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REVIEW PAPER

Recent Advances in Antitank Guided Missile Systems

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ABSTRACT

The recent advances in tactical antitank guided missile (ATGM) systems are discussed. The main driving factors for the technological advances towards realisation of third generation ATGM systems have been the more demanding operational needs of the user services and limitations of earlier generation ATGM systems. The tasks of system design, hardware realisation, integration, testing and qualification have become extremely challenging to meet these stringent operational requirements. The technologies required to be mobilised for meeting these operational requirements and performance envelope and satisfying the operational and logistics constraints are again very demanding. The high technology content and the high level of performance required out of the subsystems have led to the present generation missile systems. The evolution from the earlier generations to current systems has been briefly discussed. Imaging infrared (IIR) and Millimetre wave (MMW) guidance systems employed for achieving the fire and forget capability of the third generation ATGM are described with specific reference to progress achieved so far. Translating the mission requirements to preliminary system specifications is another area wherein an innovative approach only can lead to meet the multiple performance criteria. Performance growth profile and emerging trends in ATGM systems are also analysed.

1. INTRODUCTION

The rapid advances and growth in technologies relating to the short range tactical antitank guided missile (ATGM) systems and their supporting subsystems over the last three decades have changed the antitank warfare scenario and consequently, the ATGM system deployment concepts, significantly. The major contributing factors for these changes are :

(a) The ever-increasing surveillance and target acquisition capabilities for detection, recognition and identification using electro-optical and radar sensors.

(b) Advances in microelectronics and packaging have enabled realisation of onboard, real-time image/signal processing, digital autopilot and compact seekers to be accommodated within the stringent space, weight and power constraints of ATGMs.

(c) Advances in electronic and electro-optical counter-measure and counter counter-measure capabilities.

(d) The need to minimise the exposure time or dwell time over the hostile target area for the missile and delivery platforms, leading to fire and forget/launch and leave capabilities.

In this paper, the third generation ATGM system has been discussed in detail focussing on the recent advances in the technological inputs and covering the following aspects of ATGM systems:

(a) Driving factors

Operational needs and limitations of existing/earlier generations[1] systems Technological advances.

(b) Technological implications of fire and forget and top attack capabilities

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Guidance system—the critical technology
Total design management (TDM) – considerations, constraints and approach – a case study of TDM
Emerging trends.

OPERATIONAL NEEDS AND LIMITATIONS OF FIRST & SECOND GENERATION SYSTEMS

While analysing the performance growth profile of ATGMs from first generation to third generation systems, the most important performance index is the operator's role index (ORI). While, in the first generation ATGM system the missile operator was required to perform a number of functions, in the second generation ATGM system the operator is required only to acquire and track the target. In the third generation ATGM system the missile operator's task has been further reduced to only acquiring the target and handing over the same to the missile seeker through an automatic process (handing over algorithm). Thus, on a relative scale, the ORI for third generation ATGMs is only 10 points compared to 100 points for the functions required to be performed by the operator of first generation ATGMs. This has been made possible due to the fire and forget capability of the third generation ATGM. To appreciate the two important operational needs of fire and forget and top attack capabilities of the third generation ATGMs, the shortcomings of the first and second generation ATGM systems are briefly discussed in the next two sections.

3. FIRST GENERATION ATGM SYSTEMS

The first generation ATGMs with manual control to line of sight (MACLOS) and typical range of 1.5-2 km suffered from the following disadvantages.

(a) Difficult role of the operator to simultaneously track the tank and the missile and to generate up-down and left-right commands on a joystick for sending to the missile through the guidance wire. The kill probability of the missile system depends on the operator's skill and training and his capability to perform in the actual battlefield scenario.

(b) The guidance wire dispensation from the missile and the operator's response time for guiding the missile limited the missile speed to 100-180 m/s. The operator and the missile system were vulnerable to enemy counter action during the prolonged flight time due to this low speed.

(c Engagement was feasible only on front or side of tanks, where armoured protection is much more compared to the top.

(d) Large minimum range by the time the operator gathers the missile through the sight and brings it on to the line of sight using the limited lateral acceleration capability of the missile. These shortcomings led to the evolution of the second generation ATGMs.

4. SECOND GENERATION ATGM SYSTEMS

The relative advantages of the second generation ATGMs employing semi-automatic control to line of sight (SACLOS) over their predecessor are :

(a) The operator is required only to track the target. He is not required to track the missile as it is done by the IR Goniometer nor he is required to generate the guidance commands which is done automatically by the command generation system on the launcher. The operator's reduced role results in a better hit probability.

(b) Higher missile speed of 150-280 m/s could be achieved due to reduced role of operator.

(c) Reduced wing size due to increased speed leading to tube launching and reduced dispersion. This along with reduced role of operator led to smaller minimum range.

However, some of the disadvantages of the second generation ATGMs are :

(a) Though the missile speed could be increased to 150-280 m/s, still the flight time to maximum range is 10-15 s and during this time and the target acquisition time, the system and the crew remain vulnerable to enemy counter fire.

(b) Being a line of sight missile attacking the tank from front or side (for ground deployment), the disadvantage of engaging only on the front or sides remains as in the case of first generation ATGMs.

Hence, even in the second generation ATGM system, the exposure time of the system and operating crew to enemy counter action, though reduced compared to the first generation ATGM system, is still unacceptable, especially considering that it is a direct fire/line of sight (LOS) system. Thus, there is a pressing operational need to minimise this exposure time or the dwell time over enemy target area, which is all the more relevant for the helicopter version.

5. ACCEPTABLE & AFFORDABLE ATTRITION LEVEL (AAA LEVEL)

With the technological advances, the operational capabilities of the ATGM systems and their deployment platforms, both vehicle and helicopter-based, have increased considerably. Consequently, their costs have also gone up. The relative cost of the firing platform is typically 30-100 times that of the ATGM. It deploys depending upon the type and vintage of the system and the target acquisition system (TAS) it deploys. In view of this, high cost of the firing platform, its trained crew and the missiles it carries, there is a need to ensure that the attrition levels of such platforms are acceptable and affordable to the user forces. This brings out the need for limiting the exposure of the platform and the crew to the minimum essential duration to just facilitate the acquisition of target and firing the missile after handing over the same to the missile. This calls for the fire and forget capability to be bestowed on the new generation ATGMs.

Also, with the advances in armour it is becoming increasingly difficult to defeat futuristic armour–including those fitted with explosive reactive armour (ERA)–in front attack, where the tank enjoys maximum armour protection, or even in side attacks depending on the azimuthal presentation of the target area. However, the top of the tank is relatively weak. Though efforts are being made to improve the quality and quantity of armour protection to the top of the tank due to threat from top attack missiles and submunitions, from the considerations of mobility, the top would enjoy lesser protection compared to front and sides of the tank. The top attack capability in which the missile dives on to the top of the tank (as different from over fly attack capability) needs to be built into the missile by suitable shaping of the trajectory taking into account the seeker and other missile constraints and range of values for the impact angle for the missile/warhead. A discussion of the technological implications of the twin operational requirements of fire and forget and top attack capabilities, are discussed in a later section (Sec. 7).

6. TECHNOLOGICAL ADVANCES RELATING TO ATGMs

The surveillance and target acquisition capabilities for detection, recognition and identification using radar and electro-optical sensors, often deployed as a multi-sensor system with real-time processing and displays, have increased considerably. This has resulted in day and night and all weather capabilities and increased ranges of operation. With surveillance and reconnaissance capabilities at satellite level, movements of tank formations can be monitored in conjunction with GPS. For tracking movements of individual tanks or small group of tanks, day sights and thermal imaging sights have been realised with recognition range capabilities of 4 km and more. Also, the electronic and electro-optical countermeasure and counter countermeasure capabilities have grown considerably and are competing in an eternal race to outwit each other's performance. This calls for the missile systems to be made immune to the countermeasures.

Advances in microelectronics and packaging have enabled realisation of onboard, real-time image/signal processing, digital autopilot and compact seekers to be accommodated within the stringent space, weight and power constraints of ATGMs. For example, the first and second generation missiles typically had the minimum onboard electronics to decode the commands received through the guidance wire and send to the actuators. Compared to this, a microprocessor-based guidance and control computer performs all the functions during flight on an autonomous mode in the third generation ATGM for the mission, except the initial acquisition of the target by the operator and handing over the same to the missile seeker. With the type of devices available till late seventies, realisation of such compact onboard computers for missions like fire and forget ATGM was not feasible.

6.1 Cost the Killer, Technology the Winner

There is an increase of about ten times in the unit cost of second generation ATGMs (ATGM-2) compared to the first generation ATGMs (ATGM-1). The cost of the third generation ATGMs (ATGM-3) of the fire and forget and top attack type is estimated to be about hundred times more compared to that of the ATGM-1 or ten times that of the ATGM-2. As an example, the 1990 estimates of the European TRIGAT, third generation ATGM, programme are as follows.

6.1.1 Unit Cost

TRIGAT MR (medium range) $ 20,000-45,000 (Rs. 6-15 lakh)

TRIGAT LR (long range) $ 37,000-80,000 (Rs. 12-25 lakh)

6.1.2 Programme Cost

TOTAL : $ 1.4 Billion (Rs. 4500 crore)
Medium range Rs. 1200 crore
Long range Rs. 3300 crore.

6.1.3 Requirement

Numbers : Medium range 210,000
Long range : 87,000

Thus the investment required to be made for third generation ATGM systems is very high. Twelve countries developed the first generation ATGMs and even a single country, like France developed three different first generation ATGMs – SS10, ENTAC and SS11. As against this, six European countries are jointly funding the TRIGAT ATGM-3 programme with four more countries evincing their keen interest to participate in the programme. Thus the increasing development cost has prevented many from independently developing the ATGM-3. Instead, they have been forced to collaborate by pooling their resources so that the development cost is shared and consequently, the unit cost of the system in production becomes affordable (*cost, the killer concept*). From the time the need for a new type of missile system is felt by the user from operational considerations (e.g. the need for ATGM-3 as brought out earlier), the typical life cycle time, i.e. for its conceptualisation, system realisation, testing, performance evaluation and demonstration to user services, production and deployment and product improvements based on user feedback, spans over about 30 years. Hence the choice of technologies and system configuration has to be very carefully made through a technology forecast and SWOT (strengths, weaknesses, opportunities and threats) analysis, so that the missile system is contemporary in technological and operational capabilities and competitive over similar systems throughout its deployment phase. As Dr APJ Abdul Kalam, a noted expert in missiles, pointed out earlier, the lead technologies have to be chosen in such a way that they form the basic building blocks with which many a system can be configured with addition of certain incremental blocks. The examples given by Dr Kalam in his inaugural address at the of using the seeker technologies of ATGM-3 for FOGM and terminally guided submunitions (TGSMs), are very relevant in this context (*Technology, the winner concept*). Similarly, for achieving maximum cost-effectiveness at operational system levels, multi-role operation (antitank and anti-helicopter) and multiplatform deployment (wheeled/tracked vehicles and helicopters) are essential. In addition, deployment by multiusers, including export potential needs to be considered right at the conceptualisation and design phases due to the type of environment and scenarios in which the systems have to be deployed. The concept of total design management (TDM) starts with this step followed by technological implications of critical mission requirements, choice of critical technologies and other system requirements and design constraints, as discussed in the next section.

7. MISSION REQUIREMENTS OF THIRD GENERATION ATGMs & THEIR TECHNOLOGICAL IMPLICATIONS

The technological implications of the the three important mission requirements, mentioned earlier, are discussed here.

7.1 Fire and Forget Capability

Against moving targets like tanks, the fire and forget capability requires the use of a self-contained, homing guidance system for the antitank missile of small size. The active homing and passive homing guidance system are the possible options. The third type of homing system, namely, semiactive homing, does not enable the system to have fire and forget capability in the strict sense of the term. In the semiactive homing, the operator is required to continuously illuminate the target using a source of radiation. Though the missile can be located away from the illuminating source and after securing lock on by the missile seeker and after launching the missile, the missile operator can leave the launch site, the other operator has to continue to illuminate the target till the engagement is over. This makes the target illuminating system and its operator vulnerable. Hence such a system is not considered suitable for fire and forget capability.

In the active homing type, a laser radar seeker or a millimetre wave (MMW) radar seeker can be considered as possible options. A CO_2 LRF laser radar is considered essential for achieving a typical range of 4-6 km, keeping in view the attenuation in the atmosphere, including the battlefield dust and smoke. It is feasible to configure and package such a CO_2 laser radar seeker within the permissible space and weight of the ATGM. However, a laser radar of this type normally uses threshold detection techniques using amplitude of the return signal for discerning the target. However, detecting the target from the background is extremely difficult using the above technique by a laser radar, as the laser does not provide any inherent target identification against tanks deployed against competing non targets, such as ground undulations, boulders, etc. Hence only the MMW radar has been considered for the active homing. For the passive homing, an imaging infrared (IIR) seeker has been configured.

7.2 Top Attack Capability

With the advancements made in the types of armour used in modern battletanks, it is becoming extremely difficult to defeat the tank infront attack. In the top of the tank the thickness of armour used is normally almost one order less compared to the front and sides. Hence it is easier to engage and destroy the tank in the top attack mode. The first and second generation missiles when deployed on helicopter platform enjoy the top attack capability by virtue of the height advantage of the firing platform. However, in the case of the third generation ATGM, the top attack capability is required to be built into the missile itself even for ground vehicle deployment. To accomplish this it is essential to adopt a climb-and-cruise trajectory followed by a final descent phase, that is, an indirect fire trajectory scheme. While the missile follows this trajectory scheme, it is to be ensured that the seeker does not loose track of the target from launch till the impact. This calls for a good degree of gimbal freedom for the seeker, especially in the elevation plane. The size of the gimballed seeker is decided by the size and type of optics or the antenna to obtain the required lock-on range and also the seeker is to be stabilised. Hence for the given diameter of the missile and the seeker diameter, the gimbal freedom gets restricted and the trajectory scheme needs optimisation with available gimbal freedom. This is one of the constraints, for the shaped-charge warhead used in ATGM for defeating armour. The impact angle in top attack needs to be maximum for inflicting maximum damage to the tank. There is also a minimum angle of impact depending on the nose shape and velocity of impact below which the missile would ricochet on impact. Thus, maximising the impact angle is one of the design objectives. To follow the top attack trajectory scheme, the missile needs to perform important manoeuvres during the climb and final descent phases. Lateral acceleration (latax) capability available for the missile would decide the turning radius and the minimum range for engagement while meeting the gimbal angle and impact angle constraints also. In some of the ATGMs, tube launching is one of the operational requirements from logistics and handling considerations. For the tube-launched missiles, the size of the wings and control fins, especially the span, gets restricted. This results in limiting the latax capability, which in turn affects the minimum range adversely for the top attack scheme compared to the first and second generation missiles employing direct/front attack trajectory. The flight time and propulsion energy requirements for following top attack trajectory would also be marginally higher compared to the direct attack trajectory. Hence another design constraint is the limit on the maximum height of the trajectory.

7.3 Warhead Capability

Explosive reactive armour (ERA) has been developed for use against shaped charge warheads of ATGMs. To defeat armour protected by ERA, it is essential to go in for tandem–shaped charge warhead. The front charge which can be a full calibre charge or subcalibre charge, depending on the space and weight availability in the missile, is meant for defeating the ERA. The rear charge which is normally a full calibre charge, defeats the actual concealed armour. The delay between the detonation of the front and rear charges needs optimisation for maximising the penetration effect. The spacing between the two charges and the size of the front charge again are optimised such that the detonation of the front charge does not adversely affect the directionality of the jet from the rear charge. The spacing between the charges is also limited by the allowable length for the warhead in the missile. In case where ERA is not used, the front charge gives some penetration in the armour and this is followed by the penetration from the rear charge. The design of the tandem warhead, including initiation mechanism and wave shaping require optimisation using a computerised design code. Third generation ATGMs use either an active or a passive homing seeker as discussed earlier. This seeker with stabilisation system has to be necessarily housed in the nose of the missile which is usually the location reserved for the shaped charge warhead in the first and second generation missiles. Due to this location of the seeker, the tandem warhead can at best be located immediately behind the seeker. Hence the jets from the two shaped charges need to defeat the seeker obstacles first before they strike the target. This results in a certain loss of energy of the jet before defeating the ERA and the actual armour. This loss of energy becomes more in cases where certain other missile subsystems, such as onboard signal processor may have to be located between the warhead and the seeker from considerations of optimised layout of missile subsystems. Thus for a given diameter of the warhead, the actual penetration in target achieved from the tandem warhead in absolute terms could be less in some cases compared to the shaped charge warhead of earlier generation ATGMs, which are located in the nose of the missile. However, the earlier generation missiles do not have the intrinsic top attack capability while launched from ground/vehicles. Hence the quantum of armour they have to defeat infront/side attack is often one order more compared to the top of the tank which can be engaged and defeated due to the top attack capability of the third generation ATGMs. Hence the ratio of the penetration capability of the third generation ATGM warhead to the thickness of the armour to be defeated in the top of the tank is considerably higher than that of the earlier generation missile warheads (ratio of their penetration to the thickness of the armour to be defeated infront/sides of the tank). In fact, this is the ultimate performance index of an ATGM. The single shot kill probability (SSKP) given a hit of the top attack ATGM is thus much higher compared to the earlier generator missile warheads leading to K (knock out) type kill, thereby justifying the higher unit cost and mission cost of the third generation ATGMs.

8. GUIDANCE SYSTEM – THE CRITICAL TECHNOLOGIES

While the technologies relating to almost all the sub systems of the third generation ATGMs call for new developmental efforts and optimisation of performance, the critical technologies are in the guidance area. The technological aspects of the IIR passive homing guidance and the MMW active homing guidance are discussed in the following subsections:

8.1 IIR Passive Guidance Systems

The mission requirements normally call for the engagement of both moving and static tanks and other armoured vehicles in a variety of terrains and in different seasons of the year during both day and night. It also becomes essential at times to engage tanks with the engine not running. The ambient temperature variation could typically be from -20 °C to +50 °C depending on the season and the terrain. The typical temperature differential of the targets compared to the background could be 1 K. Conventional IR detectors which are used against aerial and ship targets, where the target temperature difference over the background of sky or sea is very high, cannot be used against tanks and other armoured vehicles deployed on ground in the scenario described above. With conventional IR detectors the missile can be misled easily by more powerful IR sources radiating in the selected spectral band, such as electro-optics countermeasure sources, burning tanks/ targets already destroyed by other engagements and which are within the field of view of the seeker. For tracking and engaging ground targets, such as tanks with such low temperature differential over the background, it is essential to go for thermal imaging of the target and the background in the vicinity of the target. From atmospheric transmission considerations there are two spectral windows for operation, namely, 3-5 micron medium wave infrared (MWIR) window and 8-12 micron long wave infrared (LWIR) window. Both these windows are being exploited for thermal imaging and missile guidance applications. The uniformity and contrast are usually better with 3-5 micron window. Monolithic two-dimensional focal plane array (FPA) senors based on silicon schottky barrier diode array with silicon readout devices, indium antimonide (*InSb*) detector array with silicon readout array and mercury cadmium telluride (MCT) detector array coupled with silicon readout devices are used in the 3-5 micron window. At low scene temperatures which could be up to -30 °C in typical cases, the signal content in the 3-5 micron window becomes low. Hence for operation in extremely cold environment (sub-zero temperature), the 3-5 micron FPA sensor is not a good choice. On the other hand, for operation at extremely low temperature, the 8-12 micron FPAs are a better choice; also, the atmospheric attenuation is relatively less compared to the 3-5 micron window. MCT detector arrays can operate in the 8-12 micron spectral window by adjusting the composition of the material. Array sizes up to 512 × 512 pixels have been realised for platinum silicon (*PtSi*) Schottky barrier-based FPA sensor and 256 × 256 pixels *InSb* FPA sensors have also been realised. For the MCT arrays, array size of 128 × 128 pixels has been reported. Larger array sizes are difficult to realise with this ternary material as the yield goes down significantly with increase in the array size due to uniformity problems over large areas. However, for short range applications, like ATGMs, array size of 128 × 128 pixels is considered adequate. In Sb and MCT arrays need cooling to liquid nitrogen temperature. Two possible options for cooling are: stirling cycle engine or a mini cooler based on Joule-Thomson (JT) cooling. For thermal imaging applications as in a thermal sight used in vehicles/aircraft for target acquisition involving continuous use over long durations, the first option is preferred. However, for single shot application, like missile, the JT cooler is the obvious choice from weight and size considerations. For the readout of the detector array output, charge coupled device (CCD) arrays and MOS X-Y arrays are used. CCD arrays are used as readout device for 3-5 micron two-dimensional FPA sensors as well as for linear arrays of 3-5 micron and 8-12 micron detectors. For the 8-12 micron FPA sensor, the use of X-Y readout has been reported. The FPA is encapsulated in glass/metal dewar for operation at liquid nitrogen temperature.

8.2 Image Processing

For typical maximum ranges of 4-5 km and with FPA sensor array sizes of 128 × 128, recognising a target through the missile seeker is not feasible with achievable field of view (FOV) and resolution. Hence there is a need to have a thermal sight with a medium FOV to detect and a narrow FOV to recognise and if possible, identify the target. The target recognised by the thermal sight along with its immediate neighbourhood is correlated with the lower resolution image obtained by the seeker through correlation algorithm. With the use of fast and efficient algorithms, the time required to perform the correlation and to handover the target to the missile seeker for getting a lock on-signal can be minimised. The image seen by the seeker is updated during fight at typical rates of 30-60 frames/second. Once the target size grows occupying sufficient number of pixels during the mid course phase, a centroid algorithm is used to compute the aim point on the target and the missile tries to home on to this aim point. In the terminal phase when the target overfills the sensor size, the correlation algorithm can be invoked again to home on to a point within the target. A multimode flight processor with common hardware switching over from correlation to centroid algorithm and again to correlation algorithm is needed to fulfil the requirements of fast update time/near real-time processing, minimum power consumption, minimum number of components from reliability and cost considerations and extreme space constraints in a small ATGM. A compact system for stabilisation and tracking in pitch and yaw planes is another area involving use of miniaturised gyros, torquesrs, pick-offs, etc. The missile is usually roll-stabilised for such missions.

8.3 MMW Guidance System

IIR guidance system offers the advantage of high resolution. However, in bad weather the attenuation of the IR radiation even at 8-12 micron increases, thereby deteriorating the range performance considerably. On the other hand, a MMW-based guidance system has relatively less attenuation, thereby enabling all-weather capability. The use of such high frequencies at MMW is essential to accommodate the active seeker, especially the antenna within the permissible diameter/dimensions of the ATGM. For antitank role, the use of W-band seeker is considered essential to achieve the required beam width with the limited size of the antenna. The typical power requirements would be few tens of watts for a maximum range of 4-5 km. The magnetron technology at W-band frequency has not matured yet for missile-borne use. Silicon IMPATT diodes are used for producing the required power. Usually a single diode which gives 10-20 W pulse power cannot deliver the required output power. Hence power combining of the output of multiple diodes by cavity combining/hybrid combining or a combination of both techniques is usually resorted to. Other-solid-state-devices, such as Gun-diodes and Schottky-barrier-diodes are used for local oscillator and mixer and Pin-diodes are used for fast switching. Development and production of the above types of solid-state devices are extremely challenging from technology point of view, especially due to the extremely small dimensions and tolerances for operating at W-band frequencies. Conventional Cassegrain antenna demands large annular space within the missile for achieving the required gimbal freedom in elevation and azimuth, which is essentially required for realising top attack trajectory scheme. Hence the other options, such as trans-twist antenna, wherein only the twist reflector plate is required to move, is usually employed. The advantage with such a scheme is that of limited servo power requirement for moving only the twist reflector plate instead of the complete antenna assembly and the need to move the plate only through half the required angle based on reflecting mirror principle. However, the materials to be used for such printed antenna, the three dimensional profile accuracy of the trans-reflector, the accuracy of the gratings and precision fabrication are the technological challenges for realising such an antenna to the required specifications. Similarly, at W-band frequency special materials have been synthesised to realise radomes of suitable thickness and shape with a view to minimise the attenuation and to have minimum distortion of the antenna radiation pattern.

8.4 Signal Processing

The thermal sight used in the IIR guidance system can be used for MMW guidance system also for target detection and recognition. The missile axis is aligned with the thermal sight so that the seeker looks at the target when the thermal sight is laid on the chosen target. The MMW seeker has the slewing capability by which the lock-on is achieved before launch. However, in bad weather conditions, the thermal sight range deteriorates. Since the MMW seeker will have a range capability better than that of the thermal sight under such bad weather conditions, it would be desirable to exploit this extra range capability of the seeker under such situations. For this, target identification algorithms which can perform without external aids, like thermal sight, are required. The target signature varies with the cross-section presented in azimuth and elevation, including changes in turret and gun orientation. Hence there is a need to evolve the identification algorithms which make use of aspect-invariant properties of the target. Multiple criteria, such as combination of target-to-clutter ratio (T/C), spread-to-mean ratio (S/M), etc., have been suggested for use in identification algorithms. Generation of an extensive database for different types of targets, aspect angles and target-background combinations is required to evolve such criteria and algorithms. For detection and range and angle tracking separate and special type of algorithms are required to be evolved. These functions are suitably apportioned between the vehicle-based processor and the missile-based signal processor. Fast update time for real-time processing, minimum power consumption and minimum use of components from reliability, space and cost considerations are the attributes for the flight processor.

9. SYSTEM REQUIREMENTS AND DESIGN CONSTRAINTS

Having carried out the option analysis and chosen the critical technologies, which is the first step in the (total design management), the total system requirements and design constraints for a typical ATGM-3 system are summarised below :

Fire and forget and top attack capabilities,
Lock-on-before-launch (LOBL) capability,
High impact accuracy (tens of cm) defines permissible guidance error,
Defeat of all futuristic armour including Explosive Reactive Armour (ERA),
Need to minimise minimum range,
Need to maximise impact angle for warhead effectiveness, Tube launching from operational and handling considerations leads to requirements of folding wings and fins; implies limited span/plantform thereby limiting the achievable latax capability, Need to minimise drag to keep missile weight within permissible limits dictates velocity-time profile, which in turn, decides thrust-time profiles and propulsion system choice,
Need to restrict missile diameter, length and *L/D* ratio from practical and aerodynamics/structural considerations, Preferred locations for subsystems, e.g. seeker infront leads to configuration layout constraints, and
Trajectory shaping constrained by available gimbal angle freedom, latax capability, impact angle and maximum allowable height considerations.

The choice of subsystems is dictated by the foregoing system requirements and design considerations as indicated in the following as an example.

Tandem shaped charge warhead to defeat all futuristic armour including ERA,

Composite airframe to minimise weight,

All electric actuation system for ease of operation, maintenance and safety for carrying spare missiles inside the vehicle,

Solid propellant booster-sustainer configuration to match required velocity-time profile,

IIR/MMW guidance to achieve fire and forget capability,

and

Thermal battery with low activation time and long storage life for electrical power supply.

Once the choice of subsystems is made, keeping in view the system performance requirements and considerations of available technologies and new/development needs, the preliminary design and configuration layout exercise is carried out. In the next step the vehicle sizing studies to accommodate the subsystems within the chosen diameter and length (*L/D* constraint) is carried out. A few candidate options for subsystems and configuration layout may be considered at this stage. Feasible propellant grain configurations to meet thrust-time profile (burning area, burn, rate, web size), grain geometry to withstand pressure, forward and latax environment, desired loading density, sliver fraction etc., are considered and the choice made. The configuration layout meeting the preferred subsystem locations and *L/D* constraint is chosen. Wing and fin platform shapes (for given areas) and locations are worked out to meet the latax and stability requirements during the entire flight regime. The configuration and subsystem inputs are used for three DOF and six DOF simulation studies and fine tuning of the configuration is carried out in an iterative manner. The performance achieved in the six DOF studies are compared with the system requirements specified by the user before design freeze. Based on this, system level and subsystem specifications are finalised for carrying out the detailed design.

10. EMERGING TRENDS IN ATGMs

The emerging trends in ATGM development and current development efforts are summarised in Fig. 1. In the infantry-type ATGMs, the TRIGAT Medium Range (MR) version is the typical example. A few other countries are also developing such infantry-type ATGMs as can be seen from Fig. 1. Such missiles would feature a tandem warhead without use of guidance wire, the guidance being through a laser beam. It neither has fire and forget capability nor top attack capability. Protagonists of wire guidance feel that wire is the most immune link from countermeasures point of view compared to a laser beam, and reliability of guidance in actual use is claimed to be more than 99.9 per cent Infact, they feel that reliability of the laser beam would be much less in actual battlefield operational scenarios. As far as reeling off guidance wire and its limitations on missile speed are concerned, second generation ATGMs like HOT and TOW have achieved high subsonic speeds. TRIGAT-MR being a subsonic missile, the velocity-time profile is not considered to be superior to some of these high-subsonic, second generation ATGMs. Accordingly, tactical/operational advantages to the users, if any, of the infantry-type of third generation ATGMs like TRIGAT-MR over existing missiles like MILAN, TOW, etc, which are also equippped with tandem warheads in latest versions, are not convincing.

TRIGAT Long Range (LR) and NAG are examples of the vehicle based/helicopter-borne third generation ATGMs. These systems are based on LOBL concept. LOBL capability restricts the maximum range of the missile to 4 or 5 km. This restriction is due to the limit imposed by the maximum achievable range of the thermal sight and missile seeker due to operational constraints of size, weight, power, etc. To increase the maximum range capability, it would be essential to go in for lock-on-after-launch (LOAL) capability. In this scheme, the missile is fired based on a priori information in the general direction of the targets. The flight profile and missile system capability ensure that the missile reaches the target area within certain specified error basket. The seeker is activated at this point and with the scanning capability built into the seeker, it would be able to perform target detection and recognition functions. However, this would need a lot more intelligence to be built into the missile signal processor in the form of fast and efficient algorithms based on

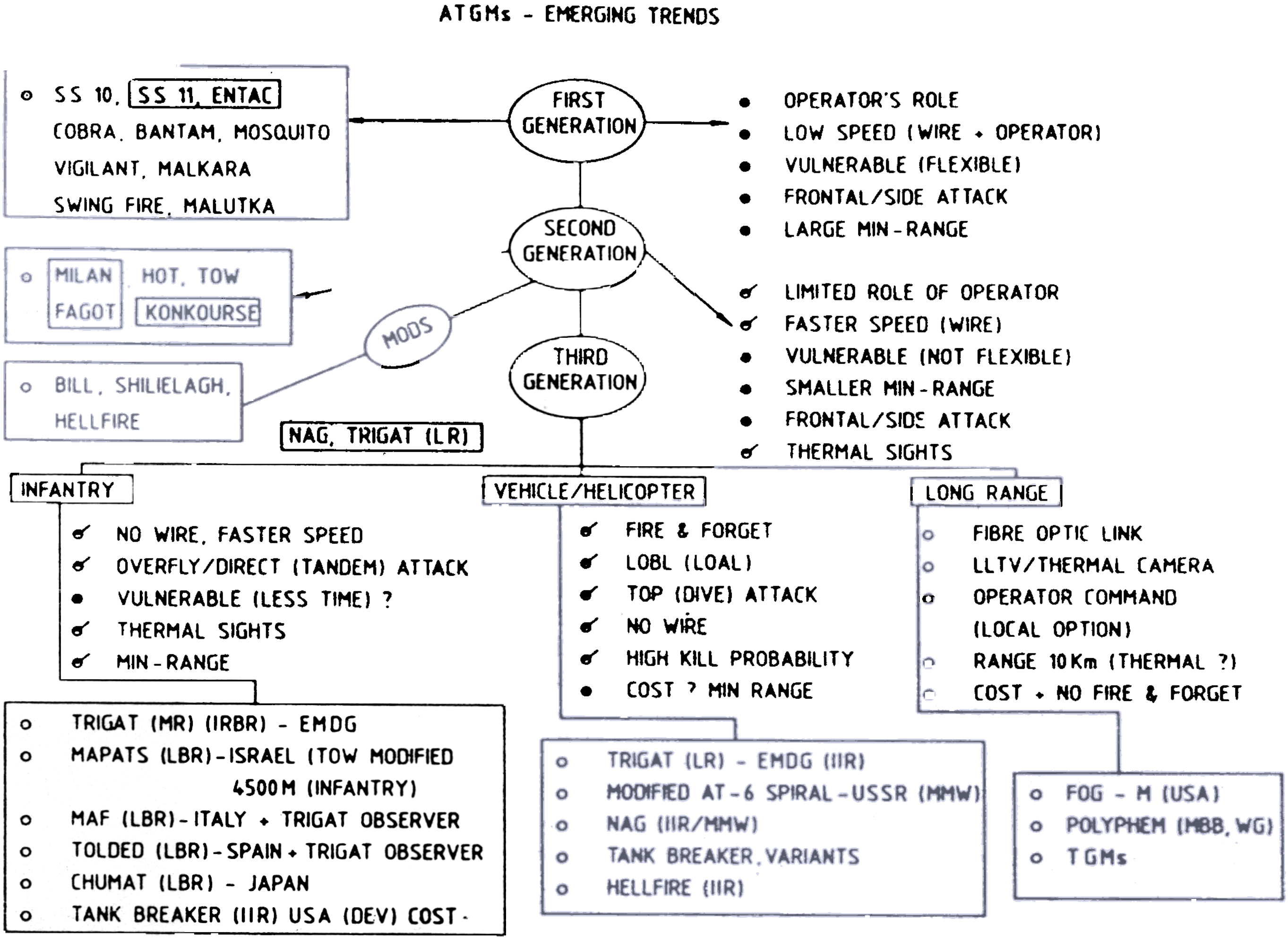

Figure 1. Emerging trends in ATGM development and current development efforts.

suitable criteria for target detection and recognition, which is otherwise done with the help of the missile operator in the vehicle for the LOBL mission. The LOAL class of missile can also be used for terminally guided submissiles (TGSMs) in a many versus many scenario (multiple missiles being carried in a big bus missile against multiple targets). Dual mode sensors, as and when configured for actual missile-borne use, would combine the advantages of the allweather capability of MMW system and the high resolution capability of the IIR system, apart from improved failure resistance features to be built in. However, the integrated design of the two seekers with the need for commonality in subsystem modules of the seeker to the exploitable extent and packaging the dual sensor based seeker within the already stringent dimensional and weight constraints of the single sensor-based seeker are the technological challenges. Hyper velocity missiles (HVM) and supersonic ATGM-3 with LOAL and dual sensor capabilities built into the seeker are other areas being focussed upon.

For longer range applications, especially for indirect fire, where the target scene is hindered by obstacles like hills, sand dunes, line of trees, etc, fibreoptics guided missiles (FOGMs) is the option. Such a missile has an umbilical connected to the ground system through the fibreoptic cable, which is reeled off from the missile and hence is not a fire and forget type missile. However, since the missile range is quite large (say 10 km) and since it is an indirect fire system, the system and crew are not directly exposed to the enemy counter attack. Secondly, it has the top attack capability and can be fitted with tandem shaped-charge warhead to defeat all futuristic and ERA type armour. This is one system in which development work is going on currently in the USA and Europe.

11. CONCLUSIONS

The following conclusions emerge out of this study:

(i) In view of the limitations of the first and second generation ATGM systems, the third generation ATGM systems with fire and forget and top attack capabilities and capability to defeat futuristic armour equipped with ERA are under development in Europe, USA and India. The NAG ATGM system of India which is in the final stage of development employs advanced technologies in all its subsystems including the IIR and MMW seekers. The possible technological options were evaluated and the chosen sub systems and technologies would ensure that the NAG system would be contemporary and competitive during its entire deployment cycle with similar systems under development abroad. With concerted efforts, the development, evaluation, and deployment of this system would be completed at least one year ahead of similar systems under development in Europe and the US.

(ii) The author is not personally and convinced about the tactical/operational advantages the infantry-type third generation ATGMs like TRIGAT MR would bestow on the users for the reasons outlined above.

(iii) To make the ATGM-3 system in particular and any missile system in general more cost-effective and to enhance the force multiplier effect, the feasibility of multirole, multi platform and multiuser deployment needs to be considered right at the conceptualisation and system definition phase.

(iv) FOGM and LOAL type missiles are required for longer range ATGM applications. With the technologies mobilised for NAG project and other programmes, all the technological and design capabilities are available to configure such systems with incremental efforts to be put in to meet any specific operational requirements.

(v) The concept of TDM is essential to evaluate and choose the appropriate technological and design options to ensure competitive edge over other similar and contemporary systems in terms of technology and operational capabilities and to have built in stretch potential to incorporate performance improvements based on user feed-back/field experience, and to enhance the useful deployment life of the missile system.

(vi) Expensive systems like third generation ATGMs need to be deployed judiciously against target scenarios, where third generation features like fire and forget and top attack capabilities are essential and can be fully exploited to realise allowable and affordable attrition levels to the deploying platforms by engaging the targets from outside the kill zones of the enemy tank weapons. Against target situations with less severe threat, existing second generation ATGMs retrofitted with tandem warhead can also be used. Such an optimum mix of ATGMs would lead to cost-effective operational solutions.

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