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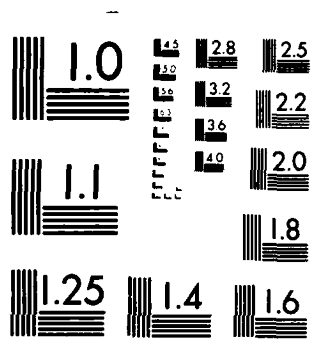

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TACTICAL MISSILE TECHNOLOGIES: THE EUROPEAN PERSPECTIVE

[Allier*, M.; Technologies des missiles tactiques: la perspective européenne, L'Aeronautique et L'Astronautique; No. 89, pp. 51-57; French]

*Director of the Tactical Missile Division, Aérospatiale, Châtillon.

In presenting to you tne perspectives derived from studies pursued in Europe, which have an impact on tactical missile systems, I wish to call your attention to the progress that one can reasonably hope to see achieved before the end of the century, then to the possibilities they will provide us to influence military tactics. /51*

I believe that this progress will be considerable in certain areas, so considerable that their applications will not constitute improvements, but radical changes justifying the use of the term "new generation" for tactical missiles.

The first part of this exposé is thus a rapid overview of the principal technologies involved:

-chemical propulsion;

-jet propulsion;

-airframes;

-warheads;

-electromagnetic and optronic sensors;

-inertial sensors;

-data processing.

In the second part, I will attempt to view the impact of progress in these technologies on application concepts in the following areas:

-performance characteristics and areas of application of the missiles;

-range of the missiles ("fire and forget" concept):

-penetration of defenses, including counter-countermeasures.

Prospects for the Evolution of Technologies

Chemical Propulsion

Solid propellants will still be used, with an expansion of their characteristics.

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*Numbers in right margin indicate pagination in original text.

The performance characteristics will be improved: the range of combustion rates (currently from 4 to 30 mm/sec for pressures of 40 to 200 bars) will be principally expanded upward in order to probably attain from 30 to 60 mm/sec for 70 bars.

These values will be more stable throughout the temperature application range: one will be able to use propellants of the 0.1% per degree Centigrade class, i.e., the thrust will vary only 10% from -40°C to +65°C, instead of the current 20 to 30%.

The increase in density of the powders, despite a small reduction corresponding to the I_{sp}, will permit a 25% increase in propulsive force per unit of volume (fig. 1).

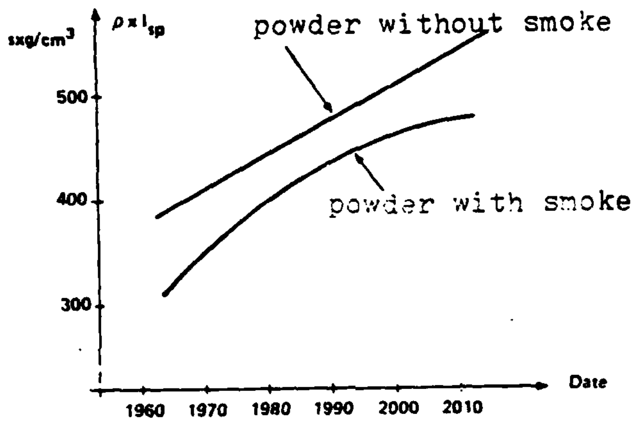


Fig. 1

All of this in conjunction with optimal packing will permit, with identical thrust and duration, more compact engines carrying greater payloads.

This is explained in Fig. 2, which presents:

- -above, a current engine (booster + sustainer) of a recent surface-to-air missile;

- -in the middle and below, what the engine will become, with identical performance characteristics, after the improvements anticipated in 1995 and 2010, depending upon whether there is research on the total elimination of smoke. /52

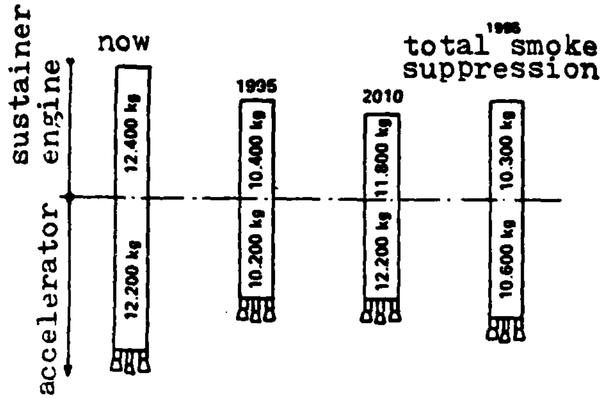


Fig. 2

In fact, another characteristic which will be improved is smoke reduction.

In order to achieve secrecy during the firing and flight of the missile, the metal powder charges and the perchlorates will be eliminated and replaced by nitrated propellants.

Progress in smoke control will also be obtained through the judicious choice of inhibitors and thermal protections.

Jet Propulsion

I will essentially treat ramjet engines,which open a new domain to tactical missiles, and I simply cite turbojets to point out that their dimensions are greatly reduced and are approaching values where the mechanical clearances are no longer negligible in relation to the dimensions of the blading. The main thrust of the research is to obtain low fuel consumption.

Further, and to obtain speeds up to M4+, the ramjet is the best-suited jet engine.

The models already under development have a booster integrated into the combustion chamber and use conventional fuels. They already attain M2.5 at ground level and M3 above ground, and are limited in speed only by structural temperatures.

Research and exploratory work are oriented in three directions:

-The first is research on greater performance characteristics: longer ranges, higher speeds and major payload factors, such as space requirements and constant volume in order to respond to the evolution in defenses with a capacity for increased penetration. This will be accomplished through the utilization of higher specifc impulse fuel and through new launch geometries.

The adaptation of kerosene technologies to use denser ($1 < \rho$. 1.1) but more viscous liquid fuels, already available for tests, will soon lead to range increases on the order of 25%.

The use of a self-decomposing solid fuel with a high boron content (40% to 50%) will bring about improvements in range on the order of 50%, but these improvements will be limited to low altitude trajectories due to combustion difficulties and limitation of the maximum fuel delivery ratio to a value on the order of 4.

The second direction is the utilization of simpler, lighter variants with the employment facilities of simple munitions, but with reduced performance characteristics applicable to small, short-range missiles. Different variants, in which the solid fuel is housed either in the combustion chamber itself or in a separate generator, are in exploratory research.

The third concerns airframes, which I will now discuss.

Airframes

In the realm of airframes, traditional materials (aluminum alloys, steel and special alloys) will be strongly challenged by composite materials, whatever the temperature used. The principal reason for this evolution is research on minimal mass.

A comparison between these materials is presented in Fig. 3. Concerning "low-temperature" airframes, below 300°C, tangible progress in utilization techniques, the development of utilization of fibers such as carbon, polyaramides, etc., and thus the lowering of costs, will favor the composites over the aluminum alloys (Fig. 4).

In high-temperature domain, reserved until now for steel and special alloys, the appearance of composites, achieved through materials and technologies still in the process of laboratory development, will be a novelty. Thus one hopes to see composites with aluminum or graphite fibers embedded in matrices of magnesium, aluminum or glass and leading to low-density (about 2) airframe materials, usable up to 1000°C.

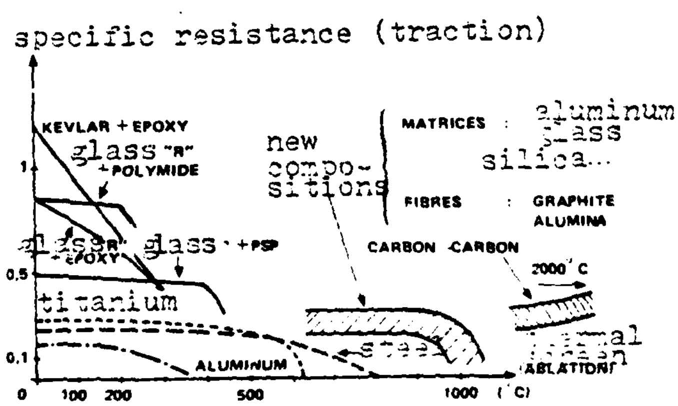
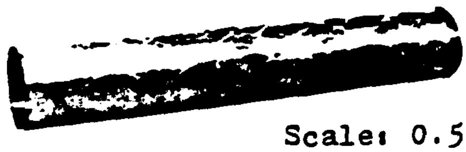


Fig. 3



Scale: 0.5 m

Fig. 4

For:	This tube has a mass of:
-the same mechanical performance (resistance to external hydrostatic pressure)	200 kg Kevlar-carbon 250 kg glass-carbon 310 kg light alloy 650 kg steel
-the same external geometry	

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Thermal protection will be enhanced by development of 3D-type materials, sometimes alloyed with carbon or oxides, which will give ablative components /53 a level of mechanical performance much higher than that achieved with current materials. This will permit reduction of metal reinforcement parts and will lead to improvements in weight.

Warhead Development to the Year 2000

Effectiveness and safety will be enhanced for all types of warheads: anti-tank, anti-aircraft, anti-ship.

But the most extensive changes will be required in the area of anti-tank warheads, due to the considerable advancements embodied in the armor plating against hollow charges which will be employed in the coming generation of battle tanks. Some of the new concepts to be explored are"

- Double (or tandem) hollow charges,
- Use of new explosives (compounds with active binding agents),
- Use of new metals for the casings of hollow charges, more ductile and/or more dense than copper,
- Warheads for attack from above, designed to be effective despite a long range of attack (small sub-charges dispersed from an air-to-ground missile) or despite a high traversing speed above the target (attack during overflight by an anti-tank missile).

Major advances will also occur for warheads used on surface-to-surface and air-to-surface missiles designed for wide-area coverage. These warheads will be made up of smaller sub-charges with differing principles of operation. Some will be equipped with true terminal guidance, others with a device which will permit them to detect the objective during descent to earth and which will trigger the immediate formation and launching of armor-piercing projectiles upon the target.

For anti-aircraft and anti-ship warheads, concepts of pre-set fragmentation will be further developed. Employment of new-composition explosives with high specific energy will provide the capability for more rapid and hence more effective detonation (an increase of penetrating power of 30% or more over current levels) with enhanced safety against impact of projectiles and against fire. Anti-ship warheads will be hardened so as to resist projectiles from anti-missile guns through the use of composite shielding.

In the area of pyrotechnic safety fuses, mechanical operation will in the future be replaced in part by electronics, notably for delayed action timer systems. This development will contribute to weight reduction and greater reliability.

Sensors

In order to form an idea of the probable development of sensors up to the year 2000, it would be instructive to classify them according to operating ranges within the electromagnetic spectrum.

So the first question must be to ascertain which are the ranges of the wave-length spectrum which correspond to the windows of acceptable atmospheric transparancy, i.e., those where the maximum attenuation does not exceed several dB/km (see Figure 5).

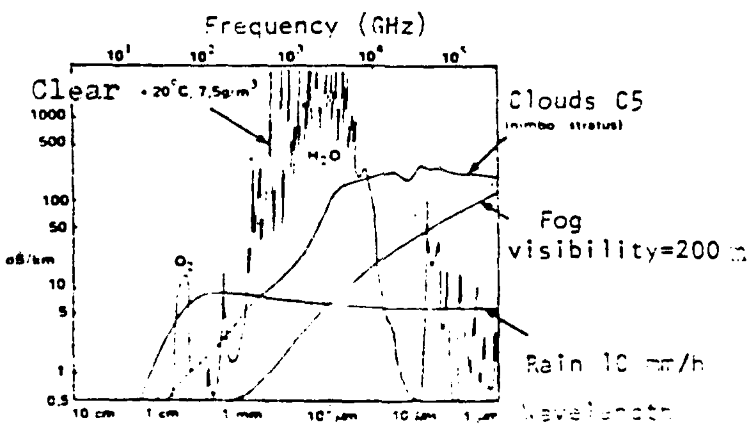

Fig 5

This composite chart is limited to the range from 10 cm to 1 micron. It may be assumed that radioelectronics for the range above 10 cm is a familiar subject. Moreover, the high usage of frequencies in that range render it of little use for weapons systems. At the other end of the scale are near-infrared and visible light.

Two potentially usable bands are clearly evident: the wavelengths above one millimeter, i.e., within the operating range of radio systems and the wavelengths below 13 microns (middle infrared).

Between these is an extended band which is virtually impenetrable, characterized by attenuation up to 1000 dB/km and more.

It does not seem possible, therefore, that there will be sensors operating in other bands by the year 2000.

It is clear, moreover, that the radio bands are more favorable to all-weather operation than the IR bands.

A second useful line of inquiry is to examine the potential for sensors which are secure, that is, passive. Here it is instructive to examine the arrangement of the radiation curves of a blackbody. The targets of a weapons system and the surrounding terrain will conform to the same laws, according /54
to their own spectral emissivity (Figure 6).*

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* Tr. note: see McGraw-Hill Encyclopedia of Science and Technology (1977), v. 6, p. 660, s.v. "Emissivity."

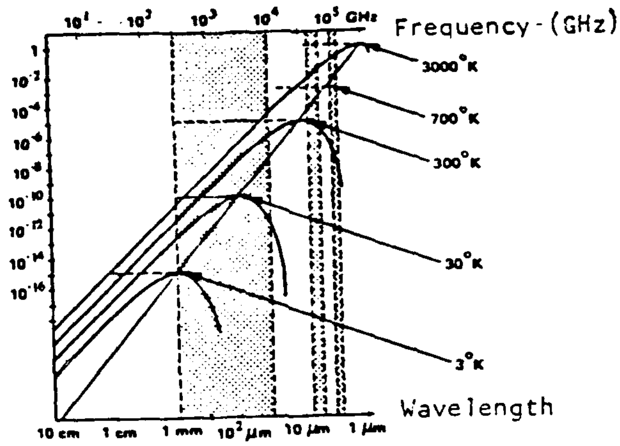

Fig. 6

The shaded areas on this chart are the principal ranges of atmospheric absorption. The chart indicates:

- The significance of the 3-5 micron band, where the maximum radiation of a blackbody occurs at 700 degress K, the temperature of jet aircraft exhaust gases. This band of the spectrum has particular importance for air-to-air and surface-to-air missiles.

- The significance of the 8-13 micron range, where the maximum radiation of the blackbody occurs at 300 degrees K, i.e., ambiant temperature. This band has application primarily for FLIR /Forward-looking infrared/.

In the use of these two bands, the advances which are to be expected up to the year 2000 apply primarily to the technology of detectors and to the processing of detected signals. Today's technology employs groups of detectors, from several units to several hundred, obtaining a useable image through systems of electro-mechanical scanning. In the future, large-scale mosaics will be used, involving several tens of thousands of cells with CCD /charge-coupled device/ readout. These will provide a quantum increase in performance as well as considerable simplification.

Within the radio-frequency bands, in addition to active systems, the employment of passive systems is also certainly to be expected, although the levels of energy radiated by the terrain is much weaker (from 10^6 to 10^7 times weaker than at 10 microns). With the use of superheterodyne technology it is nonetheless possible to detect that energy and the contrasts which is presents.

For applications within these bands, rapid progress can be expected in the development of oscillators and circuits operating at above 100 GHz. It is important to emphasize as well tht by the use of these bands it is possible to obtain antenna directivity even within very small diameters (for example, within a diameter of 150 mm, an antenna can be implaced with an 11 mr /milli-radian7 beam area.*

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* Tr. note: See McGraw-Hill, op. cit., v. 4, p. 251, s.v., "Directivity;" v. 1, pp. 483-4, s.v., "Antenna" (Electromagnetic).

Within this field, finally, the processing capabilities of digital circuits suggest the possiblity of:

- Electronic scanning antennas,
- Composite antennas,
- Pattern recognition systems.

Inertial Sensors

The significance of inertial systems for tactical missiles no longer requires demonstration. Whenever it is technically feasible, such systems are the heart of the missile's guidance system.

In general, inertial systems generate:

- Navigational data, in an autonomous mode not dependant upon external input once the missile is in flight ("Fire and Forget") thus guaranteeing immunity to jamming,

- The totality of control data required by rhe missile,

- Data elements permitting optimum penetration, in an autonomous mode or in combination with other sensors.

These advantages are currently limited by the cost and size of these systems, which prevent their employment on smaller missiles, despite spectacular size and cost reductions (see Figures 7 and 8).

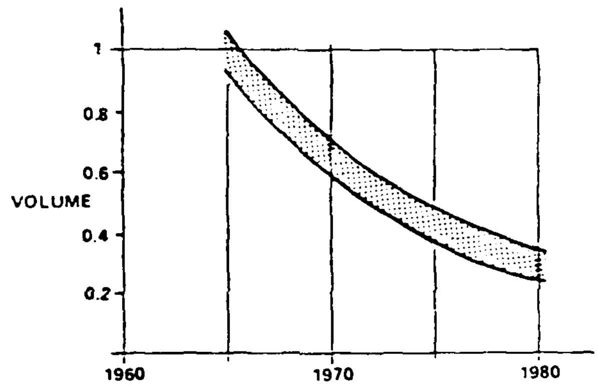

Fig. 7

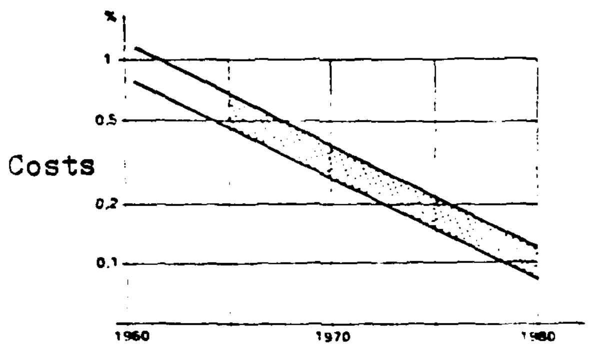

Fig 8

One avenue seems now to be open with the advent of fixed component ("strap down") systems, but significant technical work is still required before the desired results can be achieved.

These systems lend themselves to use with small missiles because:

- The role of electronics in their operation is greater than in stabilized-platform systems,

- The size and cost of the electronics are diminishing quickly and steadily;

- The size of the gyroscopes used is relatively small.

The key operating element of these systems is the gyroscope, in one of two principal models: the balanced elastic suspension gyroscope (tuned dry gyro) and the laser gyroscope (ring laser gyro).*

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* Tr. note: See McGraw Hill, op. cit., v. 7, pp. 99-101, s.v. "Inertial Guidance Systems;" and 1978 supplement, p. 14, s.v. "Gyroscope." "Balanced elastic suspension gyroscope" is a literal translation of gyroscope à suspension élastique compensée. Nothing appearing to correspond to this phrasing was found in any of the references consulted. The McGraw-Hill supplement cited does discuss the laser gyro as one variety of strap-down system.

As these devices are refined, we can look forward not only to a general reduction in costs, but also, in the first case, to an increase in the range of measurement and, in the second case, a reduction in size for general performance between 0.1 degrees/h and 100 degrees/h.

For the range of 20 to 100 degrees/h, the most common for small missiles (Ø ≅ 150 mm), the desired volume is between 1.5 and 2 liters.

Data Processing

The problems of interal data transmission between elements of the missile or within the firing station and the problems of communication between these sub-elements of the weapon system will be resolved by means of general application of digital series ("bus") transmissions through cables or optical fibers.

The miniaturization of circuits has certainly not reached its limits and advances in this area will continue to be significant and uninterrupted. This will allow the elimination of cost considerations in the miniaturization of funcational elements in order to achieve better performance, versatility and simplicity of interfaces.

So we can loo, forward to equipping small missiles with their own means of automiatic control, IFF, etc.

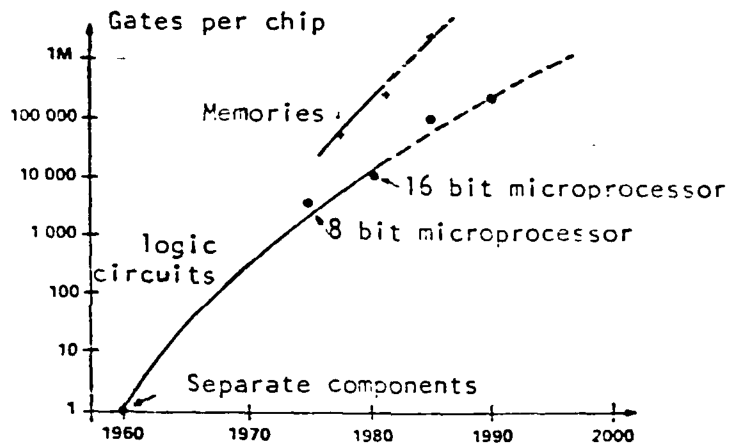

Fig. 9

Data processing will be employed primarily in the performance of the following functions:

- Navigation,
- Pattern recognition (target and terrain),
- Identification of countermeasures,
- Decision-logic in responding to changes in targets or countermeasures.
- Signal processing in the case of virtual antennas,

- control of rocket engines,

- steering,

- automatic control.

Miniaturization permits the multiplication of memory units and logic and computing circuits, without significant effects upon weight and volume. The increase in reliability, and hence system availability, will compensate for any increase in complexity (see Figure 9).

Development of Employment Doctrine

After this very quick review of the major areas of progress in technologies developed by the European countries, I will touch upon their consequences for tactical missile employment doctrine.

In view of the variety of threats and of defense, it will become necessary to design "battlefield systems" with the capabilities to:

- Detect and evaluate all threats,

- Activate defenses against these threats so as to achieve optimal results, in terms of considerations of cost-effectiveness.

These issues cannot be further developed here since they are beyond the present subject. But I would like to cite one aspect which is of immediate relevance: extending the application of automatic defense systems to combat units.

In considering this subject, it must be observed that the range of target acquisition has physical limits, for example limits of visibility in the case of very short range weapons. On the other hand, the range of interception will have a potential for augmentation, due to progress in the technologies involved.

Figure 2, above, showed the augmentation in weight which will be possible for a surface-to-air missile, with a given speed and range. These improvements in solid fuels and structural materials can be used to augment the range and speed, while remaining fully compatible with the capabilities of highly mobile platform vehicles.

Figure 10 shows the anticipated development of target interception range from the present to the year 2000 for a surface-to-air missile carried by a tank.

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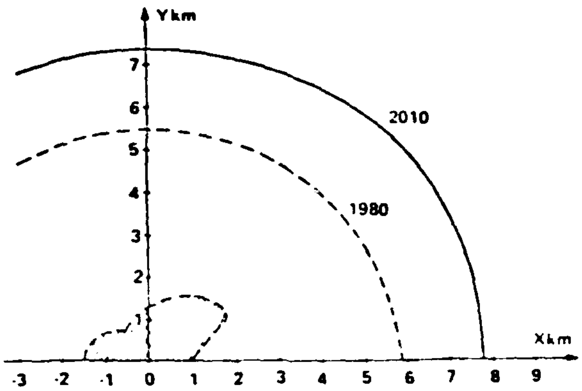

Fig 10

Development of the "Fire and Forget" Concept

This concept is already being applied in several systems put into development very recently. It provides the following advantages:

- Freeing the firing station from the necessity of continuously monitoring the target throughout the flight ofthe missile, thus enhancing its defensive capabilities and also permitting the firing of another missile in quick succession.

- Reducing transmissions between the firing station and the missile, transmissions which are for the most part inherently susceptible to jamming.

This concept will be applied through the combined employment of advances in sensors (primarily inertial and optronique) and in signal processors which are required to handle data very rapidly and in large quantities.

While the missile's onboard equipment will play varying roles in the detection and identification of the target prior to launch, this equipment will necessarily require the capability for reliably maintaining the identification of the assigned target during flight, despite relative movements which modify its appearance, cross-movements by similar-appearing objects, the presence of intentional or unintentional decoys (such as chaff), signal interference caused by the terrain, certain various obstacles (tree lines, fog, dust), and finally despite any countermeasures.

So, in the case of a guidance system requiring a very detailed thermal image, the signal processor or processors will require the capability to perform several functions: to make calculations of density and contrast for an image consisting of several thousand component points and to repeat these calculations with a frequency consistent with the precision of the guidance system, to establish correlations between present and preceding images, to derive flight deviations from these data and provide steering orders based upon image changes and reference data furnished by inertial elements and, at the final phase, to activate the warhead.

Penetration of Defenses and Counter-Countermeasures

It is to be expected that, within the relatively near future, anti-missile defense systems will appear upon the scene involving the use of guns, missiles and perhaps high-energy lasers. These will threaten the virtual invulnerability which tactical missiles currently enjoy. In order to restore their capabilities for penetration, furture missiles will have to be furnished with technical advancements along the lines just covered, advancements, more specifically, in areas such as the following:

- Emissions security (SER, thermal, smoke, etc.)

- ECM (use of decoys, active jamming, etc.),
- Hardening,
- Flight profile (very low or very high altitude),
- Increase in speed,
- Evasive maneuvers.

The coordinated application of two improvements will often prove particularly effective. So a common characteristic of coming generations of missiles will undoubtedly be the combination of supersonic speed adn high-developed pre-programmed maneuvers.

One significant example of such progress is the potential for improved performance against a defense system using medium-range surface-to-air missiles with standard proportional-navigation guidance.

Against this type of guidance, spiral maneuvers prove to be extremely effective. Such motions create in effect a sinusoidal pertubation on each of the two guidance channels of the missile. If these pertubations are in adjacent quadrants, the resulting guidance error will be a vector of constant magnitude, with only the direction depending upon the moment of interception.

Under certain very plausible assumptions calculations will show that a period of spiral (T) on the order of 7 to 10 times the guidance time-constant (Tg) of the missile is optimal and will produce the greatest possible passing distance.

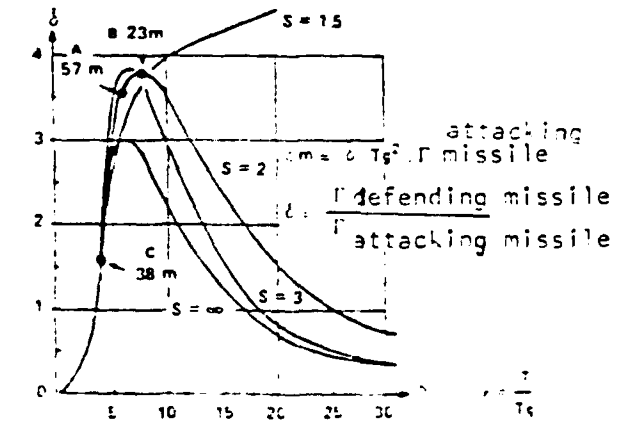

Fig 11

For example (see Figure 11), a spiral maneuver with a period of 2.5 s and amplitude of 10 g would produce, for a current-generation surface-to-air missile (20 g per guidance channel, Tg = 0.4 s), a passing distance of 55 meters (point A), well beyond the effective radius of a conventional warhead.

Against more advance missiles with better adaptation to anti-missile /57 defenses (30 g per channel and Tg = 0.2 s) a maneuver at 15 g with a 1.6 s period would be more effective. It would provduce a passing distance of about 23 meters (point B). This same maneuver would still be very effective against current-generation missiles (38 meters, point C).

Of course a random variation in the spiral period could be programmed in order to defeat attempts at prediction be a defense system more sophisticated than those currently under consideration.

Moreover, maneuvers of this kind owuld far exceed the capabilities of defense by an guns now conceivable and would probably be effective against laser defense systems since, due to the turning motion, the beam would never strike the missile continuously in the same spot.

Other possibilities will be available, for example:

Penetration by missiles equipped with advanced ram-jets, described above, can also be enhanced by their capability to fly at low altitudes (at Mach 2) and at high altitudes (at Mach 4).

Jamming techniques, and hence anti-jamming techniques, depend upon conditions of weapons employment and particularly upon the nature of their targets. Clearly the appropriate countermeasures will not be the same for defense of a ship at sea and for tanks on the battlefield. But it is possible to identify certain general lines of future development.

One of these will be the development of jamming aimed at preventing or delaying the activation of weapons systems, i.e., jamming of the firing process. In the electromagnetic area, progress will involve the regulated increase of the radiating power of the jammer (progress due especially to antenna performance and design) within frequency bands of several octaves. In the infrared and optical ranges, techniques will be developed for production of smoke or aerosol screens with high persistance and effectiveness through a wide range of wave-lengths.

Another line of development will involve techniques for interfering with the missile itself or reducing its effectiveness. These jammers will be "smart" and will be coupled with monitoring devices ("Electronic Support Measurement" /sic/) which will"

- Evaluate the threat, ascertaining its identity (through comparison with a bank of signatures), its direction and its significance;

- Determine defensive tactics adn the most effective jamming measures (types of modulation, choice of decoys, sequence of employment, etc.)'

- Activate and coordinate the employment of countermeasures.

These countermeasures will be of two principal types:

- Active

- Passive (decoys and "chaff")

and their operation will be coordinated, since the operation of each in isolation would not be sufficiently effective.

In each case, the type of response required may be different.

For purposes of weapons and weapons systems, anti-jamming measures and techniques will in all probability be developed along lines similar to those pertaining to the countermeasures themselves. It may be anticipated that anti-jamming processes will be directed toward achieving two primary effects:

- Delaying the activation of countermeasures.

- Reducing the effectiveness of countermeasures.

The first effect will be achieved primarily by developing the security of the weapon or weapons system, through:

- Reduction of electromagnetic, IR and optical signatures of delivery platforms and missiles, and
- Use of passive means of detection, identification and location.

Reduction of countermeasure effectiveness will be achieved through:

- Improvement of signal processing devices (adjustment to jamming when encountered, pattern recognition, imagery),
- Use of mult-mode sensors, including use of the missile's inertial devices, and
- Saturation of detection and identification devices (with decoys or chaff).

These techniques will be the objects of significant and continuous progress during the coming two decades. The value of a weapon system will be judged by its adaptability in light of the development of ennemy countermeasures.

Conclusion

All indications tell us that if aggression occurs, defensive forces will be confronted, tomorrow as they are today, with attack by tanks, aircraft, warships and of course surface-to-surface and air-to-surface missiles.

This threat will involve weapons capabilities advanced beyond anything known today. But the various concepts outlined in this article provide assurance that progress now anticipated through introduction of new-generation missiles will permit continued resistance to attacking tanks, aircraft and ships, with an increased rate of attrition.

For obvious reasons, however, I will not make a prediction as to the outcome of the battle of attacking missiles versus anti-missile missiles.

In fact, the progress described will require considerable expenditures for research and development. The situation may be viewed, in short, as an economic confrontation between potential aggressors and potential defenders.

Having stated this conclusion as plainly as possible, it only remains for me to urge the Europeans and our friends in the United States to make the best possible use of our collective resources.