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MEDUSA: A Concept for Countering Multiple Targets From Theater Ballistic Missiles Final Report

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April 1994

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Background

In April of 1992, a proposal was submitted to the Lawrence Livermore National Laboratory Directed Research and Development Initiative to examine technologies to defeat multiple targets from a tactical ballistic missile. The proposal was for $175K. During the fiscal year we were given $47.5K by the Nonproliferation, Arms Control and International Security Directorate. This funding allowed us to develop a concept and perform preliminary estimates of system parameters and possible technologies. This study led to what has become known as the MEDUSA project, which incorporates the use of small, semi-autonomous kill vehicles aboard a Patriot or Standard Missile. The system concept is shown in Figure 1.

Technical Approach

Several system approaches were examined: active kill vehicle (KV) homing with onboard laser radar (LIDAR), semi-active homing with off-board target designation, passive sensor infrared (IR) homing and several combinations of sensors/designators. Livermore's expertise in pulsed-diode laser technology, advanced propulsion, image processing and simulation allowed us to evaluate the important system options and develop a baseline design. Several important conclusions from that study that I believe are germane to these types of concepts are worth noting here, insofar as they distinguish our results from that of more traditional types of tactical ballistic missile (TBM) defenses.

Of the myriad target possibilities shown in Figure 2, we chose a Scud-delivered submunition payload, with a nominal threat modeled after the known chemical submunition payload, e.g. thick-walled, small, cylindrical canisters in large numbers (> 50) aboard a Scud or Al-Hussein TBM. The choice of fractionation ratio, to a large degree, dictates the effectiveness of the interceptor system. Another aspect of the problem with a submunition target is the presumed lethality of the interceptor KV(s) when the target is in a non-deployed state, as might be the case for the normal military use of a TBM payload above 15km. Lethality concerns are discussed in this context later in this report.

We packaged approximately 24 KVs with a sustainer or "kick" motor aboard the Patriot Anti-Tactical Ballistic Missile (ATBM) Capability (PAC) and Standard Missile II/ Block 4 (SM2/4) missile systems as an integrated part of the warhead section, with no weight increase for the missile. The baseline design concept is shown in Figure 3. The replacement warhead section acts essentially as a second stage, known as the maneuvering vehicle (MV). The function of the MV is to guide the payload to a nominal intercept window and deploy the KVs as shown in Figure 4. Figure 5 illustrates a typical flyout profile for a Patriot-like MEDUSA carrier vehicle. For this simulation, we assumed that the missile completes its normal first stage burn and then coasts for a few seconds. In the analysis, we varied the start of burn and coast period for the second stage to study the effect of drag and additional thrust on the total range and altitude capability. For near optimal performance, the intercepts now occur above 50km for the 600km threat, which has significant impact on the KV design in terms of aerodynamic heating on the optical window and maneuverability. When the KVs are within acquisition range of the targets, the warhead compartment shroud is ejected and the KVs begin an initial divert to an inertially-designated point along the intercept path.

Total individual KV weight with a cooled IR seeker and a dual-grain solid propulsion system was approximately 2.5 kg. A version with a 10 cm aperture, 1 μm laser was 0.25 kg heavier. The first version is the one shown in Figure 3. Extensive work was done to select and design the propulsion system. Figures 6A and 6B indicate the wide range of propulsion options that were examined. Such systems as no. 4, a nitrogen-tetraoxide and monomethyl hydrazine were compared for total system use, as well as for Atitude Control Systems (ACS) on the hybride systems. Advanced technology such as Expansion-Deflection (E-D) nozzles were also considered. For the minimum weight system, we chose a solid propellant with dual grains for both divert and vehicle stabilization (no. 7 in the figure). Both active and passive KV types could acquire an individual target at ranges of about 10 km. The major difference in KV performance was in the area of response to countermeasures and propellant efficiency. Figure 7, indicates the tradeoffs in system parameters for the nominal threat. The important parameters for KV design are acquisition range (or time-to-go), seeker field-of-view and divert requirement. An important trade occurs between propulsion system burn time and the g-capability of the KV. If you are very close to the target cluster when you commence divert, the total propellant requirement may be reduced, but the resultant acceleration may exceed the capability of the KV. Figure 7 can serve as a simple design nomograph for the assumed case of a 7-10 second acquisition time and a 4 second propellant burn time. If we assume that we are able to achieve a 200 meter/second divert velocity and have a 100 percent efficient system, the KV could cover a target uncertainty radius of 400 meters. Kinetic parameters which tend to drive sensor design are the closing velocity and the error in target position. For our previous example, a 400 m target uncertainty and 10 second acquisition time at 3 kilometers/second closing velocity translates to a seeker field-of-view of 1.5°.

Results

Using our simulation tools, we modeled the interceptor performance based on known parameters and our estimates for the additional stage. The combination of sustainer motor and KV payload gave the hybrid Patriot-based system a greatly increased footprint against nominal range (600-1000 km) threats. This is shown in Figure 8. Note that the unmodified Patriot system as modeled has virtually no capability against threats where the closing velocity is in excess of 3 km/s, which is the innermost contour in the figure on the left. This is an accurate reflection of the experiences of the Gulf War and similar studies done by the Army. Addition of the kick motor extends the available battle space to useful ranges (in excess of 200 km) and adds capability against > 3 km/s closing velocities. Note that the innermost contour in the figure on the right now represents the capability against a threat with closing velocity in excess of 3.5 km/s. In fact, for the modified system, the limiting system performance factor against the nominal threats is radar acquisition range.

A major problem facing a terminal or midcourse system such as MEDUSA is the fractionation efficiency against a highly proliferated threat coupled with the uncertainty associated with enforcing miss distances on the order of the target minimum dimension. For the case of the small submunition threat, the 3-sigma guidance/seeker errors usually exceeded the limits needed to reliably hit the submunition. Guidance simulation results are shown in Figure 9. For these examples, we ran a number of end-game simulations with nominal values for the major contributors to miss, i.e. seeker noise, gyro bias, gyro noise and system time delay. One of the parameters was then allowed to vary while the others were held constant. The results indicate that a 3-sigma miss of about 10 cm is the best that can be realistically acheived. This would be excellent for a normal target, such as a missile warhead section, but is not good enough for a payload of small submunitions requiring 1-on1 kill. Strategies such as N-on-1 KV assignment are not efficient for a large number of targets. In our model, redundant targeting was prevented by enforcing adequate dispersion from the MV and limiting the effective field-of-view of the individual KVs. Taking into account best-case enforceable miss distances and the reliability of sensor and guidance subsystems, it is estimated that a MEDUSA payload would be able to attrit about 30% of the dispersed Scud submunition payload. Although this is certainly better than 0%, it may not be considered adequate for a "low leakage" defense such as might be needed to protect a large, soft target such as a city.

Because of the somewhat lackluster performance against the baseline threat, we initiated a preliminary study of a technology which eliminates the primary error source in hit-to-kill (HTK) homing, i.e. propulsion-induced jitter, and instead uses a number of explosively formed projectiles (EFPs) with a high-resolution tracker/fuze. Figure 10 indicates some of the relevant system elements required for this improved KV payload. We believe this idea has great promise, both in reducing miss distances and increasing the fractionation efficiency.

Another issue concerning effective TMD is the capability of the conventional warheads or KV designs to kill a non-deployed submunition threat as might be encountered during a high endoatmospheric intercept. The individual, hard targets inside the missile body present a formidable challenge from the standpoint of assuring lethality against a large number of submunitions. MEDUSA provides an opportunity to enhance the effectiveness of the KV payload by putting more energy on target as shown in Figure 11. There is also the possibility of enforcing different impact points, as shown in Figure 12, which allows the KVs to penetrate and destroy more submunitions that might otherwise have been "shielded".

Summary

We feel that the concept of intercepting a fractionated threat from a tactical ballistic missile is potentially feasible and would have very high payoff for the defense. Many other concepts have been suggested to solve this problem, although they have mostly been more futuristic approaches, e.g. aircraft-based lasers. We also believe that current technologies are not likely to be adequate for the expected types of very small submunition payloads, especially in the presence of relatively simple countermeasures. The MEDUSA concept, or its clones, may very well provide a vehicle for the study of less stressing threats, e.g. separating warheads and provide a lethality enhancement for non-deployed payloads. An opportunity also exists to investigate alternative technologies, such as the explosively-formed "disk" idea. The use of high-precision, limited field-of-view sensor-fuzed munitions is a subject of interest in other Defense Department programs and may have application to the important area of theater missile defense.

Figure 1

TMD threat

TBMs

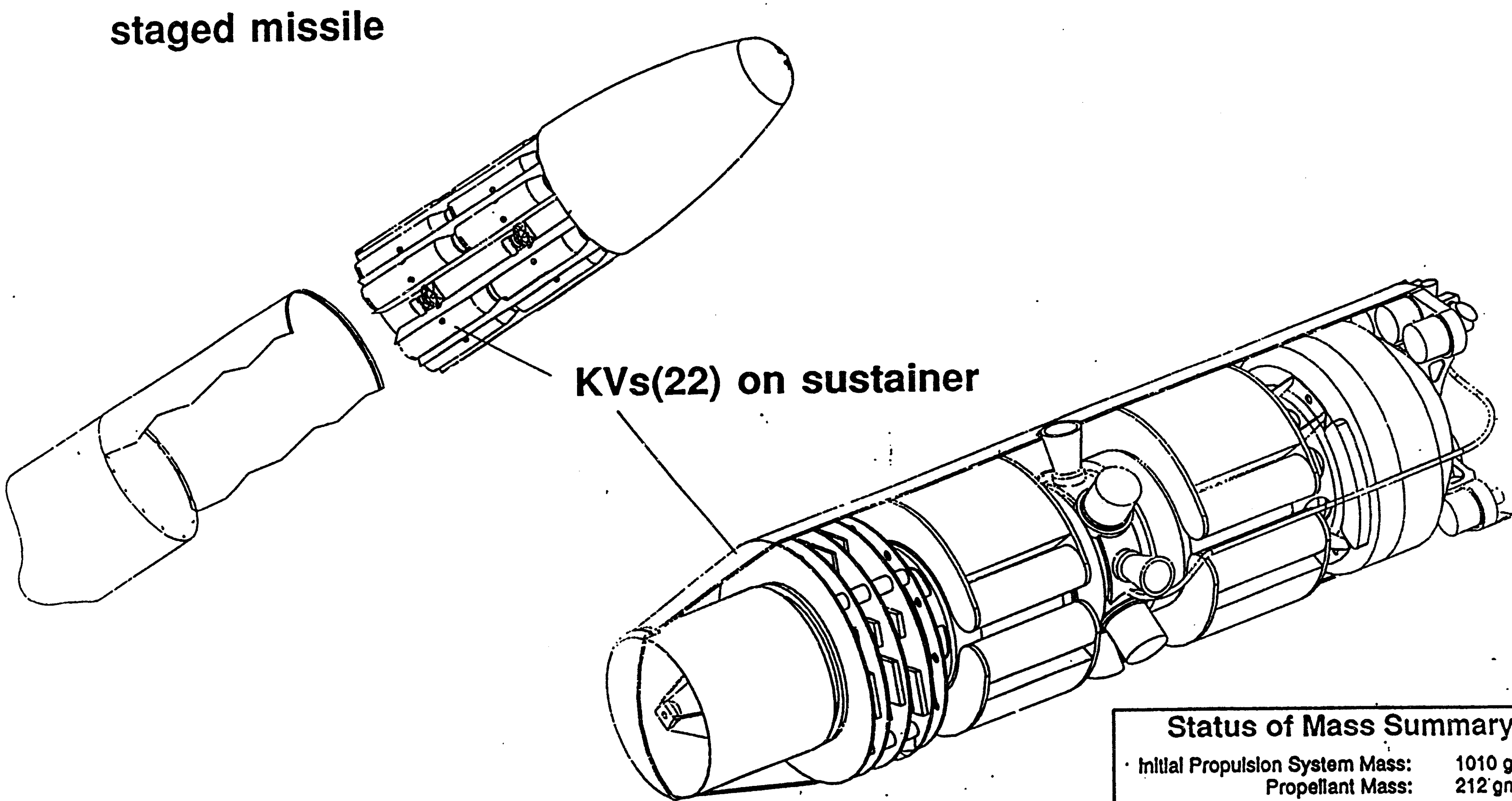
SS21,23
SCUD
Alacran
Condor
S-series
M-series
FROG
CSS series
Prithvi
Agni
NHK
Pluton
Jericho
Sky Horse
Green Bee
Hatf

Warheads

bulk HE
bulk chemical
- internal tank
- integral tank

chemical submunition
bulk ABO
ABO submunition
third world nuclear
advanced nuclear
- seperating RV
- multiple w/h

Design concept - MEDUSA for TMD



Status of Mass Summary

Initial Propulsion System Mass:	1010 gm
Propellant Mass:	212 gm
IMU:	200 gm
Structure & Mechanizes:	100 gm
Subtotal:	1522 gm
Target Mass for KKV:	2500 gm
Mass Target for Sensor, Power and Avionics:	978 gm

Figure 3

MEDUSA operational sequence

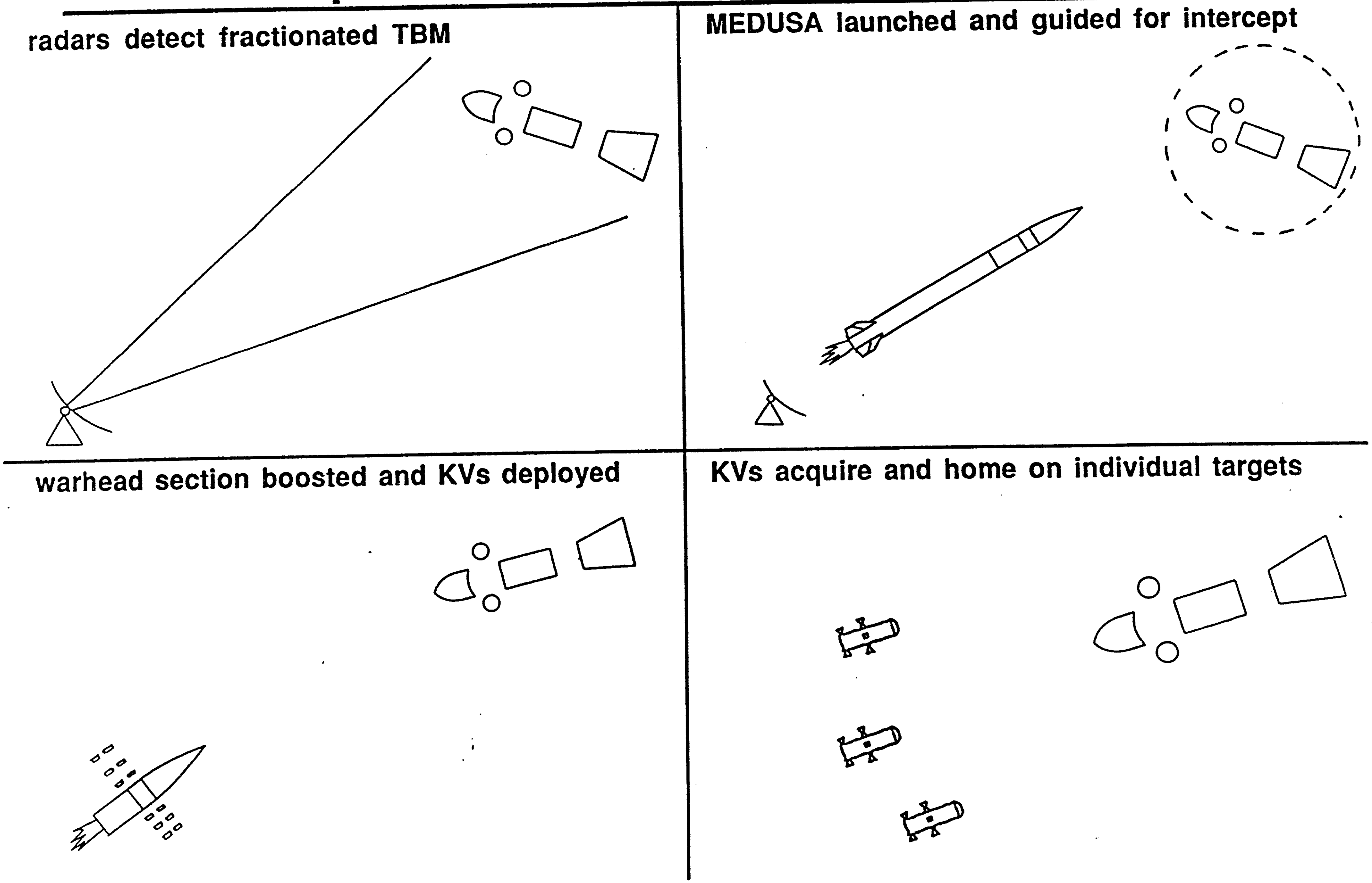
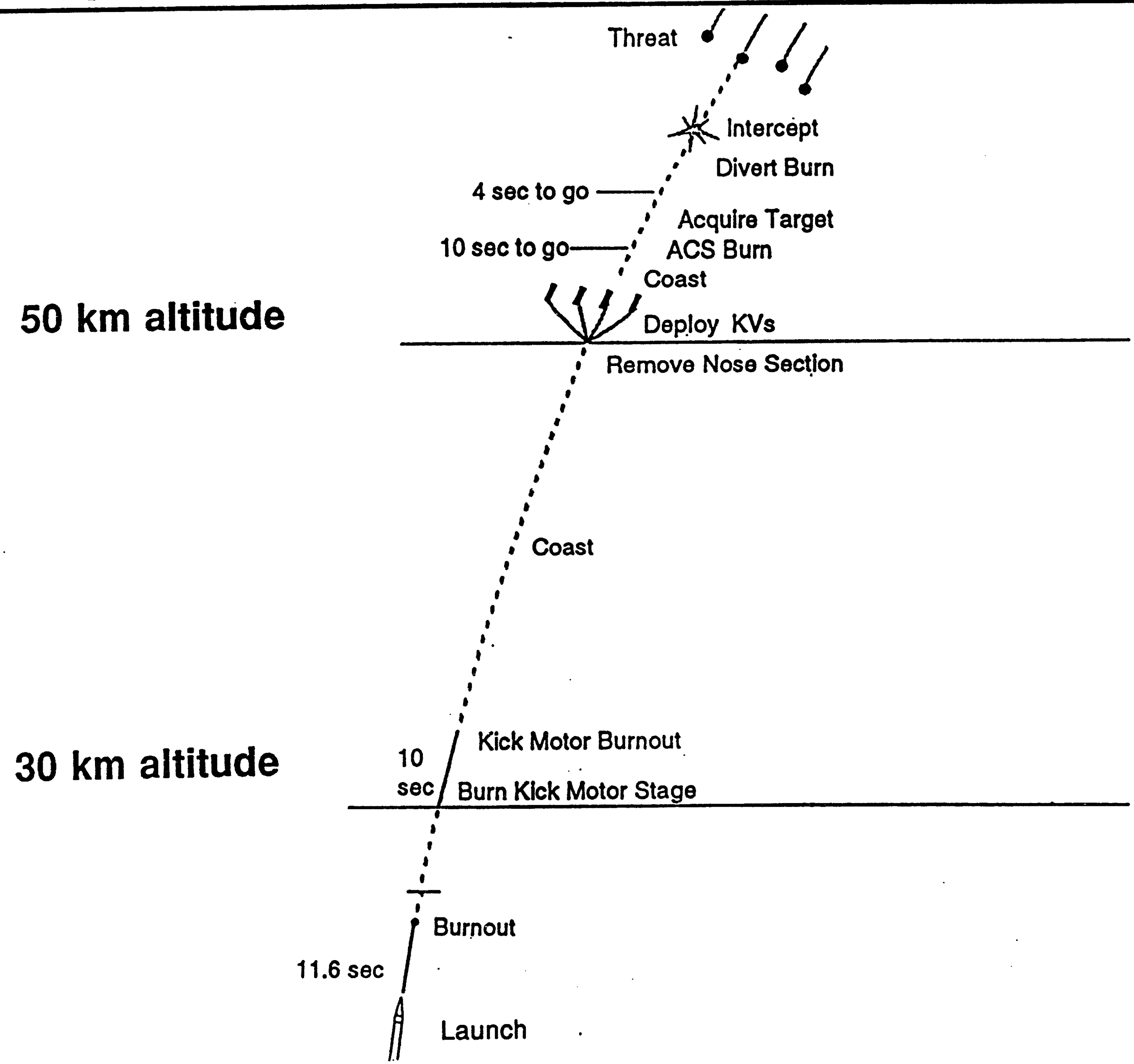


Figure 4

TMD Operational Concept with MEDUSA



Alternative Divert Rocket Propulsion Systems Considered

No. Divert Maneuver	Attitude Control	Conclusion
1. Nitrogen gas	Nitrogen gas	Much too heavy, too large
2. Monopropellant hydrazine	Nitrogen gas	Too heavy, too large
3. Monopropellant hydrazine	Monopropellant hydrazine	Too heavy, too large
4. Bipropellant N_2O_4 - MMH	Helium gas	Too heavy, too large
5. Bipropellant Cl_5F_5 - N_2H_4	Helium gas	Toxic, large volume Discarded

* Continued on next slide

Alternative Divert Rocket Propulsion Systems Considered

No.	Divert Maneuver	Attitude Control	Conclusion
6.	Dual grain solid propellant (LEAP) running continuously with 4 divert hot gas valves and nozzles (Thiokol Corp. proposal)	Hot gas valves and nozzles with gas from same grain	Smallest, lightest, but has stability problems, exceeding sensor field of view
7.	Modified, balanced version of item 6. Separate ACS system.	Same as 6, but separate system, smaller thrust	Selected this system
8.	High performance pulsed solid propellant grain and single nozzle (no hot gas valve) with multiple pulses	Separate solid propellant grain with hot gas valves and nozzles	Unproven, discarded, too many igniters
9.	Dual grain solid motor with E-D nozzles and proportional control (Aerojet concept)	Separate He system	More difficult to control

Figure 6B

FIELD–OF–VIEW AND DIVERT VELOCITY TRADES

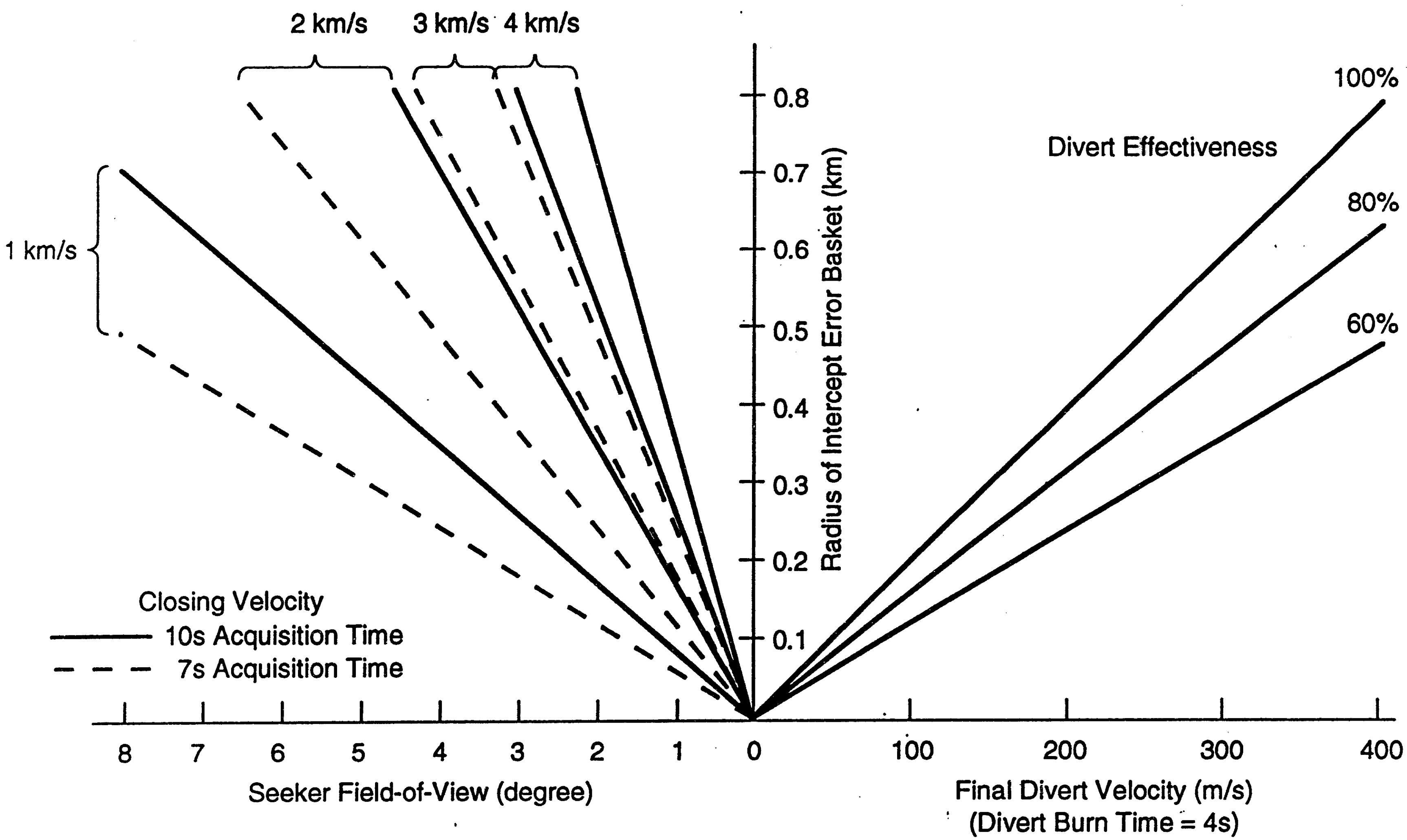
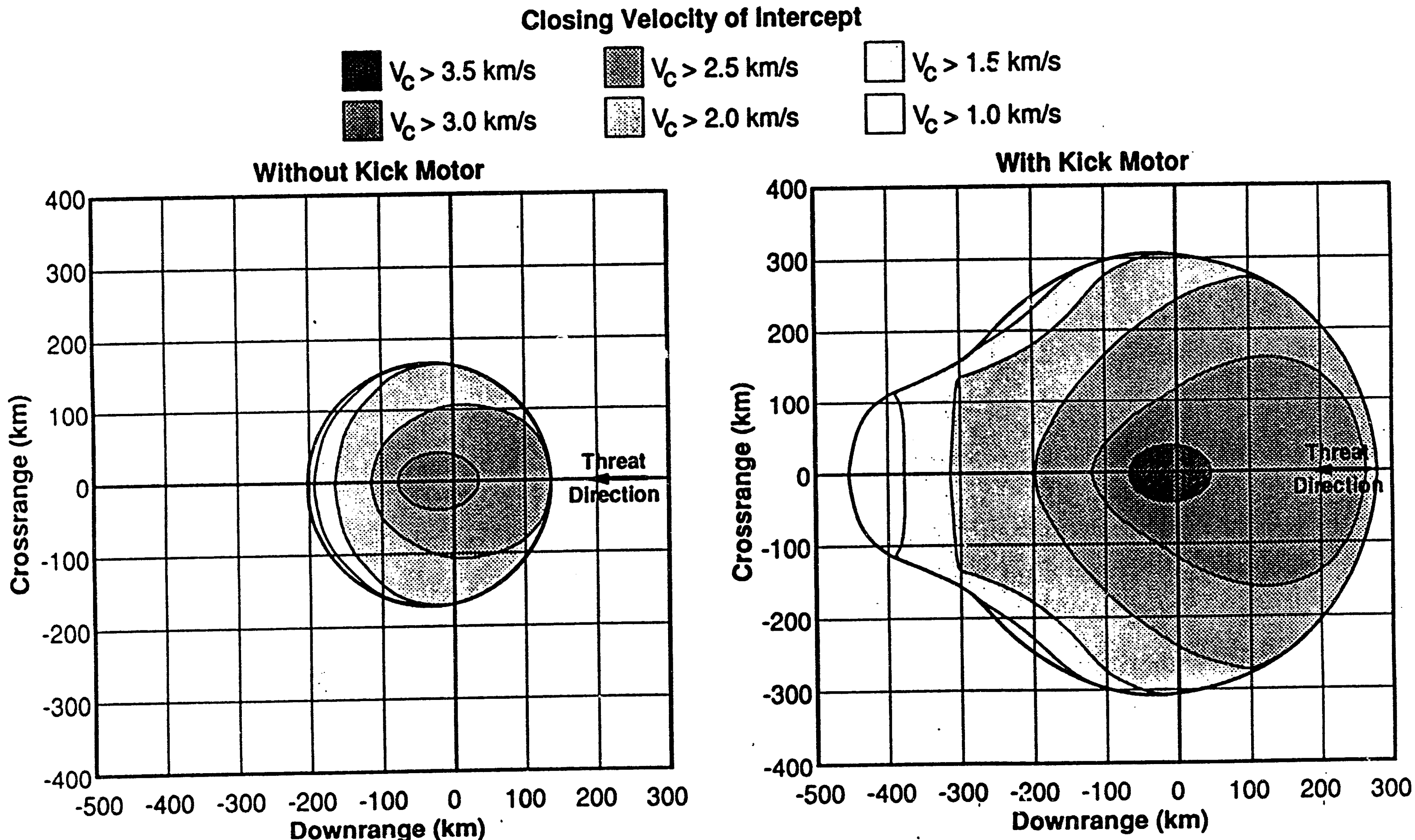


Figure 7

GROUND DEFENDED AREA - THREAT B

Unlimited Radar Range, 30 km Minimum Intercept Altitude



** Tail caused by interceptor apogee > target apogee*

Figure 8

PRELIMINARY MISS DISTANCE SENSITIVITY ANALYSIS

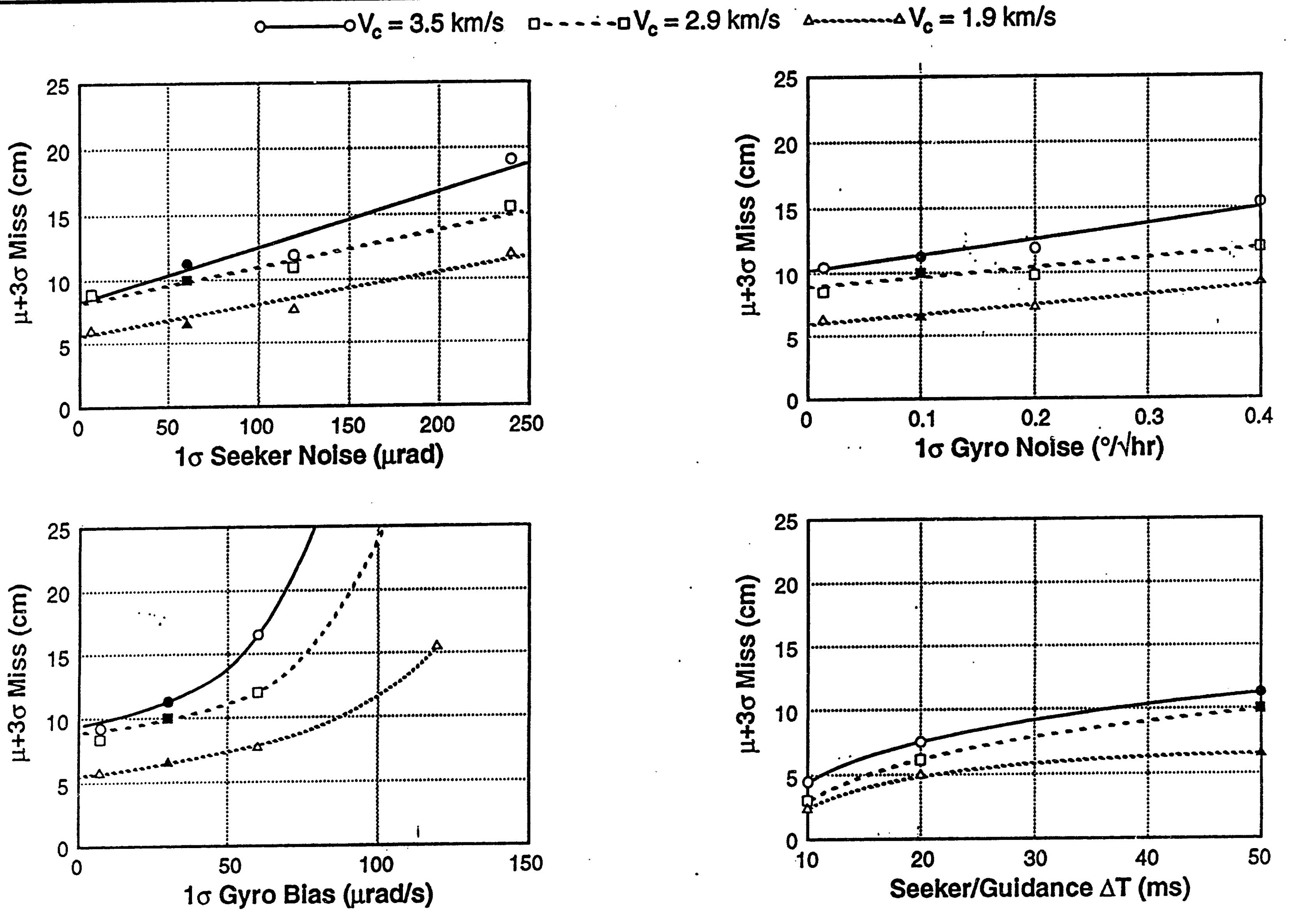


Figure 9

An alternative warhead concept for MEDUSA

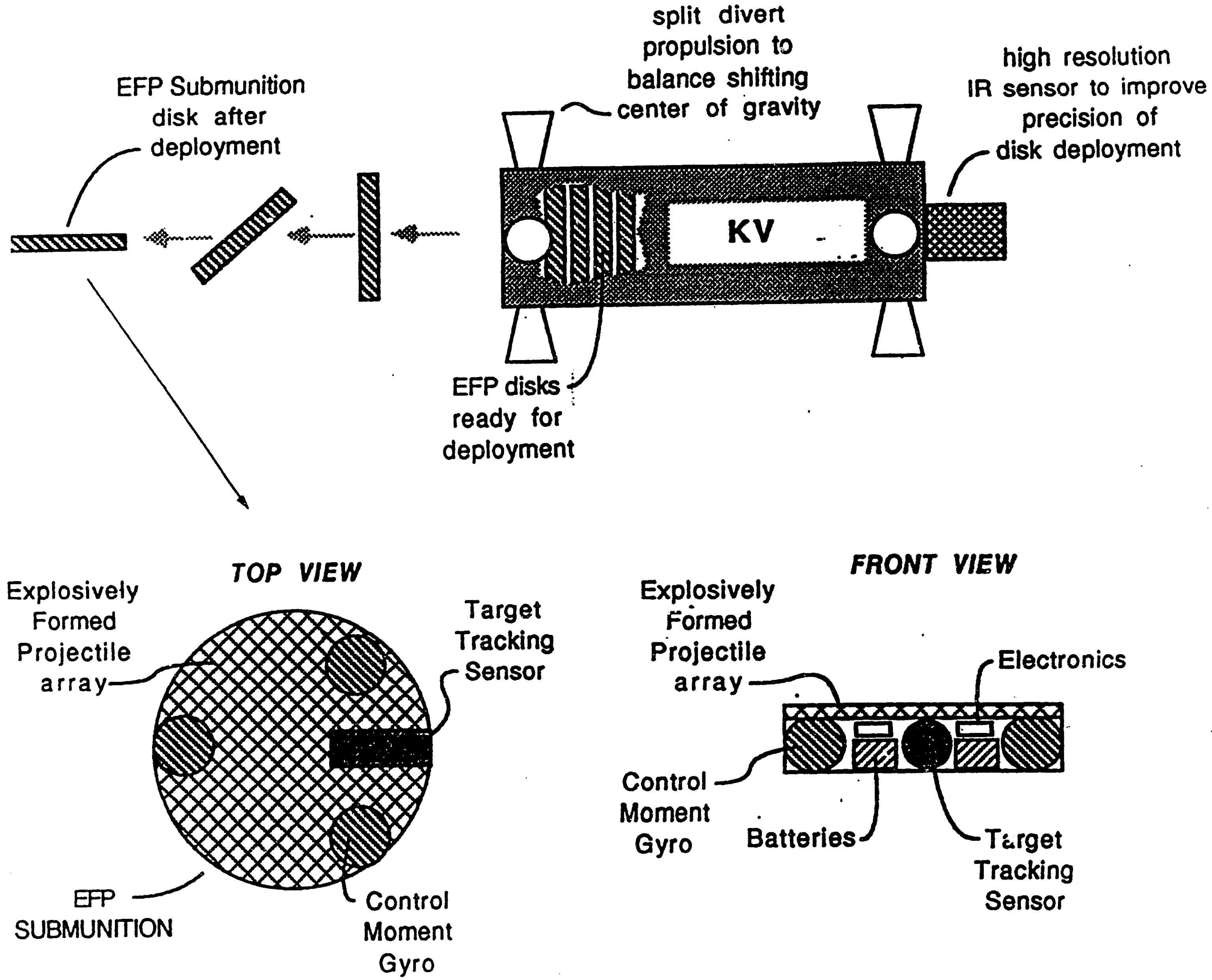


Figure 10

MEDUSA has the potential for providing much better lethality against submunition payloads prior to threat fractionation

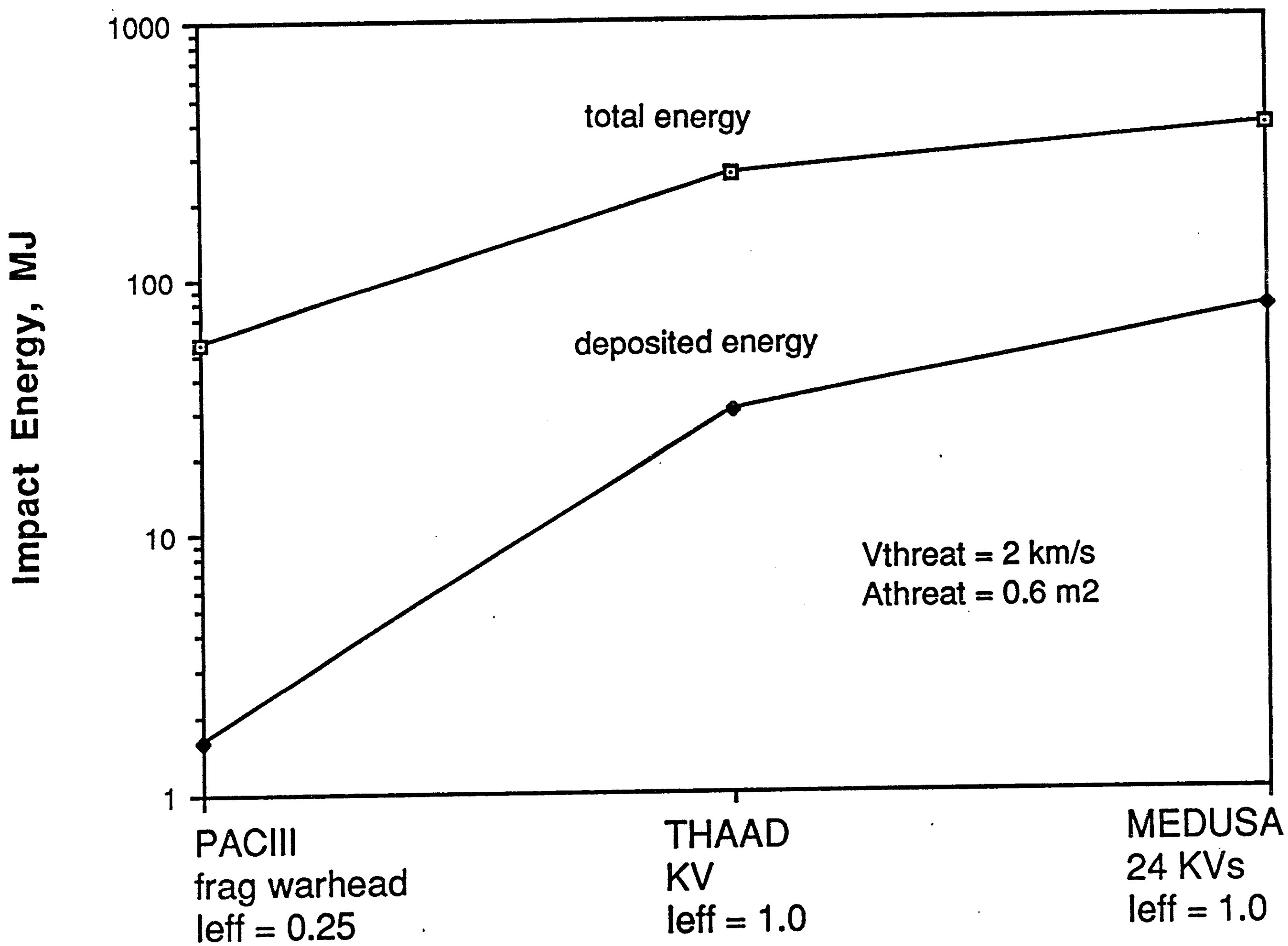


Figure 11

Current lethality (PAC and THAAD) against hardened targets is uncertain. MEDUSA uses a different approach.

issues
- warhead location
- aimpoint selection
- end-game kinematics
- target interactions

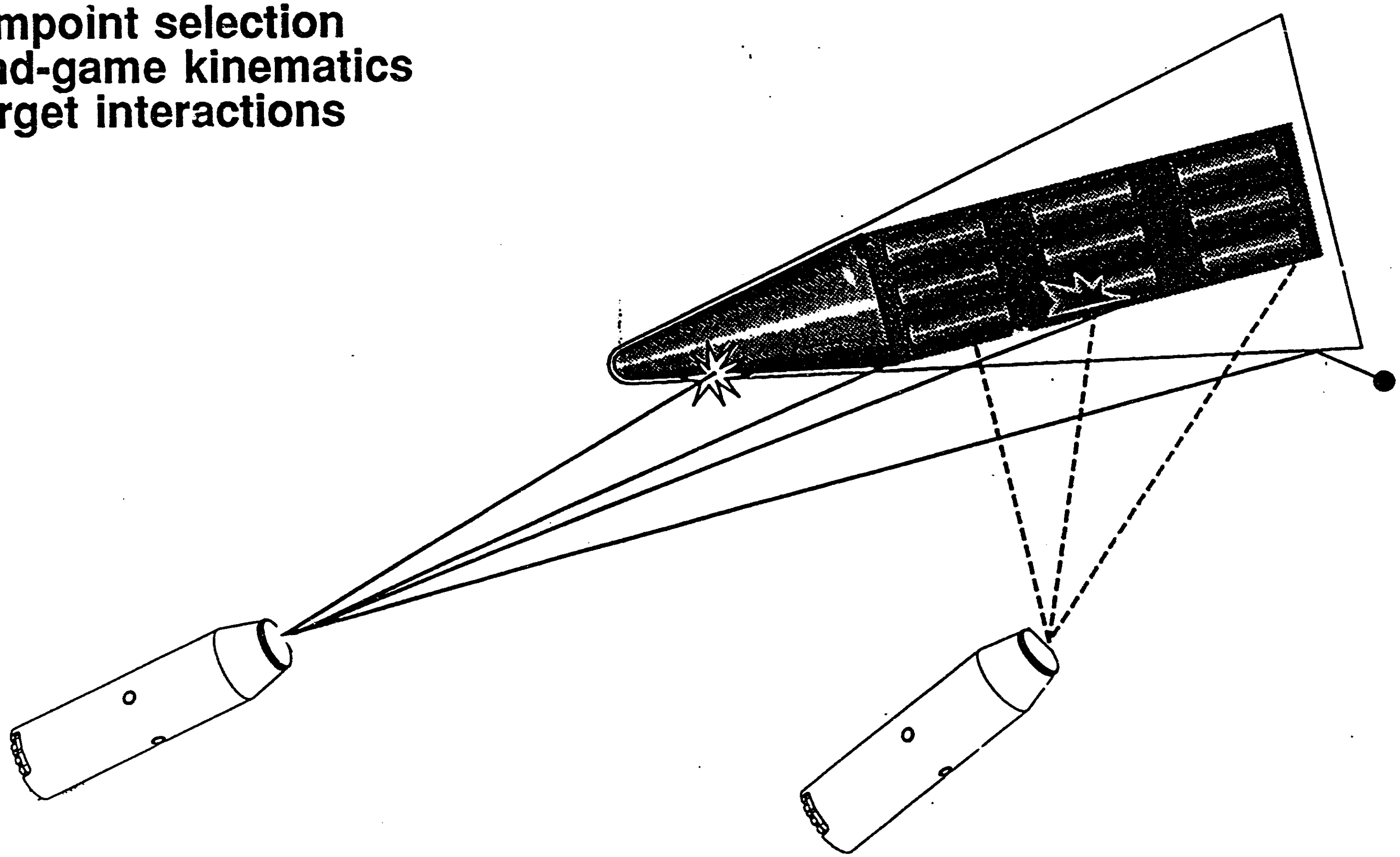


Figure 12