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Rajaram Nagappa

List of Abbreviations

AP	Ammonium Perchlorate
Al	Aluminum
ASFC	Army Strategic Forces Command
CEP	Circular Error Probable
CP	Carbon Phenolic
EPDM	Ethylene Propylene Diene Monomer
FLSC	Flexible Linear Shaped Cord
FRP	Fibre Reinforced Plastic
HTPB	Hydroxyl Terminated Poly-Butadiene
IGMDP	Integrated Guided Missile Development Programme
INCOSPAR	Indian National Committee for Space Research
IRNA	Islamic Republic News Agency
MTCR	Missile Technology Control Regime
NDC	National Defence Complex
NDE	Non Destructive Evaluation
NTI	Nuclear Threat Initiative
PVC	Poly Vinyl Chloride
R&D	Research and Development
SP	Silica Phenolic
SUPARCO	Space and Upper Atmosphere Research Commission

Assessment of Ballistic Missile Production Capacity in Pakistan

Summary

Pakistan has an active ballistic missile programme comprising four missiles based on solid propellant and one missile based on liquid propellant. Frequent reports are seen in the media regarding the missile flights along with statements pertaining to completion of troop exercises and handing over to the Army Strategic Force Command. In this report an attempt is made to assess the solid propellant based production capacity and gauge the number of missiles that may be produced and that may be in stock in Pakistan.

It is well known that the Pakistan missile effort has drawn extensively upon French and Chinese inputs pertaining to technology, equipment and materials. At the same time Pakistan appears to have developed capability to indigenously design and realise solid propulsion systems for use in ballistic missiles. Using this and other inputs, an assessment of material requirements is made for the principal subsystems. Process cycle for the propellant and nozzle realisation and the process time are estimated to arrive at the possible throughput in missile propulsion systems. These numbers are compared with the actual reported flight numbers of the missiles to arrive at the possible numbers produced, the number in stock and the deployment status.

It is argued that the Abdali is made in the Space and Upper Atmosphere Research Commission (SUPARCO) propellant plant while the other missiles are made in the National Defence Complex plant located at Fatehjang. It is estimated that the maximum number of propulsion units of Ghaznavi, Shaheen 1 and Shaheen 2 adds to a total of 12 units annually and the current production is lower than this number. The immediate production emphasis will be towards a) preparation of further numbers of Shaheen 1 for handing over to the Army Strategic Force Command by 2008; and b) completion of further flight tests of Shaheen 2. It is estimated that four to five years of full capacity production effort is required for matching the missile numbers to the missile borne nuclear warheads.

Introduction

Pakistan has developed and launched ballistic missiles with different ranges coming under the Hatf 1 to Hatf 6 nomenclature. The missiles have alternate designations like Abdali, Ghaznavi, Ghauri and Shaheen. All the missiles with the exception of Ghauri employ solid rocket propulsion. Beginning with the launch of Hatf 1 in Feb 1989, launch of these missiles has been reported by the Pakistani and the International Press at periodic intervals. Since the year 2002, there is an increase in the launch frequency and range of the missiles. This would indicate that Pakistan's capability to produce solid propellant missile has made substantial progress and is not to be under-estimated. An attempt is made in this paper to assess Pakistan's solid propellant missile production capacity.

Background

The development of solid rockets in India and Pakistan started about the same time in the early 1960's. Both the countries obtained sounding rocket technology from Sud-Aviation of France and set up manufacturing facilities. Both programmes were set up by civilian organisations—the Indian National Committee for Space Research (INCOSPAR) in India and SUPARCO in Pakistan. The similarity perhaps ends there. India went on to build a strong civil space programme improving on the solid rocket technologies and developing other launch vehicle technologies. Missile development in India started later as a totally separate programme and evolved on its own.

The rocket technology attempts in Pakistan on the other hand, after an initial spell of sounding rocket launch activity, went into a period of lull. Perhaps the Indian Guided Missile Development Programme (IGMDP) initiative in 1983 stirred up the missile development activity in Pakistan as evident from the launch of Hatf 1, which more or less coincided with the initial launches of India's Prithvi and Agni missiles. The Hatf 1 was derived from the French sounding rockets—Dragon and Dauphin[1]—and was limited in range and performance. For Pakistan to narrow or annul the technology gap in a short period of time, indigenous development was not the answer. The answer lay in leap-frogging through technology acquisition to aid the indigenous capability and this is what Pakistan set about doing.

By the early eighties, the Chinese had decided to change over to solid propellant systems for their missile programme.[2] By this time their avionics, control and guidance systems had also attained a level of maturity. Adapting them to the solid propulsion systems was fairly straightforward. The DF 15 / M 9 and the DF 11 / M 11 are the better known of the shorter range solid propulsion missiles developed by the Chinese for both domestic use and the export market. The M 9 development started in 1984 and the missile was deployed in 1988. The M 11 development started in 1985 with operational deployment of the missile in 1988. This period matches fairly well with Pakistan's attempt towards missile parity with India. The chronology of missile development in Pakistan and its comparison with the rocket / missile technology status in India is listed in table 1.

[1] See S. Chandrashekar "An Assessment of Pakistan's missile capability", Missile Monitor, Number 3, 1993 For an update see S Chandrashekar, Arvind Kumar and Rajaram Nagappa, "An Assessment of Pakistan's Ballistic Missile Programme: Technical and Strategic Capability" NIAS Report R5-06, Oct 2006, (Bangalore: National Institute of Advanced Studies).

[2] For a detailed documentation of this effort see John Wilson Lewis and Xue Litai, *China's Strategic Seapower: The Politics of Force Modernisation in the Nuclear Age* (Stanford: Stanford University Press, 1994).

Table 1: Pakistani Missile Development Chronology

Year	Indian Event	Pakistani event	Remarks
1960's	Launching of Sounding Rockets Sounding Rocket Production under licence from Sud Aviation, France	Launching of Sounding Rockets Sounding Rocket Production under licence from Sud Aviation, France	SUPARCO launched over 70 sounding rockets such as Judi-Dart, Nike family, Centaure, Dragon and Petrel. Production and assembly facilities would have formed part of the licence agreement.
1970's	Technology indigenisation in the Civil Space programme	No significant event	Lull in SUPARCO activities from 1973
1980's	Major strides in civil launch vehicle programme IGMDP is launched in July 1983. Agni 1 is flight tested in 1989	Establishment of solid propellant plant in SUPARCO HATF 1 is test fired in the late 1980's	China completes the development of M 9 and M 11 missiles. Pakistan signs an agreement with China for the procurement of 34-80 M 11 missile systems and a smaller number of M 9 missile systems[3].
1990's	Operationalisation of Agni 1 and development of variants.	Spurt in the missile development activity. Family of Missiles with different ranges developed. There is an increase in the launch frequency	US intelligence detects missile manufacturing facility at Fatehjang[4]. The facility is reported to be built by the Chinese in 1997 or 1998.
2000's	Flight tests of IGMDP missiles	22 missile launches between 2002 & 2006	

It appears that the Pakistan's Ghaznavi missile is derived from China's M 11 and there are similarities in the missile configurations. The analysis of the missile image confirms the similarities but shows that the Ghaznavi is shorter than M 11 in length[5]. The findings of the analysis are summarised in Table 2.

[3] State Department Posting Text, n. 230, July 2, 1991 (STATE DEPARTMENT ON CHINA: M-11 MISSILE), available at the website: http://www.fas.org/nuke/control/mtcr/news/910702-188884.htm

[4] The details on this manufacturing facility can be seen on the website: http://www.nti.irg/e_research/profiles/Pakistan/Missile/3294_3327.html The facility is stated to be a copy of the M 11 plant in China's Hubei province and is located at Fatehjang a suburb of Rawalpindi

[5] n.1 , S. Chandrashekar, Arvind Kumar, Rajaram Nagappa, pp. 12-13

Table 2: M 11 Ghaznavi Missile Characteristics

Missile	Length, m			Diameter, m
	Warhead	Motor	Total	
M 11	N.A	N.A	11.34	0.89
	3.81 m	5.76 m	9.57 m	
	4.09 m	6.54 m	10.65 m	
	4.80 m	6.17 m	10.97 m	
Ghaznavi	3.76 m	5.05 m	8.81 m	0.91
	4.01 m	4.90 m	8.91 m	
	4.31 m	5.17 m	9.48 m	
	4.11 m	4.80 m	8.90 m	

Another assessment[6] shows the length and diameter of M 11 to be 9.09 m and 1.01 m respectively. Most sources however indicate the diameter to be 0.88 m. The estimated range of this missile is 280 to 350 km with 800 kg / 500 kg payload. This violates the Missile Technology Control Regime (MTCR) export restrictions and consequently, it is possible that the Chinese may have sold a shorter MTCR compliant version of the M11 to Pakistan. The image analysis carried out by Chandrashekar et al confirms the similarity between the shorter version of the M 11 warhead (3.80 to 4 m long) and the one used on the Ghaznavi. The analysis also confirms that the rocket motor is shorter than the M 11 rocket motor. However its estimated range with a 1000 kg and 700 kg payload is 269 km and 347 km respectively. This would suggest that this export did violate MTCR regulations.

Similar co-relationship between the Chinese M 9 and the Shaheen 1 missile are seen. Table 3 provides details of the measurements made by Chandrashekar et al on the Shaheen 1 and the M 9 missiles.

Table 3: Shaheen-1/M 9 Missile Characteristics

Image	Warhead (m)	Motor+nozzle (m)	Length (m)
Image 1 (Shaheen 1)	N.A	N.A	9.62 m
Image 2 (Shaheen 1)	3.71 m	6.18 m	9.89 m
Image 3 (Shaheen 1)	3.56 m	6.36 m	9.92 m
Image 4 (Shaheen 1)	3.28 m	6.40 m	9.69 m
Image 5 (Shaheen 1)	4.27 m	7.15 m	11.43 m
Image 6 (Shaheen 1)	4.81 m	7.88 m	12.69 m
Image 7 (Shaheen 1)	4.45 m	7.18 m	11.64 m
Image 8 (Shaheen 1)	4.83 m	8 m	12.83 m
Image 23 (Shaheen 1)	4.75 m	7.45 m	12.20 m
Image 9 (M 9)	4.41 m	4.45 m	8.86 m
Image 10 (M 9)	4.08 m	4.81 m	8.89 m
Image 11 (M 9)	5.08 m	4.62 m	9.70 m
Image 12 (M 9)	3.53 m	4.87 m	8.40 m
Image 13 (M 9)	4.29 m	4.54 m	8.84 m

6 Mark Wade, “Encyclopedia Astronautica” available at the website: www.astronautix.com/lvs/shkval.htm

The diameter of the Shaheen-1 and the M 9 can be independently verified to be 1 metre. In the case of the Shaheen 1 missile the rocket motor lengths are longer than the rocket motor lengths of the M 9. They also exhibit a trend of progressive increase in lengths showing that Pakistan may have internalised the technology they have obtained from the Chinese and could now do things on their own. The internalisation effort has led to the two stage adaptation for Shaheen 2. The dimensional similarities and the fact that in a short span of five to six years Pakistan could develop, test and operationalise these missiles definitely points to significant technology inputs from China.

A complete missile system comprises the warhead, navigation, guidance and control system to steer the missile, onboard computer and avionics, instrumentation and telemetry system, auxiliary systems and the propulsion system. Our concentration in this paper will be on the propulsion system, which is normally referred to as the missile motor. It is assumed that in all probability Pakistan depends on imports from China for the navigation systems and related electronics. It is also assumed that Pakistan has adequate design and manufacturing capability with reference to the other missile systems.

Description of the Missile Motor

The solid fuelled missile propulsor, normally referred to as a motor, is a system with no moving parts. The main component is the propellant grain, which is either cast in a mould and then assembled into the motor case or directly cast into the insulated motor case. The main ingredients of such a propellant are an oxidiser like Ammonium Perchlorate (AP), elastomers like Poly Vinyl Chloride (PVC) or Hydroxyl Terminated Poly Butadiene (HTPB), for fuel and a metal fuel like Aluminum (Al) powder. Small quantities of other chemical additives like curators, catalysts and plasticisers make up the complete composition.

The motor case is made of alloy steel or Fibre Reinforced Plastic (FRP). The propellant is ignited by a charge containing hot gas / particles. The combustion gases are accelerated through a nozzle which converts the pressure generated by combustion into kinetic energy. For steering the rocket, thrust vector control devices like deflection of aerodynamic surfaces, jet vanes, flexible nozzle bearing systems and fluid injection in the nozzle are employed. As stated earlier, Pakistan has benefitted from French and Chinese technology inputs in its

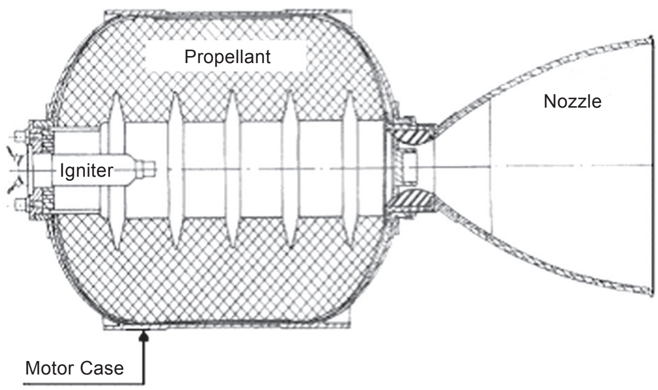

Fig. 1: Schematic of a Solid Fuelled Missile

missile development effort. Table 4 summarises the technology inputs Pakistan would have derived from the French and the Chinese rocket/missile technology transfers.

Table 4: Inputs derived from French and Chinese Transfer of Technology

Motor Component	French input	Chinese input
Motor Case	15CdV6 steel composition, fabrication and testing.	CrMnSiA steels with different percentage of alloying elements, fabrication and testing.
Insulation	PVC tubing	Nitrile and EPDM rubber
Propellant	Free standing AP/PVC Plastisol propellant grains.	Case bonded AP/Al/HTPB grains (China has expertise in other solid propellant compositions too).
Propellant Processing	Raw material preparation, sigma mixers, vacuum mixing, cast/cure, machining and non destructive evaluation (NDE) techniques.	Raw material preparation, vertical mixers, vacuum casting, curing, machining and non destructive evaluation (NDE) techniques.
Nozzle Liner	Moulded asbestos phenolic and silica phenolic liners and paints, graphite throat insert.	Silica and carbon phenolic liners, tape winding process, graphite throat insert.
Igniter	Hot gas and particulate pyrotechnic ignition system.	Pyrogen ignition system.
Thrust Vector Control	None	Jet vane and secondary injection system. Probably flexible bearing system.
Manufacturing	Equipments and machinery for hardware fabrication, heat treatment, pressure testing, propellant processing and non- destructive evaluation, grain charging, assembly fixtures.	Equipments and machinery for hardware fabrication, heat treatment, pressure testing, propellant processing and non destructive evaluation, assembly fixtures.
Testing	Ground test stands and instrumentation.	Single and 6 component test stands and instrumentation.
Separation System	Explosive cord stage separation system.	Flexible Linear Shaped Charge (FLSC) separation system.

Assessment of Pakistani Capabilities

Among the elements of the missile motor described in the previous section, the hardware, the propellant and the nozzle systems are the complex ones, requiring special facilities and manufacturing/processing techniques. These are described below:

1. Missile Case Hardware

It can be safely assumed that the motor casing for all the Pakistani missiles is made of low alloy steel. As indicated in the table above, technology inputs for 15CdV6 steel with yield strength of 800 MPa would have come as part of the sounding rocket technology transfer. Also this material is freely available in sheet and forging form from a number of steel makers in Europe. The fabrication process also follows conventional rolling, welding, heat treatment and machining process and can be manufactured with the appropriate tooling. The Chinese have developed high strength low alloy steels for their missile and space motor applications. Published information indicates that for the JL 1 they have developed a weldable quality steel. For space motor applications, they have developed 45CrNiMoV steel, which has yield strength of 1470 MPa and is equivalent to D6AC steel used in many US rocket motors. The Chinese have developed various steel alloys with carbon content varying from 0.25 to 0.45%. The exact type of steel, the Chinese have used in their M9/M11 programmes is not explicitly spelt out. One can surmise that this will also be a low alloy steel of the type developed for the JL 1. The steel composition and fabrication process including the tooling would form part of the M 11 technology transfer package. The People's Steel Mills Ltd[7] located near Karachi produces alloy and special steels. AISI 4340 produced by the Mill is of aerospace grade and can be used for missile motor case fabrication. The steel can be rolled into sheets and can be forged. It is also amenable for welding and can be heat treated to obtain strength in the range of 1055 MPa. The Mill can produce sheets of 3 mm or higher thickness and hammer forged components upto 2000 kg weight. Consequently, the missile case choice will be 15CdV6 for the earlier missile like Abdali and AISI 4340 for the later missiles like Ghaznavi, Shaheen 1 and Shaheen 2. This will pose no special problems for the fabrication of 1 m diameter motor cases.

2. Propellant System

This is the heart of the missile motor and provides the power for the launch and acceleration of the missile. The propellant system constitutes the major weight of the missile powerplant and accounts for 80-90% of the missile initial mass. Its preparation involves mixing the ingredients into a thick slurry, casting the slurry into the insulated motor case, curing it in an oven and doing the finishing operations. The process as described here appears quite simple, but in actuality, is quite involved and a sequence of steps with due regard to quality and safety have to be taken to obtain an acceptable product.

Mention was made in Table 4 that Pakistan would have obtained the technology of PVC plastisol propellants from France. This is a low energy system using ammonium perchlorate as oxidiser and PVC as fuel, with typical specific impulse[8] in the region of 2050 N-s/kg. The main advantage of the system is that the propellant is free standing and its production is independent of the availability of the motor hardware. Therefore the propellant grains can be separately produced, stored and charged into the hardware as required. From handling and grain sagging considerations, the maximum size of the grain is limited to 700-1000 kg. The Hatf 1, from the similarity of the fin configuration to the French Sounding Rockets appears to be a direct adaptation and would have used the PVC based propellant. Pakistan has however, improved the performance of the subsequent variants of this missile—the Hatf 1A/Abdali and in the process made improvements in the propellant energetics by addition of aluminum

[7] See more information on Peoples Steel Mills Ltd—Typical Grades at http://www.psmltd.com/flow.htm

[8] Specific impulse is defined as the thrust produced per unit mass flow of propellant and is a figure of merit for a propellant system.

or change of composition. They may have replaced the free standing feature of the propellant by directly casting into the case. The production related advantages of a free standing grain system have already been touched upon and it is therefore likely that the free standing grain feature is still retained.

For the larger missiles like the Ghaznavi, Shaheen 1 and 2, the propellant is cast directly into the chamber using what is called the case-bonding technique. The ingredients of this propellant will be ammonium perchlorate, HTPB as fuel binder and aluminum powder. Such systems can provide a specific impulse in the region 2450 N-s/kg. The basic technology would have come to Pakistan as part of the M 11 technology transfer deal and Pakistan would have extrapolated and innovated on the technology for its larger missiles. The author has not been able to obtain authenticated details of Pakistani propellant material production capabilities. It is stated in the NTI's Pakistan profile overview[9], that a propellant plant was established in Pakistan with Chinese help in 1997-98. As per the overview, the Solid Propellant and Chemicals Plant for Missiles owned by the National Defence Complex (NDC) manufactures aluminum powder, ammonium perchlorate oxidiser, HTPB binder, curing agents and other ablative materials. In the absence of any other corroborating evidence, the NTI statement is used as the basis for gauging the Pakistani production capabilities.

Ammonium Perchlorate (AP) is a major constituent in solid propellant compositions. There are reports of ammonium perchlorate imports by Pakistan prior to 1997-98 as evidenced by impounded shipments of AP[10] by Taiwan on 12 March 1996, by Hong Kong on 29 April, 1996 and again by Hong Kong on 13 December 1996. The impounded quantities were respectively 15 tons, 15 tons and 10 tons. From this it would appear that the AP production in Pakistan prior to 1996 was either non-existent or inadequate for the programme. With the commissioning of the NDC plant in 1997-98, this shortfall could have been overcome. This could explain the absence of reports pertaining to import/impounding of Ammonium Perchlorate beyond 1996. Alternately, imports could have continued (Hong Kong reverted to China in 1997) through the land route from China. The other major and minor constituents are either manufactured in the NDC facility or procured from the market. The processing equipments however must have all come from China[11].

3. Nozzle and control systems

The nozzle is made of high temperature resistant materials as the hot combustion gases are accelerated through it. The critical elements here are high temperature erosion resistant materials and their fabrication. The materials are termed as ablative materials and are essentially carbon or silica fabric reinforced plastics. Phenolic resin is the matrix system. Graphite is generally used as the nozzle throat material. As part of the M 11 technology transfer, the Chinese may have supplied the processing equipments but not the technology for producing the raw materials.

[9] On Pakistan see the website: http://www.nti.org/e_research/profiles/Pakistan/Missile/3294_3327.html

[10] Missile Chronology Pakistan 1947-2002. Source: http://www.nti.org/e_research/profiles/Pakistan/Missile/

[11] DX Zhang & DY Ye "*Evolution of Solid Rocket Propulsion Technology for Space Missions in China*" , The Fourth Academy of China Aerospace Science and Technology Corporation.

This guess is made on the premise that the technology for the ablative reinforcements like carbon and silica is quite different as opposed to the propellant chemicals. Also the quantity demand is not very high and it is not difficult to procure these materials from China or through traders. The technology of making large sized graphite blocks indigenously is also difficult and this requirement is also likely to be met through import.

For missile steering purposes, besides using the aerodynamic control surfaces, the Chinese have adopted rotating nozzles and secondary injection in their missiles of 1960/70 vintage (JL-1 for example)[12]. In the later space motors, they have used flexible bearing nozzles[13]. Rotating nozzle is useful only for multiple nozzle systems. As all the Pakistan missiles have a single nozzle, the missile steering will be based on secondary injection, reaction control systems and aerodynamic surfaces.

It may not be difficult for Pakistan to procure all the materials required for making nozzles and control systems. The Chinese trading company <Alibaba.com> founded in 1999 lists many of the materials required for missile propellant and nozzle making.

Production Cycle

The production of the missile is governed by the major subsystem process time. In the missile subsystems listed in the previous section, the motor case will in all probability be supplied by a fabrication industry. Steel fabricators will have the setup for tooling, machining, welding, heat treatment, inspection and pressure testing. The requirement of sheets and forgings can even be procured from abroad to supplement the indigenous production. The processing of propellants and nozzles on the other hand will be mostly done inhouse.

The process steps and production cycle for case bonded propellant systems is shown in figure 2. The process durations are for a Shaheen class of motor. The estimated time requirement for each step is also indicated in the figure.

12 n.2

13 n.11

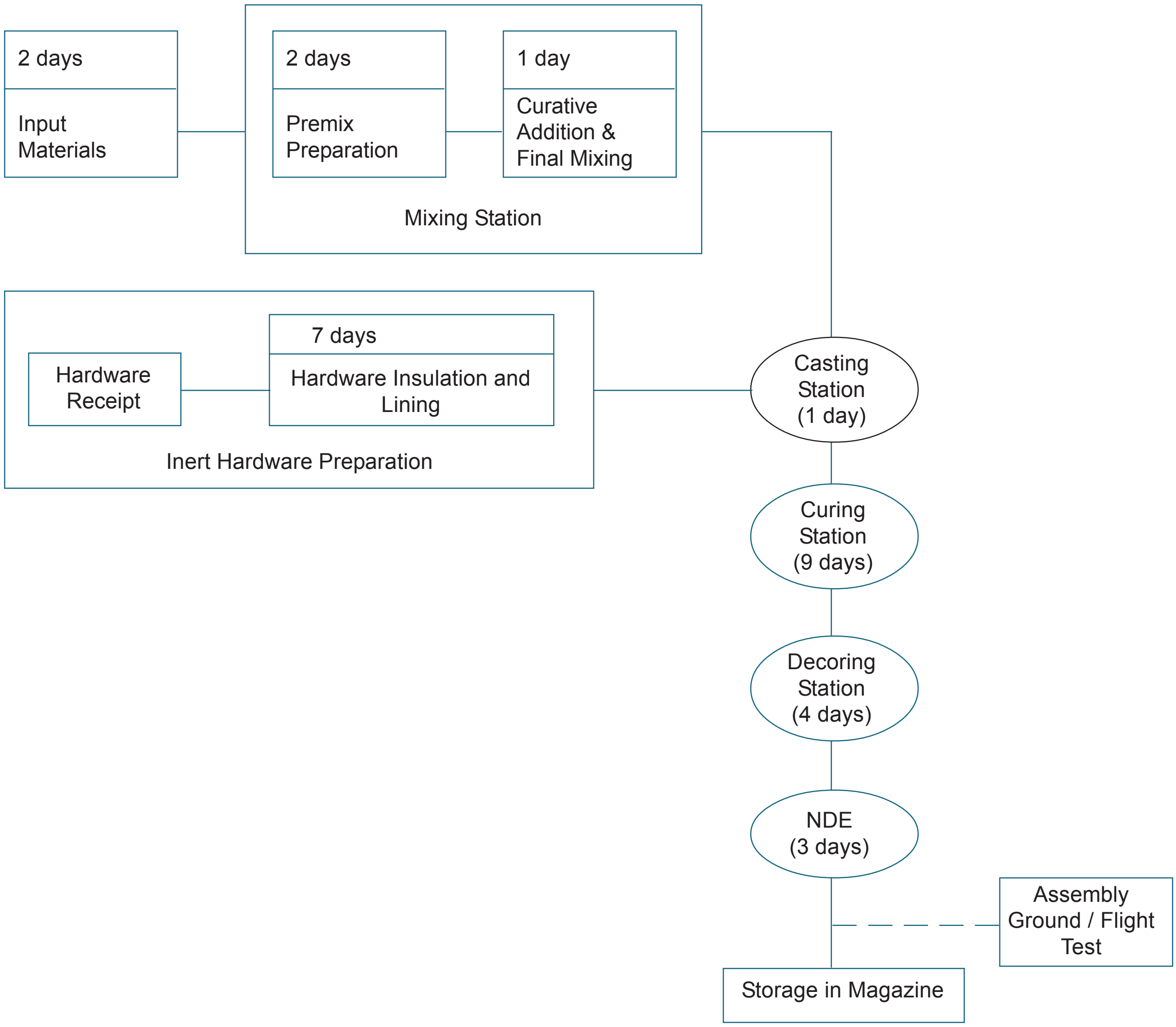

Fig 2: Propellant Process Flow Chart

The process duration, assuming the input raw materials and motor case hardware is available is estimated to be 22 days. Critical facilities like the mixing station and cast / cure station are duplicated for increasing the throughput and for maintaining production in case of breakdown or mishap in one of the stations. The longest occupancy is of 9 days in the cure station which will govern the total production throughput. 25 units (Ghaznavi and Shaheen 1 will account for one unit each while Shaheen 2 will account for 2 units—one unit for each stage motor) could be produced in a year of 250 working days based on this estimate. This assumes that the essential inputs like hardware and raw material flow are maintained to sustain this rate of production and that there is no queueing in some critical facilities like non-destructive evaluation. Real life conditions are far from ideal and there are bound to be disruptions, equipment breakdowns, material shortfalls and technical glitches, which will have an impact on production. The actual annual production can be expected to be lower than this number.

Figure 3 depicts the missile nozzle, which is made up of two parts—the convergent section and a cone or bell shaped divergent section. The two sections are processed separately and then assembled together. As explained earlier thermal resistant materials like carbon phenolic (CP) and silica phenolic (SP) are used for thermal protection. Graphite is used for the throat section. Each of these is processed separately, machined and then bonded to the hardware. A final machining of the assembly results in the required contour. The process is quite involved as dimensional matching between mating parts is involved and the liners have to be cleared through inspection and non-destructive evaluation at several points during the production process.

Figure 4 details the steps involved in the realisation of nozzle liners along with the approximate process times. Practically all the steps are in sequence and therefore the operations are serial. It should be noted that the process time indicated is for either the convergent or the divergent section. To realise one complete nozzle assembly, the total process time gets doubled. The process time indicated is representative for the nozzle of a Shaheen class of missile.

The cycle time for a sub-assembly is of the order of 33 days and on a continuous basis a theoretical frequency of one sub assembly every 10 days could be maintained. On this basis, in a 250 working day year 25 nozzle convergent or divergent sub-assemblies, i.e. 12 full nozzle assemblies can be realised. As in the case of the propellant system, this will assume timely availability of inputs like raw materials, structural hardware, mating control system components (like secondary injection thrust vector system) and no queuing in any work station.

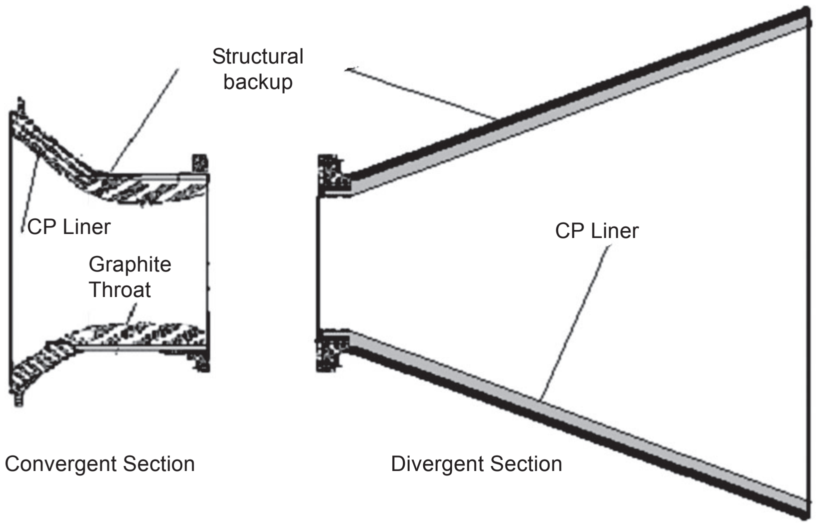

Fig 3: Missile Nozzle

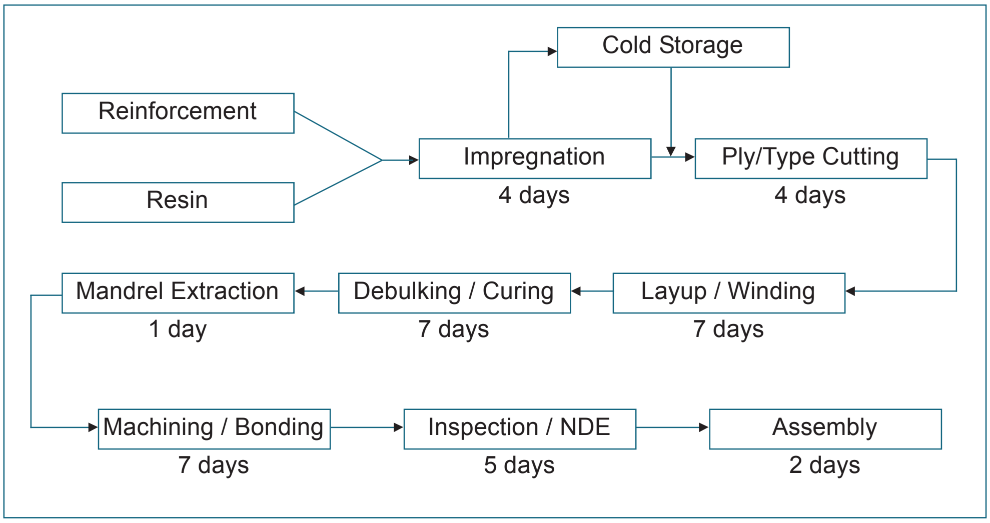

Fig 4: Nozzle Process Sequence

Throughput can be increased by having more work stations, but cost, quantity requirements of input materials, process tooling, space and operational requirements pose constraints. The thermal protection system for the re-entry vehicle requires the same materials and processes. It is quite possible, the two requirements are made in the same facility or co-located facility, sharing some of the process and inspection equipments. This facility could also be under the control of the Pakistan Atomic Energy Commission as part of the warhead preparation unit.

Though the propellant processing numbers could be higher, it is appropriate to peg the production to match the nozzle production numbers. It would therefore appear that 12 motor assemblies per year will suffice to match with the 12 nozzle assemblies. This number also seems more realistic, keeping in mind the inventories, hardware flow, process tool sets, accessories, plant upkeep, maintenance, storage, transportation and related issues. An examination of the Pakistani missile launch log is also indicative of lower order of production.

The Pakistani missile launch log shows a total of 26 launches between April 1999 and December 2006. (22 of these missiles have been launched between May 2002 and December 2006). Out of these 7 are Ghauri missiles, which have a liquid power plant. Therefore excluding these we have a total of 19 solid propellant missiles comprising Abdali, Ghaznavi, Shaheen 1 and Shaheen 2 launched between 1999 and 2006. The launch log relating to the solid propellant missiles is shown in table 5.

Table 5: Pakistan Solid Propellant Missile Launch Log

Date	Missile Type
April 15, 1999	SHAHEEN 1
February 7, 2000	HATF 1
May 26, 2002	GHAZNAVI
May 28, 2002	ABDALI
October 4, 2002	SHAHEEN 1
October 8, 2002	SHAHEEN 1
March 26, 2003	ABDALI
October 3, 2003	GHAZNAVI
October 8, 2003	SHAHEEN 1
October 14, 2003	SHAHEEN 1
March 9, 2004	SHAHEEN 2
December 8, 2004	SHAHEEN 1
November 29, 2004	GHAZNAVI
March 19,2005	SHAHEEN 2
March 31,2005	ABDALI
February 19 2006	ABDALI
April 29th 2006	SHAHEEN 2
November 29th 2006	SHAHEEN 1
December 9th 2006	GHAZNAVI

Launch Summary	
Year	**No. of launches**
1998	0
1999	1
2000	1
2001	0
2002	4
2003	4
2004	3
2005	2
2006	4
Total	19
Missile Type	**No. of launches**
Abdali	5
Ghaznavi	4
Shaheen 1	7
Shaheen 2	3
Total	19

In the case of Shaheen 1, there is a long gap of three and a half years between the first and second flight. The 1999 flight of Shaheen 1 was the first one after the NDC plant came up in 1997/98. In spite of the M 9 pedigree, there could have been problems in the first flight. The identification of the issue, its correction and confirmatory tests may account for the time between the flights. Subsequent numbers and frequency is indicative of a satisfactory solution to the problem.

The propellant mass in these missiles is estimated based on the missile powerplant dimensions determined from the images[14] and is used to compute the propellant mass in the missiles. Data from the year 2002 is taken for computing the total annual propellant quantity used for the missile flights. The details are shown in table 6.

[14] n. 1

Table 6: Missile Propellant Estimates

Year	Missile Flown		Estimated Propellant Mass, tonnes	Total propellant produced for flight tests in a particular year, tonnes
	Name	Nos.		
2002	Ghaznavi	1	3.78	
	Abdali	1	1.03	
	Shaheen 1	2	6.3 x 2	17.41
2003	Abdali	1	1.03	
	Ghaznavi	1	3.78	
	Shaheen 1	2	6.3 x 2	17.41
2004	Shaheen 2	1	4.0 + 1.54*	
	Ghaznavi	1	3.78	
	Shaheen 1	1	6.3	15.62
2005	Shaheen 2	1	4 + 1.54*	
	Abdali	1	1.03	6.57
2006	Abdali	1	1.03	
	Shaheen 2	1	4.0 + 1.54*	
	Shaheen 1	1	6.3	
	Ghaznavi	1	3.78	16.65

**Shaheen 2 has two stages and the propellant mass of each stage is indicated*

One can conclude from the table that Pakistan has approximately used 17.5 tonnes of finished propellant quantity per annum for flight purposes. It may not be right to peg the production at this rate as some of the units could be used for ground qualification requirements and for stockpiling. As the missiles could be transported and stored under different terrain and weather conditions, they are subjected environmental conditioning to simulate such conditions followed by proving tests. Also a minimum number of flight tests are required to confirm the system performance and firm up the CEP. Some numbers are also earmarked for crew training purposes. Each country follows its own guidelines with regard to the number of proving flights required before declaring a system operational. The US services employ a very comprehensive test programme for their missiles[15]. The R&D tests number about 24 each for the Minuteman, the Peacekeeper and the Trident missiles. It is unlikely that Pakistan would plan such an extensive test programme for its missiles. From time and cost considerations, it will opt for deriving the maximum inputs from minimal tests through extensive instrumentation and from the inputs drawn from the exposure to the Chinese M 9/M 11 programmes. An assessment of the minimum complement of tests is shown in table 7.

[15] Staff Working Paper, "*The MX Missile Test Program*", The Congress of the United States, Congressional Budget Office, January 1986

Table 7: No. of Tests for Operationalisation

Test Objective	Ground tests	Flight Tests	Remarks
Motor Development	2		
Motor Qualification	3		
Development Flights	—	2	
Qualification Flights	—	3	
Training Flights		5	2 tests by development crew with the service crews.
			1 tests by service crews with development crew support.
			2 tests by service crews with development crew supervision.
Surveillance Tests	1	—	This requirement is infrequent and is used for checking the aging criteria of the propulsion system.
Total	**6**	**10**	

A total of 16 motors will have to be ground and flight tested for declaring the system operational. The number can be pruned to some extent. The surveillance test is an infrequent requirement with the objective of ensuring the soundness of the motor with storage time. The motor will be drawn from the production batch as the need arises and hence it need not be counted as a prerequisite for operationalisation. Part of the crew training tests can be combined with the qualification tests. This would mean a complement of 5 ground and 7 flight tests would be required to declare the missile system operational. Based on this assessment, the following inferences are drawn:

Abdali: Published reports as well as the fin shape of Hatf 1 confirm the Sud Aviation sounding rocket ancestry of this missile. Abdali is a modified version of this and uses the acquired French technology for PVC based propellants. It is possible that Pakistan has improved on the composition by adding a certain percentage of aluminum to improve its energy. Abdali is a short range tactical missile and intended to be produced in numbers. Pakistan has long experience in the manufacture of this type of propellant and rocket system and consequently would have required very little development and qualification effort. The modifications may not significantly alter the primary parameters and therefore add to the test numbers. Therefore the earlier Hatf 1 flights along with 5 Abdali missile launches till December 2006 may meet the criteria for operationalisation. Based on this argument, it is concluded that a) the propellant is produced in the SUPARCO plant, using a modified PVC composition and retaining the free standing feature of the propellant grain; and b) the missile is in production and inducted into the services.

Ghaznavi: This missile is derived from the Chinese M 11 missile. Pakistan is also reported to have procured 34-80 of these missiles including the manufacturing know-how. The Chinese connection would have provided adequate technology inputs to Pakistan and enabled it to make the design transition to Ghaznavi. The M 11 pedigree would have also enabled Pakistan to derive confidence with the minimum number of qualification tests. The first test[16] of this missile was reported on May 26, 2002 and the fourth on December 9, 2006. According to the Islamic Republic News Agency—IRNA[17] dated April 26, 2007 "the solid fuel Ghaznavi Ballistic Missile System was successfully fired as part of a training exercise in December last year by troops." To quote the main story carried by the news agency[18] "Pakistan on Thursday handed over a batch of nuclear capable ballistic missiles to the army at a ceremony attended by Prime Minister Shaukat Aziz, state media reported. The final production batch of Hatf III 'Ghaznavi' missiles was handed over to the Army Strategic Force Command (ASFC), Radio Pakistan reported". Based on this report, it is safe to conclude the missile is in production and inducted into the army. It is safe to assume that the service crews already are trained in the preparation and launch of M 11 and as such will require very little training and adaptation to the Ghaznavi. Also the production of Ghaznavis may be pegged at a lower number keeping in mind the existing inventory of M 11 missiles. The production batch of Ghaznavis handed over to the ASFC may number 6-8.

Shaheen 1: There is a gap of three and a half years between the first and second flight tests of Shaheen-1. This could be due to technical problems/failure[19] encountered in the first flight. Between 2002 and 2006, the missile has been flight tested 6 times with two missile tests each in 2002 and 2003.

The test of November 29, 2006 is reported to be carried out by the troops of the ASFC as per press reports[20]. The report also stated "the event marked the culmination phase of the training exercise and validated the operational readiness of the strategic missile group equipped with Shaheen 1 Missiles". This statement confirms the development phase of the missile is complete and the missile is ready for production and operational deployment. Also the numbers flight tested is in conformity with the numbers shown in table 7. It is certain that Pakistan would accord production priority to hand over the first batch of missiles to the ASFC at an early date.

Shaheen 2: Four flight tests—one each in 2004, 2005, 2006 and 2007—of this missile have been reported so far. Being a two stage system, it is more complex and will have higher reliability issues. In tune with table 7 figures, further 3 flights of this missile are required for completely qualifying the system. In this case also a higher priority for completion of the remaining tests is obvious.

The scenario discussed above is summarised in Table 8.

16 "Pak test-fires another missile", *Tribune* (Chandigarh), 27 May 2002, Available at the website: http://www.tribuneindia.com/2002/20020527/main2.htm

17 For details see the website: http://www2.irna.ir/en/news/view/line-16/0704268066191425.htm

18 Ibid;

19 See the website: http://www.astronautix.com/lvs/shaheen1.htm

20 See "Pakistan Test Fires Nuclear-Capable Missile" Space Wars, November 29, 2006, Available at the website: http://www.spacewar.com/reports/Pakistan_Test_Fires_Nuclear_Capable_Missile_999.html

Table 8: Status Summary

Missile	Status
Abdali	❀ Development complete ❀ Troop exercise complete ❀ The missile is under batch production and handed over to ASFC
Ghaznavi	❀ Development complete ❀ Troop exercise complete ❀ Production batch (6-8 missiles) handed over to ASFC ❀ Production priority may shift to Shaheen 1 & Shaheen 2
Shaheen 1	❀ Development complete ❀ Troop exercise complete ❀ Production batch being readied for handing over to ASFC
Shaheen 2[21]	❀ Development flight tests in progress ❀ 3 more tests including troop exercise needed for development completion.

Production Summary

Based on the production cycle, it has been argued in the previous sections that the missile motor grain and nozzle production will be 12 units per year. This excludes Abdali which is probably being produced in the SUPARCO plant. The NDC plant at Fatehjang is reported to be operational during 1997-98[22]. It can be safely assumed that it may have taken some years for the plant to attain full rated capacity. Further, the realisation of the full rated capacity is dependent upon a number of external parameters like timely availability of hardware, input materials, resolution of technology glitches and quality issues and this hampers the rated capacity realization. The fact that Pakistan has flown only 14 Ghaznavi, Shaheen 1 and Shaheen 2 missiles in the 7 year period between 1999 and 2006 is a pointer to this. A likely missile propulsion system production scenario is inferred from these pointers and is shown in Table 9.

[21] It is not clear why Shaheen 2 does not use Shaheen 1 powerplant for the booster stage. Besides obvious improvement in the range, it will add to the standardization of hardware and reduction in the number of qualifying tests and reduction in the number of process and handling tools. It will also provide flexibility of interchange. It is possible that they are designed and produced by two different groups. The similarity of the stage 1 dimensions to the Chinese M – 9 may have some bearing.

[22] See, n.10

Table 9: Production & Utilisation Summary

Year / Missile	1998	1999	2000	2001	2002	2003	2004	2005	2006	Stock inventory in 2007
Ghaznavi										
Production	1	2	2	1	1	2	2	2	2	6 missiles handed to ASFC
Ground Test	1	2	2	-	-	-	-	-	-	
Flight Test	-	-	-	-	1	1	1	-	1	
Shaheen 1										
Production	2	1	2	2	2	2	1	2	2	4 missiles
Ground Test	1		2	2						
Flight Test		1			2	2	1		1	
Shaheen 2										
Production				1	1	1	1	1	1	Nil
Ground Test				1	1	1				
Flight Test						1	1		1	
Total Production	3 units	3 units	4 units	5 units	5 units	6 units	5 units	6 units	6 units	

Notes:
1. *There is a lag between the production and utilisation.*
2. *One unit comprises the motor hardware, propellant grain, nozzle, ignition and control systems (excluding reaction control system)*
3. *Each stage of Shaheen 2 is considered as one unit*
4. *The number of Shaheen 2 ground tests could be less based on Shaheen 1 experience*

Observations and Inferences

1. Immediately after the readiness of the plant in 1997-98, one flight of Shaheen 1 has taken place in 1999. Thereafter no flights of Ghaznavi, Shaheen 1 and Shaheen 2 are reported till 2002.

2. Two flights of Shaheen 1 in October 2002 are closely spaced.

3. Two further closely spaced flights of Shaheen 1 have taken place in October 2003—almost exactly a year later.

4. The long gap between the flight of 1999 and the flights of 2002 is indicative of a major problem in the 1999 flight and which have taken time to resolve and qualify the corrected design.

5. Preparing two articles for testing is a commonly accepted practice. The second unit can be tested to re-confirm the article performance. At the same time further modifications, if required can be quickly carried out on the second article.

6. It also shows that two Shaheen 1's per year could be the current capacity, based on input materials and plant constraints.

7. It is unlikely that the Shaheen 2 preparations would have started till confidence in the

Shaheen 1 performance is gained. Shaheen 2 is a new design, derives from the pedigree of Shaheen 1 and therefore its ground tests could have started after confirmation of the Shaheen 1 corrections and proving ground tests—ie., in 2001.

8. No flights of the strategic missiles have taken place in 2005. Two Abdali flights perhaps are gap fillers. The reasons for this could be:

   a) Some technical issues with the other missile systems
   b) Some problem with the plant equipment or shortage of raw materials.
   c) Some technical issues with the Shaheen 2 flight
   d) Deliberate scheduling

   Out of these, the problem with the plant equipment or shortage of critical raw material like Ammonium Perchlorate appears as the more plausible reason.

Production Forecast

On the basis of the assessment done in this study, one can make a modest attempt in forecasting Pakistan's solid propellant missiles production capacity. The forecast is elaborated below:

Ghaznavi

The production numbers of this missile are not likely to be high until the M 11 stocks are liquidated. M 11 import numbers vary between 34 to 80. In the absence of any conflict situations, the application of these missiles will be restricted for regular crew training drills and flight tests of new or improved missile systems. The M 11 missiles are 8 to 10 years old and maybe near the end of their life. Though it may be possible to extend their life, Pakistan will consider phasing them out in two to three years time and replace them with the higher capability Ghaznavi. This exercise has begun with the handing over of the first batch of Ghaznavis to ASFC in April 2007.

Shaheen 1

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With completion of seven flight tests, the qualification and training of the ASFC personnel can be treated as complete and the first production batch is being readied for handing over to the ASFC. It should be possible to hand the first batch of six motors to ASFC in 2008. Readiness of further batch numbers will be based on priority accorded to the missile types. Assuming Ghaznavi and Shaheen 1 are accorded equal priority, a batch of six flight units can be readied once every two years.

Shaheen 2

Four flight tests have been completed. Three more tests are to be completed for qualification and training purposes. Even if some level of priority is accorded, the readiness of the first production batch is minimum five to six years away.

The development time of Shaheen 2 could have been shortened if Shaheen 1 stage had been used in the missile. The reason for not adapting this is not clear. In future developments, it is most likely that Pakistan will change booster stage dimension to that of Shaheen 1 with the attendant advantages. Possibility of incorporating a third stage cannot be completely ruled out.

Conclusion

A study of the Pakistan strategic missile production scenario is presented. The conclusions on the maximum number of missiles that can be produced have been derived based on the process time. The theoretical numbers have been compared with the actual known flight information and it is concluded that Pakistan currently has not exploited the full production potential. This may be due to material constraints, input hardware constraints, number of toolings availability, transportation and storage constraints. It does not appear to be due to any technology shortcomings.

Ghaznavi and Shaheen 1 are in production, while Shaheen 2 needs to undergo further flight trials before it can be declared operational.

Present production appears to be six units per year consisting of two units each of Ghaznavi and Shaheen 1 and 1 stage each of Shaheen 2. The typical product mix for the production of twelve units per year could consist of three numbers of each of the missiles. However, the number can be altered to a different mix based on the existing priority needs. Estimates of Pakistan's nuclear warheads are put at sixty as per the 2007 assessment prepared by Natural Resources Defence Council[23]. Assuming two thirds of these will use missiles as carriers (the rest could use aircraft delivery), it would take about four year's production effort at the full rated capacity of 12 units per year to match the missile and warhead numbers. This would mean that only by 2011-2012, Pakistan would be able to provide the missile carrier system for all these warheads. The time period may be even slightly stretched to account for design modifications and requirements of training/surveillance tests.

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[23] NRDC Nuclear Notebook, *Bulletin of the Atomic Scientists*, (Chicago: USA), V. 63, no. 3, May/June 2007, pp. 71-73.

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