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Assessment of Pakistan's Babur-HATF 7 Cruise Missile

Executive Summary

Pakistan has developed the Babur subsonic cruise missile and conducted five flights of the missile between August 2005 and December 2007. The range of the missile was stated to be 500 km in the initial flights. However, an increased range of 700 km was claimed in the latest flight. There was also a suggestion that the range may be further increased to 1000 km. While the Pakistan media have shown pictures of the missile in the static and flight conditions, no dimensional or mass details of the missile have been officially released.

An assessment of the missile dimensions has been carried out by studying these images. It is surmised that the missile diameter may be 560 mm and the total length 6.6 m. Other features of the missile have also been outlined.

The compartment lengths for the major missile subsystems have been worked out based on available information on the US Tomahawk missile. Data provided by small gas turbine engine manufacturers and industry practice. The subsystem masses have also been worked out and the total mass of the cruise missile is assessed to be 1039 kg with a fuel content of 120 kg. The missile payload is assumed to be 450 kg.

The missile range is computed using Tomahawk missile aerodynamic data. There is sufficient commonality in shape and dimensions between the Babur and the Tomahawk to justify this assumption. Our analysis indicates that the claimed range of 500 km for the missile is achievable.

Our assessment also indicates that the range could be extended to 700 km by internal re-engineering to house extra fuel. However, for extending the range to 1000 km, the missile length will have to be increased by about 0.75 m.

A brief assessment of the missile manufacturing capability is also provided.

During the preparation of this report, Pakistan launched an Air Launched Cruise Missile, Raad on August 25, 2007. The Raad pictures have also been studied. Our preliminary findings indicate that the missile is different from the Babur. The Raad missile is 4.86metres long and has a diameter of 880 mm.

Introduction

Pakistan took the world by surprise by flight testing the Babur cruise missile for the first time on August 11, 2005. According to Jane's Defence Weekly[1], the missile range was 500 km with terrain following features. The missile was developed by Pakistan's National Engineering and Scientific Commission (NESCOM). Subsequent launchings of the missile have taken place on March 21, 2006, March 22, 2007, July 26, 2007 and December 11, 2007.

1 "Pakistan Tests Cruise Missile", Jane's Defence Weekly, 17 August, 2005

In the flights carried out in 2007, the range claimed was 700 km—200 km more than the first flight. There has been widespread speculation that Pakistan had access to unexploded Tomahawk BGM 109 cruise missiles launched by the US on targets in Afghanistan[2] and the Babur is the result of reverse engineering the Tomahawk missile. There are obvious similarities in the two missiles. Dr Samar Mubarak Mand[3] in a TV interview dated March 27, 2005 has stated that the Babur missile is an indigenous development and the March 22, 2007 flight had a range of 700 km. He has also stated that the missile carried 5 cameras onboard to aid the TERCOM capability and the missile could fly at altitudes as low as 50 or 100 m. According to him, the missile is at an advanced stage of development and production will be taken up soon. There are reports that the range is planned to be increased to 1000 km.[4] Static and flight images of the missile are available in the public domain though it is difficult to relate these images to specific launches of the Babur taking place on specified dates. This paper examines the available images, gauges the dimensions of the missile and then tries to assess its performance.

Comparison between the Babur and the Tomahawk Missiles

The images of Tomahawk[5] and Babur[6] are shown in figure 1. As can be seen there are broad similarities in the missile airframes. Both the missiles are initially boosted by a solid rocket motor. The interface between the booster and cruise stage are similar. The Tomahawk missiles are equipped with four foldable tail fins. The Babur picture shows 3 fixed tail fins in place. The cruise missile airframe is cigar shaped in both cases and the location of the air intakes also appear to approximately match. The images of the Babur missile in the public domain are either images of the missile on the ground or in the boost phase of their flight with the wings in the undeployed condition. Therefore, no inference can be made on the shape of the wings, their dimensions or their location in the fuselage section of the cruise missile.

Figure 1: Tomahawk and Babur Missiles

2 "Cruise Missile Technology Proliferation Takes Off", Robert Hewson in Janes Intelligence Review, October 01, 2005

3 Dr Samar Mubarak Mand-Babur Cruise Missile. TV interview at http://www.youtube.com/watch?v=-8OnJLoRhmo

4 Babur-Pakistan's Cruise Missile, see http://www.pakmilitary.net/army/arsenal/cruise_missile.html, generated 25 Sep, 2007

5 "Tomahawk Cruise Missile BGM 109 A Configuration Overview" available at http://www.fas.org/man/dod-101/sys/smart/tlam-a.jpg

6 "Babur6.jpg" available at www.defencetalk.com/pictures/showphoto.php/photo/8176/si/Pakistan

No details of the dimensions of the Babur missile or its payload capabilities have been made public by Pakistan. One source states that its length is 7m[7]. Information in the public domain seems to suggest that the dimensions of the Babur will be similar to that of the US Tomahawk cruise missile. Some important specifications of the US Tomahawk missile are shown in Table 1.

Table 1: Tomahawk Specifications

Detail	Tomahawk[8]
Total Length	6.25 m
Cruise Missile Length	5.56 m
Payload	450 kg
Wing span	2.62 m
Lift off mass	1440 kg
Booster burn duration	12 sec

A Tomahawk ground test video shows the sequential deployment of fins and wings during a booster burn followed by the jettisoning of the booster. The air intake deployment is not seen in this video[9]. An early animated video of Babur launch shows similar sequence, but it would be wrong to derive any timing events from the video. However, a launch video[10] provides some limited information. The estimated occurrence of flight events derived from the video of both Tomahawk and Babur are compared in Table 2.

Estimate of Overall Dimensions

Two static images and a few flight images of the Babur are available in the public domain. As already stated earlier there is no certainty that an image shown along with the report of the launch actually corresponds to the launch of the missile on a particular date. The image shown could be an earlier file picture and not an image of the actual launch. Dimensions of the missile are derived in a similar way as was carried out in an earlier study on ballistic missiles[11]. Figures 2 and 3 show a sample of the images[12] analysed for getting the various dimensions of the missile.

Table 2: Video estimation of flight events

Event	Estimated from ground test/flight video	
	Tomahawk	Babur
Solid Booster Ignition	T_0	T_0
Tail Fin Deployment	T_0 + 9 sec	Fixed tail fins
Wing Deployment	T_0 + 11 sec	Not observed/observable
Booster Burnout	T_0 + 14 sec	T_0 + 17 sec
Booster Separation	T_0 + 19 sec	Not observed

7 n. 4

8 Data for RGM/UGM-109A/B/C/D, see http://www.astronautix.com

9 Indian Head Division, Navsea Warfare Centers, RGM109C Tomahawk Functional Ground Test, 24, January, 2000

10 PakistaniDefence.com-Hatf VII "Babur" Cruise Missile, Test Fire Number 2. see www.youtube.com/watch?y=ydmizCzn9Cl

11 S. Chandrashekar, Arvind Kumar, Rajaram Nagappa: "An Assessment of Pakistan's Ballistic Missile Programme", R5-06, NIAS Study Report-2006.

12 http://www.pakistanidefence.com/images/BaburCruiseMissilePictures.htm

Figure 2: Babur Images

Image 1 shows the missile underslung on a rail launcher. The upper part of the airframe is between the rails and therefore the full diameter of the airframe is not visible. In this image, the solid rocket booster is also not seen completely. The air intake is visible between the two hydraulic pistons used for elevating the launcher boom. The forward nose section attachment to the cylindrical part of the airframe is not distinguishable. A conical attachment between the booster and the cruise part of the missile can be made out. The booster is painted grey.

Image 2 represents the Babur in flight. From the image it is apparent that the diameter of the rocket booster and the diameter of the cruise missile are the same. The booster and cruise interface is not distinguishable. The booster is painted grey. This could well be the flight image of the missile seen in Image 1.

Image 3 also shows the missile underslung on a rail launcher. The full length profile of the missile is seen in this image. The air intake is aligned with the launcher hydraulic pistons and is not visible. A black band appears to be the interface between the missile nose and the cylindrical section of the airframe. The jet vane control system can be made out at the aft end of the rocket booster. The booster is painted red.

Image 4 is another image of Babur in flight. This image also confirms that the booster and cruise airframe diameters are identical. The nose cone portion is distinguishable. The booster is painted red and has a white band painted nearly midway. This could be the flight image of the missile seen in image 3 (the white band on the booster identical to the flight image is not visible as it is hidden by the launcher rear frame). In addition to these some more flight images were studied.

Figure 3: Babur Images

In images 1 and 3, a ladder is seen at the aft end of the launcher. The ladder rung width could be a possible calibrator for determining the missile dimensions. The rung width based on various standards is estimated to be either 250 mm or 300 mm. As image 3 is the only picture showing the full length of the missile, this image is used for estimating the missile dimensions. Table 3 shows the dimensions derived from image 3. Distances indicated are from the missile nose tip.

Table 3: Inferred Babur Dimensions from Image 3

Component	Length corresponding to rung width of	
	250 mm	300 mm
Total length	5.49 m	6.60 m
Booster length	1.18 m	1.42 m
Sustainer length	4.31 m	5.18 m
Booster diameter	0.471 m	0.566 m
Nose cone section	0.42 m	0.5 m
Sustainer to total length ratio	0.79	0.785
Length to diameter ratio	11.65	11.58

Table 4: Dimension ratio derived from flight images

Image No.	Length/Diameter	Sustainer to Total Length ratio
2	14.3	0.80
4	11.95	0.81
5	10.78	0.82
6	11.73	0.80
7	11.56	0.81
8	8.7	0.81
3	11.58 to 11.65	0.79

From this it would appear that the length of the Babur Cruise missile can be estimated to be between 5.49 and 6.60 metres. These estimates of the overall length and the estimates of length of the major sections of the missile will constitute the basis for assessing the performance.

The flight images shown in figure 2 and a few other flight images were examined. Since there are no calibration sources for the images which show Babur during flight they can only be useful for deriving some ratios. These ratios can serve to corroborate our analysis. Table 4 lists the ratios derived from these images and their comparison with data from table 3.

From Tables 3 and 4 the following points emerge:

a. There is good correspondence among the images in respect of the sustainer length to the overall missile length ratio. The average value is 0.81.
b. Except in two instances (image 2 and image 8) the length to diameter ratio is also close. One does not expect the diameter to be arbitrarily changed in these two cases and obviously the diameter arrived at in these two images is in error.
c. The sustainer length to the total length ratio in these two images also is close to the average observed values.
   The measurement in image 3 is calibrated using the ladder rung width and the diameter measurement from this image should be close to the actual. The length to diameter ratios from images 4 to 7 are close to the ratio derived from image 3 and hence the average value of the length to diameter ratio can be taken as 11.51.
d. The static image 3 provides the maximum details—both the ends of the missile are visible and the rocket booster diameter can be gauged from the projection behind the launcher rail.

e. In the absence of exact value of the rung width, it is fair to state that the missile diameter is between 471 to 566 mm; the rocket booster length could fall between 1.18m and 1.42 m; and the sustainer length between 4.31 and 5.18 m.

f. The missile dimensions derived by using a rung width of 300 mm are close to the Tomahawk dimensions.

The Abdali ballistic missile motor has a diameter of 560 mm. Obviously it is easy to adapt this motor with a reduced length for the Babur as it would save the time and cost of a new development. The current dimensions of Babur missile are not compatible for fitting he missile inside the Pakistan Navy's Agosta 90 B submarine which have a torpedo tubes diameter of 533 mm[13]. Consequently, the dimensions worked out in table 3 corresponding to a rung width of 300 mm maybe closer to the Babur dimensions. Making allowance for the booster to sustainer attachment, booster separation system and the jet vane control system, the cylindrical length of the motor chamber works out to 1 m, capable of housing about 400 kg of solid propellant. The average thrust obtained from such a booster will be about 55 kN giving a thrust to weight ratio of about 3.5 for the missile at take-off.[14]

Dimension and Mass Assessment

A cutaway section of Tomahawk BGM 109A[15] cruise missile is shown in figure 4. The length of each subsystem compartment is estimated as a percentage of the total cruise missile length and is shown in table 5. This is used along with other information and engineering judgement to work out the subsystem lengths for Babur as detailed below.

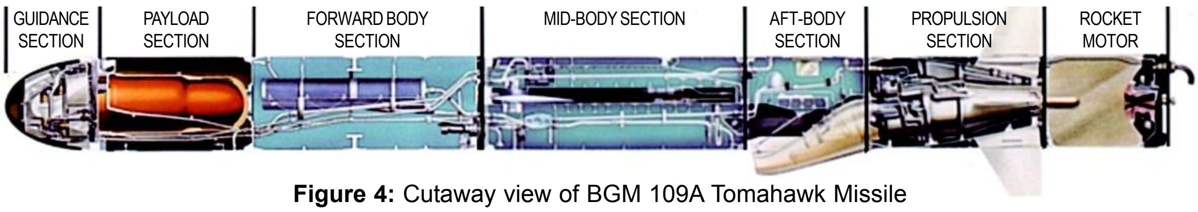

Figure 4: Cutaway view of BGM 109A Tomahawk Missile

Table 5: BGM 109A Subsystem Length

Missile Section	**% of Length**	**Length**
Guidance Section	8.6	0.48 m
Payload Section	15.5	0.86 m
Fore Body (Fuel Tank)	22.8	1.27 m
Mid Body (wings & fuel tank)	24.6	1.37 m
Aft Body (Intake & fuel tank)	11.2	0.62 m
Engine	17.3	0.96 m
Total	100	5.56 m
Rocket Motor	—	1.42 m

[13] n.1:"Ultimately, Pakistani officials said, the Babur is being developed for land and submarine launched applications, with a longer-term goal of making it suitable for airborne launch. The Pakistani source said that the intention is to have the Babur deployable on the country's French designed Agosta 90B-class attack submarines, although he noted it does not appear that the missile is small enough to fit into 533 mm torpedo tubes in its current configuration".

[14] n.11, page 8, footnotes 18 & 19

Guidance Section: In images 2 and 3 shown in figure 2, the joint of the nose cone and the missile cylindrical section is clearly marked. The length of this section is measured as 0.5 m (see table 3). In addition to the guidance system, allowance has to be made for the homing device, onboard power and avionics requirements. A provision of 1 metre is provided for the guidance section.

Payload Section: This section is taken as equivalent to 15% of the total length close to the 15.5% provided in Tomahawk. The length is rounded off to 780 mm.

Mid Body: The mid body has to house the wings, the wing deployment mechanism, the battery, the avionics and if space permits an auxiliary fuel tank. The wing span for the Tomahawk is reported to be 2.62 m. It is expected that Babur will also have a similar span as it would be difficult to accommodate a longer span without compromising on the fuel tank volume and hence on the range. The length requirement is kept equal to 1.4 m to accommodate the wing semi-span and the deployment mechanism.

Engine: A survey of small gas turbine engines[16] was carried out (see Appendix 2). It was noted that the diameter of such engines is in the range of 300-350 mm, length in the range of 800-1100 mm and weight in the range of 65-100 kg. Williams International F 107-WR 402 which powers the Tomahawk is one of the most advanced turbofan engines, but is unlikely to be available to Pakistan. The other candidate choices are the Chinese WP-11 engine which powers their WZ-5 drone and the Ukrainian MS 400 engine. Only the thrust and the length of WP-11 are listed, while the MS 400 specifications are more detailed.

The specifications[17] of the MS 400 engine are listed below:

Manufacturer	Motor Sich, Ukraine
Maximum Thrust	3.92 kN
Specific fuel consumption	≤ 0.8 kg/kgf-hr
Diameter	320 mm
Length	1100 mm (with elongated exhaust stack)
Height	455 mm (including mounting elements)
Dry mass	85 kg

Based on the survey of small engines, the Babur engine is estimated to be 0.9 metre long with a dry mass of 100 kg including mounting elements.

Air Intake: The air intake has to ingest the required quantum of air, allow its smooth passage and flow as it turns into the engine. The small inlet length of 0.62 metre in the Tomahawk is probably achieved by highly efficient design of the intake / engine system integration and may not be possible to replicate in all cases. Therefore a more conservative number of 0.85 metre is assumed for the Babur intake length.

Fuel Tank: The remaining length is the provision for the main fuel tank. The tank length works out to 0.25 metre.

15 Carlo Kopp, 'Tomahawk Variants', Air Power, Australia, Mar 01, 2007

16 Aviation Week & Space Technology, Aerospace Source Book 2007, Jan 15, 2007

17 Manufacturer's data sheet (http://www.motorsich.com/eng/products/aircraft/tde/ms400/)

The subsystem lengths estimated above are shown in table 6 and sketched in figure 5.

Table 6: Babur component system dimensions

Missile Section	Estimated Length	
	Tomahawk	**Babur**
Guidance Section	0.48 m	1.00 m
Payload Section	0.86 m	0.78 m
Fore Body (Fuel Tank)	1.27 m	0.25 m
Mid Body (wings & fuel tank)	1.37 m	1.40 m
Aft Body (Intake & fuel tank)	0.62 m	0.85 m
Engine	0.96 m	0.90 m
Total	5.56 m	5.18 m

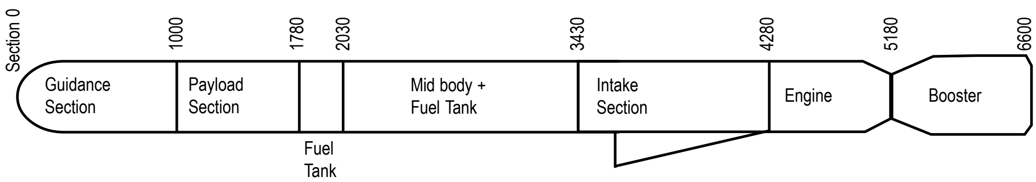

Figure 5: Babur Dimensioned Sketch

An exercise was carried out to determine the mass of the various component systems using the dimensions derived above, manufacturer's data and the Tomahawk missile data as references. The estimates are summarized in table 7.

Table 7: Babur subsystem massess

Missile Section	**Mass**	**Remarks**
Guidance	105 kg	Tomahawk guidance mass is 95 kg[18]. This is derated by 10% for Babur to account for difference in the state-of-the-art. This will include an inertial guidance unit, cameras, altimeters with processors, for terminal guidance and also some GPS navigation capabilities.
Payload	450 kg	This could be a small nuclear payload though currently Pakistan may only be able to make a warhead in the 700 kg class.
Engine	100 kg	MS 400 manufacturer's catalogue + addition for mounting brackets.
Airframe	264 kg	Taken as 25% of the total mass. This is a reasonable assumption based on realisable engineering data.
Fuel	35 + 85 kg	35 kg in the fore body region, assuming 85% of the volume is available for fuel. 85 kg in the mid body region, assuming 40% of the volume is available for fuel over a length of 1.3 m. The fuel that will be used is aviation grade kerosene
Total	1039 kg	

[18] George N Lewis & Theodore A Postol, 'Long Range Nuclear Cruise Missile and Stability', Global Security 1992, v 3, Table A1, note b, page 77.

Range Calculation

A typical mission profile for cruise missiles is shown in figure 6. The Babur missile will also follow a similar trajectory. The Babur range is calculated under cruise conditions. The rocket boost provides a small increment to the range and can be separately assessed using normal trajectory calculation methods. The forces acting on the missile under cruise conditions is shown in figure 7. It is obvious that for equilibrium the lift force is balanced by the missile weight and the thrust is balanced by the drag of the missile. As fuel is consumed during flight, the weight of the missile continuously changes, in turn affecting the lift and drag acting on the body. Consequently, the thrust also changes. The lift and drag also vary with the speed at which the missile is travelling. Specific fuel consumption (SFC) is a figure of merit for the engine and is defined as the amount of fuel required for producing unit thrust per unit time. The specific fuel consumption varies to some extent with both the speed of the missile as well as the altitude of operation. However, the variation with speed is small and for a given altitude of operation the specific fuel consumption can be taken as constant.

As already stated, it has not been possible to get an idea of the Babur wing planform or its dimensions, as the authors have not come across any images with the wings deployed. Also there is no information on the powerplant used and its characteristics. In the absence of this information

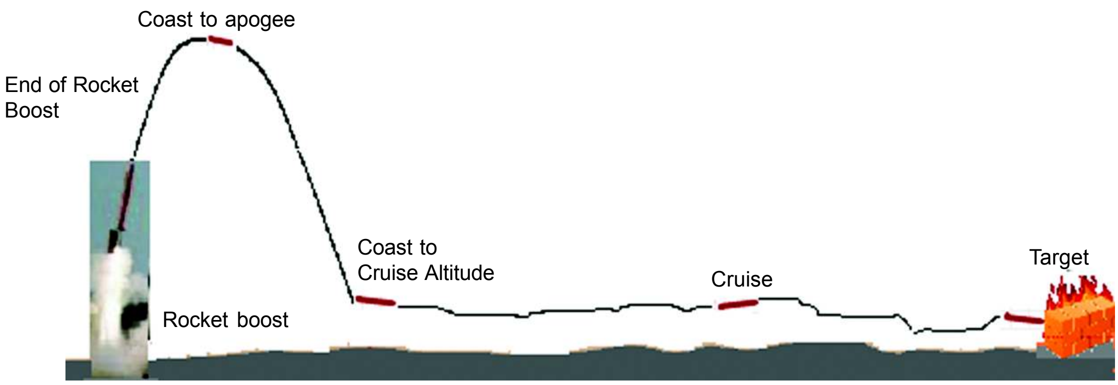

Figure 6: Typical Cruise Missile Mission

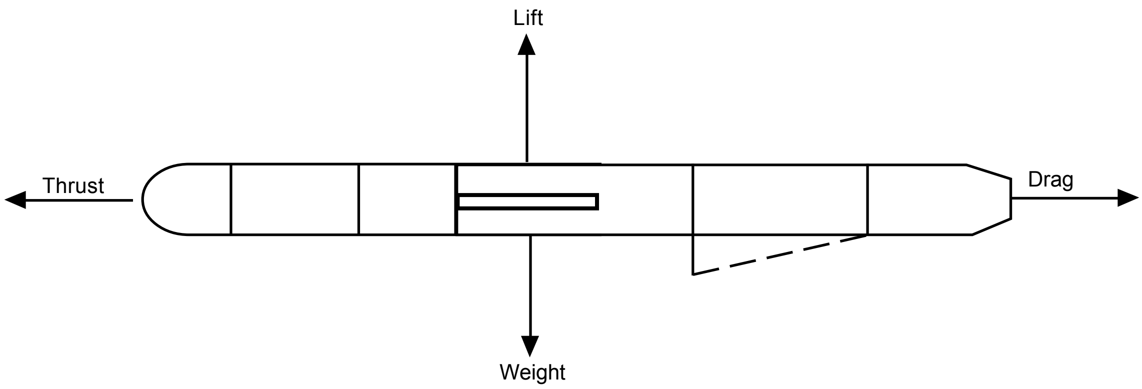

Figure 7: Forces in Straight & Level Flight

certain assumptions have been made as detailed below:

1. The SFC quoted for the cruise missile class of engines is between 0.8 to 1 kg/kgf-hr (see appendix 2).The specific fuel consumption (SFC) is taken as 1 kg/kgf-hour for this exercise.
2. The lift and drag coefficients are dependent on the wing shape and wing dimensions. These parameters are not known for Babur. For the present assessment, the physical data and aerodynamic characteristics of the Tomahawk missile[19] are taken as applicable to Babur. Keeping in mind the resemblance and proximity of dimensions of the two missiles, this may not be very much off the mark. The Tomahawk missile characteristics are:

Wing Reference Area:	1.11 m^2
$C_D = (0.034 + 0.071\, C_L^2)$	C_D and C_L being the drag and lift coefficients respectively

3. The initial mass of Babur is taken as 1039 kg as computed in table 7. The final mass is taken as 930 kg. This final mass assumes that 10% of the fuel mass is left entrapped in the engine and the plumbing.

For range calculation, the mass of the missile at the start of the cruise is the starting point. Equating this mass to the lift of the missile under steady level flight conditions, the lift coefficient and the drag coefficient and the drag are computed. This computed drag is equal to the thrust of the engine and is used to calculate the mass flow of the fuel (product of SFC and Thrust gives the mass flow). This mass flow over the selected time interval indicates the mass of fuel consumed in that time interval. The initial mass is reduced to this extent and the performance parameters are again computed for this condition. The computation is repeated till the fuel is fully consumed. The range is the product of the velocity and the total cruise duration. The summary result is shown in the box below:

Cruise Velocity	204 m/s (M 0.6)
Cruise Time	53 minutes
Average Drag	1196 N
Range	648.7 km

For this computation the average value of C_L/C_D works out to 8.076. This value is solely based on Tomahawk data and may not be fully applicable for computing the Babur performance. It is possible that the aerodynamic efficiency of the Babur missile may be lower than that of the Tomahawk. The range computation is repeated by increasing the C_D by 15%. The range works out to 545 km as summarised below.

Cruise Velocity	204 m/s (M 0.6)
Cruise Time	46 minutes
Average Drag	1376 N
Range	545 km

It must be noted that this is the straight range. In a standard cruise missile mission, there will be flight segments involving climb and descent based on the flight terrain. There could also some manoeuvres and requirements of loiter. This would render the actual range achieved to be less

[19] n.15, pp77-78

than the achievable straight flight range. The initial rocket boost contributes very little to the range and is estimated to be about 10 km.

It can therefore be safely concluded that the Babur cruise missile based on the dimensions assessed from the images and the derived subsystem dimensions and mass estimates is capable of achieving the claimed range of 500 km.

Range Improvement of Babur

An improvement in the range is claimed for the Babur missile in the flight carried out on July 26, 2007[20]. There have also been claims of further range improvement to 1000 km. The question is what does it take to achieve range increase to 700 or 1000 km. The missile will obviously have to carry extra fuel for this purpose and will need either extension to the existing fuel tanks or will need additional fuel tank. The additional volume required to house this additional fuel is computed and shown in table 10 in terms of additional length requirement.

Table 8: Fuel Requirement for Increased Range

Range, km	Extra Fuel required	Length increase
700	40 kg	0.30 m
1000	105 kg	0.75 m

The additional fuel required for range extension to 700 km can be accommodated without increasing the missile length. This can be achieved through re-design of the mid-body tank volume for efficient fuel loading—increase to 60% volumetric loading against 40% assumed in the present calculation. Also additional tankage space can be considered in the aft body in the intake section. However, for range extension to 1000 km, tank length increase by about 0.5 to 0.75 m will be necessary. Such an increase in length should be discernible in the relevant missile images.

The other scenario to achieve higher range without any configuration change is to fly with a payload less than 450 kg. The payload achievable for different range values is shown in figure 8.

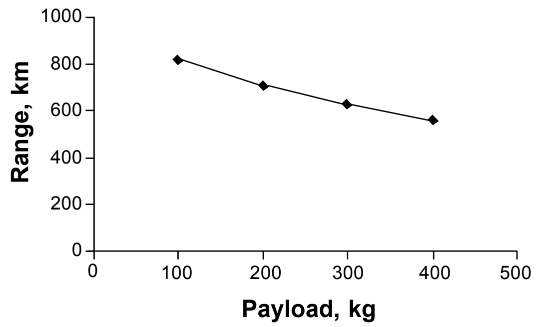

Figure 8: Payload versus Range

It can be seen that a payload of the order of 220 kg can be flown for a range of 700 km and no sensible payload is possible for 1000 km range within the constraints of the present Babur dimensions.

Manufacturing Capability

Pakistan has conducted five flights of the Babur missiles so far. The flight dates are Aug 11, 2005, March 21, 2006, March 22, 2007, July 26, 2007 and December 11, 2007. This would mean that the design and development studies must have been completed prior to August 2005 including wind tunnel tests, structural tests and engine static tests. The frequency of launch suggests at least a limited series production maybe in place.

[20] Islamabad: Pakistan Tests Nuclear-Capable Missile, AFP, July 26, 2007 available at http://www.spacewar.com/reports/Pakistan_Tests_Nuclear_Capable_Cruise_Missile_999.html

The cruise missile fabrication is a major exercise in system integration. Subsystems like the airframe, engine, avionics, the terrain following and matching systems and the warhead could come from different sources and have to be electrically and mechanically integrated, acceptance tested and delivered.

The Pakistan Aeronautical Complex[21] has capabilities in aircraft building, maintenance and overhaul. It is building the JF 7 fighter with Chinese collaboration. The Mushshak trainer is an all metal aircraft with fuselage length comparable to that of Babur missile. Pakistan will obviously draw upon these established capabilities for realizing the missile airframe. Besides, the Aeronautical Complex has capability in avionics and system integration. The Babur launch and flight environment are not as hostile as that of ballistic missiles and therefore the bulk of the avionics can be configured with Commercial-Off-the-Shelf (COTS) components.

The Babur missile is claimed to be equipped with terrain hugging and stealth characteristics capable of hitting targets with pin point accuracy[22]. These attributes will require the missile to be equipped with TERrain COntour Matching (TERCOM) and Digital Scene Matching Area Correlator (DSMAC) features. Use of commercial class inertial navigations system along with flight path correction during crucial phases of the missile flight using TERCOM to steer the missile to its target is fairly standard practice. TERCOM consists of radar altimeter and pre-stored altitude profiles of select terrain locations along the planned missile flight path. The INS is reset and the flight course of the missile is corrected using the radar altimeter measurement and the comparison with the stored data, as the missile flies over or in the vicinity of the select terrain locations. Course updates are typically required during the inertial leg, mid-course and towards the terminal leg of the flight path. The terminal phase will however, depend upon the DSMAC for accurate target pointing. Here also a set of images need to be stored in the onboard computer for comparison with the real time images from the missile cameras which are activated in the terminal phase of the missile flight. On obtaining a match, the missile heading is appropriately corrected to impact on the target. A pre-requisite is the contour maps of the area along the flight paths. Extensive survey maps of British India covering both Indian and Pakistani territory are available in survey offices in Pakistan and would have been updated through further reconnaissance/satellite imagery. TERCOM technology is not complicated, but is volume intensive as data of large number of targets each associated with many approach terrain paths have to be visualized.

Pakistan has some level of manufacturing capability of aerospace systems. While it is difficult to quantify the capability, it is substantial. Maintenance and overhaul of fighter aircraft, joint fighter aircraft development with China, commercial aircraft maintenance and export efforts for Mushshak trainer and the Baaz drone are indicative of this capability. Pakistan does not have any gas turbine engine manufacturing capability at the present time and has to depend on external sources for the procurement of the engine. It can also be safely assumed that

[21] Pakistan Aeronautical Complex, Kamra, http://www.pac.org.pk/amfsite-final/jf17.html

[22] Hatf-7 Babur Cruise Missile, April 13, 2007 available at http://www.pakistanidefence.com/Nuclear&Missiles/BaburCruiseMissile_info.htm

Pakistan depends on external sources for procurement of structural materials, fasteners, adhesives, resins, electronic components and other aerospace materials[23].

Epilogue

On 25 August 2007 Pakistan launched an Air launched Cruise Missile. The missile named Raad (meaning thunder) was launched from a PAF Mirage IIIE or Mirage 5 platform and was said to have a range of 350 km. No images of the flight were immediately released and it was initially speculated that the Babur missile without the rocket booster could have been used for this purpose.

The Pakistan Air Force has a large fleet of Mirage IIIE and Mirage 5 aircraft. The Mirage rebuild factory at Kamra has capacity and capability to service and maintain the Mirage aircrafts. The Mirage has hard points on the wings and fuselage for taking on a variety of armaments. The 5.1 m long and 1230 kg heavy Apache cruise missile is a fairly standard armament on the Mirage.

Some video images of the missile[24] are available in the public domain and the missile is seen to be quite different from Babur. The missile image is reproduced in figures 9. The aircraft carrying the Raad missile is Mirage IIIE.

The missile appears to be stubby in comparison to Babur. The wings are mounted in the lower fuselage section. The tail configuration is also different than that of Babur and appears to be

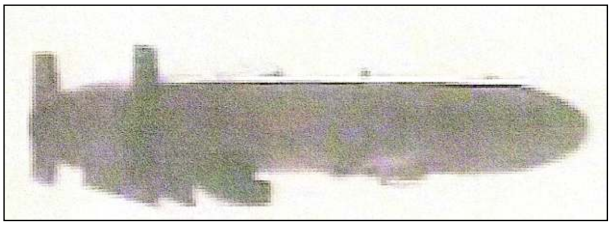

Figure 9: Raad Missile & Mirage Platform

made up of a forward tail section and an aft tail section. The haziness of the image (the stand-alone image taken from the flight video may be an animated version) makes it difficult to gauge if the projection aft of the air intake is part of the forward tail section or a part of the structure. As the Mirage IIIE aircraft dimensions (Length 15m, Wingspan 8.22m and Height 4.5 m) are clearly known[25] and as the fore and aft ends of the missile are clearly visible under the aircraft belly, it is possible to estimate the missile length and diameter. These dimensions work out as:

Missile Length	4.86 m
Missile Diameter	0.88 m

The claimed range of Raad is 350 km. A more detailed assessment of the Raad missile on the lines of Babur missile is not attempted at this stage.

23 Based on details from “International Log & Supply Chain” available at http://www.pac.org.pk/amfsite-final/New%20Ret%20%204%20Web%20List.xls

24 “Pakistan Successfully Tests New Hataf -8 Air Launched Cruise Missile”Image available at http://www.youtube.com/watch?v=HJNppgV7tFk&mode=related&search= and http://www/defence.pk/hatf-VIII_raad_alcm.html

25 Mirage III/5 (Dassault-Breguet) available at http://www.globalsecurity.org/military/world/europe/mirage -5-specs.htm

Conclusion

An attempt is made to derive the dimensions of Babur cruise missile from images of the missile available in the public domain. An assessment of the missile performance has also been carried out to confirm and validate the claimed range. The missile's capability to meet the higher range is also examined and it is surmised that with some re-engineering in the fuel tank and the mid-body regions the range of the missile can be extended to 700 km. However, to achieve a range of 1000 km, the missile length has to be increased by about a metre to carry additional fuel. It is our view that Pakistan has adequate capability and infrastructure to manufacture the missile airframe, indigenously but procures the engine from external sources. The same approach would have been followed in the development of Air Launched Cruise Missile, Raad also. While, it is difficult to estimate the resources/priority allotted for the manufacture and hence the numbers likely to be produced annually, it can be stated that Pakistan possesses the capability to design, integrate and fly cruise missiles. Pakistan at a later date might modify the dimensions of the missile to fit into the Agosta 90B submarine torpedo tube.

Appendix 1: Cruise Missile Comparison

Particular	Tomahawk	AS 18	KH55	KLUB	BABUR	
					Pak military[26]	Current assessment
Total Length Sustainer Length	6.25 m 5.55 m	Air launch —	Air launch 8.8 m	8.51 m —	7.00 m —	6.60 m 5.18 m
Diameter	0.52m	0.38 m	0.76 m	0.77 m	—	0.56 m
Span	2.62 m	5.63 m	—	3.1 m	6.75 m	2.62 m (assumed)
Chord	0.43 m	—	—	—	—	—
Aspect Ratio	6	—	—	—	—	—
Gross Take-off weight	1184 kg	928 kg	1701 kg	1996 kg	—	1556 kg (including 500 kg booster mass)
Payload	450 kg	314 kg	—	400 kg	—	450 kg
Range	2400 km	344 km	2867 km	350 km	500/700 km	500 km
Engine	F107	Saturn36	Turbofan	Turbojet	Turbojet/ Turbofan	MS 400
Thrust	2.7 kn					3.92 kn
Remark	Booster L 0.7m Thrust:26.7kN Time: 12 s	M=0.8	M=0.77	M=0.6-0.8	These dimensions are not sub-stantiated.	Booster L 1.4 m, Thrust: 55 kN Time: 17 s

[26] Babur – Pakistan's Cruise Missile at http://www.pakmilitary.net/army/arsenal/cruise_missile.html

Appendix 2: Small Gas Turbine Motors

Engine	Max SL Thrust, lb	SFC lb/lb-hr	Dimensions, in		Dry Wt, lb	Application
			Dia	Length		
TJM 3	441	1.17	14	34	102	UAV's & target drones.
TJM 4	639	1.12	14	43	123	Mfrr: Mitsubishi, Japan
DGEN PI 380	574	0.436	22.4	47.5	150	Under development
DGEN PI 390	740	0.452	22.4	475	150	Mfrr: Price Induction, France
J104-AD-100	485	1.24	11.6	19.4	41	UAV's & Missile Targets
Model 120	229	1.27	8	16	23	Mfrr: Rolls Royce, UK
TRI40-4	787	1.18	11	28	93	Missile powerplants & drones.
TRI60-1	787	1.18	13	42	116	Mfrr: Safran Group, France
TRI60-2	830	1.26	13	44.8	114	
TRI60-3	900	1.28	13	53.2	150	
Arbizon3B2	907	1.12	16.1	53.6	253	Missile powerplants
Arbizon3D	936	1.08	17	54.2	253	Mfrr: Matra/BAE/Alenia
J402CA400	660	1.2	12.5	29	102	Missile powerplant
J402CA702	960	1.03	12,5	33	138	Mfrr: Teledyne, USA
F107WR101	600		12	48.5	146	Missile power plants
F107WR105	750	—	12	38.25	—	Mfrr: Williams International
FWR400	700		9.5	32	—	
WP-11	860	—	—	—	—	Powerplant for WZ-5 drone

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