and propellant tanks, and the missile body can be made large enough that the tanks hold the total amount of fuel required by the four engines. One would expect such a missile to look like the one in the television footage of the Ghauri launch.

Could the Ghauri instead be based on the technology Pakistan used for its Hatf 1 and 2 missiles? The Hatf 1 and 2 are believed to be solid-fuel missiles based on French sounding rockets. The rocket motor for these missiles is much less capable than the Scud-B engine. The total impulse delivered by the motor, equal to the thrust times the burn time, is 4 to 7 times less than that of the Scud-B engine.[18] The Hatf 1, which has a single motor, can carry a 500 kg payload only 60-80 km. The Hatf 2 missile, which is believed to consist of two of these motors stacked to give a two-stage missile, can carry a 500 kg warhead to 260–300 km.[19] While in principle it might be possible to achieve the range/payload capability of the Ghauri by building a two-stage missile, with each stage consisting of four or more Hatf engines strapped together, such a configuration seems unlikely and would not be consistent with the parameters reported for the Ghauri.

Developing a missile with a range of 800-1000 km would therefore have led Pakistan to develop or acquire a more capable engine. Over the past few years, Pakistan may have been developing a more powerful solid motor, possibly with help from China. It may instead have decided to switch to liquid engines. Like North Korea, it may have decided to use Scud-B engines, which are presumably available on the international market. It may also have received assistance on building a Scud-like engine from North Korea or possibly from Iran.

North Korea is reported to be developing a two-stage missile with a range of 1,500-2,000 km that would use the Nodong as the first stage and a stage with a single Scud engine as the second stage. If Pakistan has used similar technology for the Ghauri, it could in the same way try to master multi-staging to create a missile with a range of roughly 1,500–2,000 km. This could be what is behind Pakistan's claim that it is developing a 2,000-kilometer-range missile called the Ghaznavi.[20]

A TEST TO A RANGE OF 700 KILOMETERS

It is possible that the range of the Ghauri test was considerably shorter than 1,100 km. The majority of press reports state that impact occurred near the city of Quetta.[21] Another report stated that the impact occurred in the northern part of Balochistan.[22] From a map it is easy to verify that such a flight would have a range of only about 700 km.

If the Ghauri trajectory covered 700 km rather than 1,100 km, this raises the possibility of a different explanation of the test. In mid-1997, Pakistan claimed to be developing an 800 kilometer-range Hatf 3 missile. An 800 kilometer-range missile on a standard trajectory would have an apogee of about 200 km and a flight time of 8 minutes. However, if the missile trajectory was lofted slightly to give an apogee of 350 km, which is the figure reported in the press, my calculations show that the missile would then have a range of about 700 km and a flight time of ten minutes. Thus the figures for the apogee and flight time given in the press are consistent with a flight range that is considerably shorter than 1,100 km and that agrees with the distance between the launch and impact locations given in the majority of press reports. This possibility therefore cannot be ruled out on these grounds.

It is interesting to note that if one had a missile with a maximum range of 800 km for a 700 kg payload, reducing the payload 200 kg would increase the maximum range to about 1,100 km.

OTHER CONSIDERATIONS

Some Indian sources appear skeptical of the claims about the Ghauri test. Such attitudes could well have political motivations. At least one report states that Indian radars did not detect a test despite the fact India constantly monitors Pakistani air space, and suggests that this is evidence that no test occurred.[23] Some Pakistani commentators have apparently turned this argument around claiming that this shows the weakness of the Indian surveillance system.

Without knowing details of the Indian radars, one cannot determine whether or not the radars are capable of detecting the launch. However, Indian radars have presumably been operated to search primarily for Pakistani aircraft. Despite their size, missiles have a relatively small radar cross-section (RCS) compared to aircraft because of the missile's simple shape.[24] The radars may have been operated in a way that optimized their search for aircraft, and for this reason may not have detected the smaller RCS of the missile. However, if this is the explanation and if the radars are sufficiently capable, India may be able to change the way it operates the radars to enable it to detect such targets. For example, by slowing the search rate of the radars and increasing the dwell time of the radar beam as it searches, India could increase the sensitivity of the radar. It could compensate for the slower search rate if necessary by adding radars. Thus it is possible that the Ghauri launch occurred without being detected by Indian radars, but that the lack of detection arose from the way India chose to operate its radars and says little about India's ability to detect such launches should it choose to do so.

In addition, air defense radars are said typically to be "gated" to exclude objects moving faster than about a kilometer per second or at altitudes higher than 30 km, since they are configured to detect aircraft.[25] If this is true of Indian radars, the speed gate would have kept a radar more than about 200 km from the launch site from registering the Ghauri launch, since the missile would have had a speed of greater than 1 kilometer/second by the time it entered the radar field of view.[26]

Several press reports question whether Pakistan would launch an unproven missile over populated areas without issuing an alert.[27] This point has apparently been used to argue either that no test actually occurred, or that if a test did occur, the missile must have been a proven design from China (North Korea does not have a proven missile of this range).

US intelligence apparently believes that a test did occur, although it is not known what range the United States believes the test covered.

Moreover, US officials reportedly believe that the Ghauri missile is liquid-fueled and is based on technology obtained from North Korea.[28] North Korea is believed to have transferred "major components" according to one source,

but the United States believes that Pakistan did not receive a whole Nodong missile from North Korea. These transfers are said to have taken place over the past two or three years.

Indeed, the United States apparently believes the evidence of such a transfer is strong enough that it is imposing sanctions against a North Korean company (Changgwang Sinyong Corporation) and Pakistan's Khan Research Laboratory, which is reported to have obtained missile parts from the North Korea company.[29]

There have been contacts between Pakistan and North Korea in the past, some of which are reported to have involved missiles. For example, there are reports of Pakistani officials visiting North Korea in 1992 to discuss the Nodong program and Pakistani officials are said to have been present in North Korea for the 1993 flight test of a Nodong. In December of 1993, Pakistani Prime Minister Benazir Bhutto spent two days in Pyongyang. These contacts are reported to have led to cooperation on developing the Ghauri missile.[30]

As noted above, Pakistan's experience with ballistic missiles has been with solid-fuel engines. Thus, if the Ghauri missile is liquid-fueled it might suggest some level of assistance from abroad. Moreover, the Hatf missile are believed to have very poor guidance, or even perhaps be unguided. Thus guidance systems is a second area in which Pakistan may have received technology and assistance.

CONCLUSION

The information given in press reports about the Ghauri flight test are compatible with the missile being liquid fueled and using a cluster of four Scud engines, as does North Korea's Nodong missile. However, the missile appears to be somewhat smaller and have a shorter range (with comparable payload) than the Nodong. This supports assertions that North Korea did not transfer a complete missile, and may support Pakistani claims that it was an indigenous design, albeit one that drew heavily on foreign technology and expertise.

If Pakistan has working Scud-type engines that it has either developed or purchased, clustering these engines should not be a difficult thing to do and would not seem to be beyond Pakistan's technical capability. Ground tests of a missile engine reported in Pakistan last year may have been of an engine it used in the Ghauri.

However, an alternate possibility that cannot be ruled out with available information is that Pakistan has a missile with an 800 kilometer range and that the April 6 test was only to 700 km. This would be consistent with a num-

ber of reports of the locations of the launch and impact sites and with Pakistani claims last year that it had developed an 800 kilometer-range Hatf 3, although apparently no test of a missile to that range has been observed.

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NOTES AND REFERENCES

1. "Pakistan test-fires 1,500-km range missile," *The News*(Lahore) (internet edition), (April 7, 1998); Akhtar, Hasan, "Pakistan Test-Fires Ghauri Missile," *Dawn*, (April 7, 1998), (this reference gives launch and impact times for the test that suggest an eight minute flight time, but this appears to be incorrect since the time given for the launch is two minutes later than the time shown on the video of the launch from Pakistani television).

2. Akhtar, Hasan, "Pakistan Test-Fires Ghauri Missile;" "Pakistan Test-Fires 1,500-km range missile," *The News*; "Pakistan Test-Fires Surface-to-Surface Missile," *Rediff on the Net*, (April 6., 1998); "Pakistan Test Fire Ghauri Missile," Pakistan government web site (www.pak.gov.pk/govt/ghauri.htm).

3. Zaafir, Saleh, *Daily Jang Rawalpindi* (in Urdu), (April 7, 1998).

4. Akhtar, Hasan, "Pakistan Test-Fires Ghauri Missile," and "Pakistan Test-Fires Surface-to-Surface Missile," *Rediff on the Net,* both give the fuel mass as 13 tonnes. "Pakistan Test-Fires 1,500-km Range Missile," *The News* and the Pakistan government web site give the fuel mass as 14 tonnes.

5. The fuel fraction is the fuel mass divided by the total booster mass, which is the fuel mass plus structural mass. The booster mass is the total missile mass minus the mass of the payload.

6. If the missile body was made of steel, one would expect a smaller fuel fraction—probably in the range of 81–82 percent.

7. "Pakistan Test-Fires 1,500-km Range Missile," *The News*.

8. Zaafir, Saleh, *Daily Jang Rawalpindi*. This reference also states that there was a decoy launch pad set up in Azad Kashmir.

9. Baruah, Amit, "Pakistan Tests 1,500-km Range Missile," *The Hindu*, (February 11, 1998), p. 13.

10. Akhtar, Hasan, "Pakistan Test-Fires Ghauri Missile"; Akhtar, Shameem, "Missile Race in South Asia," *Dawn*, (April 21, 1998). Zaafir, Saleh, *Daily Jang Rawalpindi* also gives the launch site as near Jelum.

11. Hussain, Zahid, "Pakistan Missile Test Stirs Tension," *South China Morning Post* (internet edition), (April 7, 1998), Gannon, Kathy, "Pakistan Test-Fires Missile, Irking India," *Washington Times*, (April 7, 1998), A13.

12. Zaafir, Saleh, *Daily Jang Rawalpindi*. Akhtar, Hasan, "Missile Race in South Asia" also states that the missile landed in Makran. The Zaafir report contains a number of statements that are clearly incorrect, which raises questions about its general credibil-

ity. How credible the report of the impact location might be is unknown. One Pakistani source suggested that Akhtar's report of the impact location may be drawn from Zaafir's report, and therefore may not be an independent source of information.

13. Wright, David and Timur Kadyshev, "An Analysis of the North Korean Nodong Missile," *Science and Global Security*, Vol. 4, (1994), p. 129.

14. This calculation assumes a sea-level specific impulse of 230 seconds, which is the value for Scud B engines fueled by UDMH and nitric acid, reduced a few seconds by the drag of the jet vanes that are used for guidance. The specific impulse increases during boost phase since atmospheric pressure decreases with altitude, and reaches 254 seconds at burnout. See Wright, David, "Technical Parameters of the Scud-B Missile," to be published.

15. The mass values given here for the Nodong are somewhat smaller than those given in Wright and Kadyshev, "Analysis of the Nodong Missile," since they are based on more accurate values of Scud-B parameters. See Wright, David and Timur Kadyshev, "An Analysis of the North Korean Taepodong Missiles," to be published.

16. The photo can be seen at www.jang-group.com/thenews/apr98-daily/07-04-98/frmain.htm. Two other pictures of the missile can be found at www.pak.gov.pk/govt/ghauri.htm.

17. The only dimension of the Ghauri that I have seen reported is a length of 17 m (Zaafir, Daily Jang Rawalpindi). From the pictures of the Ghauri, this length suggests a diameter of roughly 1.5 m. These dimensions seem too large for the reported mass of the missile. As noted above, the credibility of much in the Zaafir report is questionable.

18. The impulse equals the total momentum change of the missile that the engine can bring about. The Hatf 1 engine is reported to produce 70 to 100 kN of thrust with a burntime of 16 to 19 seconds (private communication, Michael Elleman, Center for International Security and Arms Control, Stanford University, August 1992). The Scud-B engine has a thrust of 130 kN and a burntime of 62 seconds.

19. Range/payload estimates for the Hatf missiles are given from S. Chandrashekar, "An Assessment of Pakistan's Missile Capability," Missile Monitor, (Spring 1993), p. 4 and private communication, Elleman, Michael, (August 1992).

20. "Pakistan to Accelerate Missile Program," *Current Missile News*, Center for Defense and International Security Studies web site, (April 1998) (www.cdiss.org/98april2.htm).

21. Hussain, Zahid, "Pakistan Missile Test Stirs Tension;" Akhtar, Hasan, "Pakistan Test-Fires Ghauri Missile;" and "Pakistan Test-Fires Surface-to-Surface Missile," *Rediff on the Net*.

22. "Pakistan: Foreign Office Spokesman on Ghauri Test," *The Nation* (Lahore) (internet version) in FBIS-TAC-98-097, (April 7, 1998).

23. "Indians Disparage Pakistan Missile Claim," *Washington Times*, (April 11, 1998), A7.

24. Calculating the RCS of a cylinder 15 m long and 1.2 m in diameter as a function of the angle between the radar beam and cylinder axis shows that except for a few degrees around normal incidence, the RCS is well under 1 square meter (personal communication, Lewis, George, MIT's Security Studies Program, May 1998). In contrast, the average RCS of a fighter or bomber ranges from a few to several tens of square meters (M. Skolnick, "Introduction to Radar Systems" (Second Edition), (New York: McGraw-Hill, 1980), p. 44). The calculation of the RCS assumes a radar frequency of 3 GHz, which is appropriate to both the US Patriot and Soviet SA-10b air defense radars.

25. Lennox, Duncan, personal communication, (May 1998).

26. This calculation takes into account the curvature of the earth and assumes the radar can look down to within three degrees of the horizon. The Ghauri speed reaches a kilometer per second at an altitude of about 11 km.

27. "Indians Disparage Pakistan Missile Claim," *Washington Times*; "Deploy Prithvi to offset Gharui," says Jasjit Singh, *Rediff on the Net*, (April 22, 1998).

28. Weiner, Time, "U.S. Says North Korea Helped Develop New Pakistani Missile," *New York Times*, (April 11, 1998), p. A3.

29. Rajghatta, Chidanand, "US Curbs on Pakistan Lab over Ghauri," *Indian Express* (internet edition), (May 5, 1998); and "US Imposes Sanctions on KRL," *Korean Firm*, (May 5, 1998).

30. For a more extensive discussion of North Korean-Pakistani missile cooperation, see Bermudez, Joseph Jr., "DPRK-Pakistan Ghauri Missile Cooperation," to be published.