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GROUND-BASED PORTABLE MINIATURE INTERCEPTOR FOR CRUISE MISSILE DEFENSE

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Abstract

A ground-based Portable Miniature Interceptor weapon system has been conceptualized to fulfill the important mission of killing/negating cruise missiles in flight. A preliminary PMI design concept offers a weapon weighing under 150 pounds with an approximately hemispherical intercept volume having a diameter of about 10 miles. The paper describes the CONOPS, PMI design, component characteristics and packaging, and performance against cruise missiles in a representative mission scenario.

Concept of Operations

The global proliferation of land attack cruise missiles and payload weapons of mass destruction has become one of the most immediate and dangerous threats to U.S. national security and allied interests. The potential near-term use of these weapons in present areas of great political instability is particularly acute.

This paper describes a ground-based Portable Miniature Interceptor (PMI) weapon system that has been conceptualized to fulfill the important mission of killing/negating cruise missiles in flight. The conceptualized weapon is optimized for killing/negating cruise missiles in theaters with various intensity levels of conflict, including OOTW. The weapon can also be used against other low-flying theater threats such as ARMs, UAVs, and attack helicopters.

The Fifth Annual AIAA/BMDO Technology Readiness Conference, Eglin Air Force Base, September 17-20, 1996.

A preliminary PMI design concept offers a weapon weighing under 150 lb with an approximately hemispherical intercept volume having a diameter of about 10 miles.

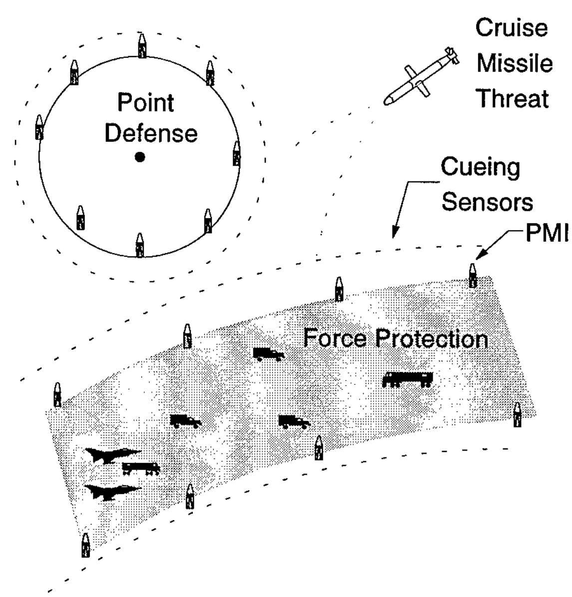

Figure 1. Ground-based PMI CONOPS illustrating a point defense scenario and a line defense/force protection scenario.

Individual clusters of PMI weapons are placed about 10 miles apart along any defended perimeter. Figure 1 shows point and line defense scenarios. Specific locations/distribution of the PMIs will depend on the threat nature/intensity of the conflict and on the troop/assets to be protected. Weighing less than 150 lb, the PMIs are easily deployed on the ground and is highly mobile. In some missions the PMIs may remain on mobile platforms, such as HMMWVs or even vans or pickup trucks for small-unit/covert operations. Surveillance or cueing sensors detect the approaching cruise missiles and other threats. Based on cueing sensor and intelligence data, predicted threat vector/time and order to commit are communicated to the selected PMI weapon at the optimum location. The selected PMI flies out to the predicted intercept volume (position and altitude), hovers in situ, acquires the target with an onboard sensor, and either maneuvers itself or deploys a separable kinetic kill vehicle (KKV) to ensure a kill by direct impact or by another kill/negate mechanism. Trade-offs exist among hit-to-kill, stand-off warhead, particulate clouds, etc.

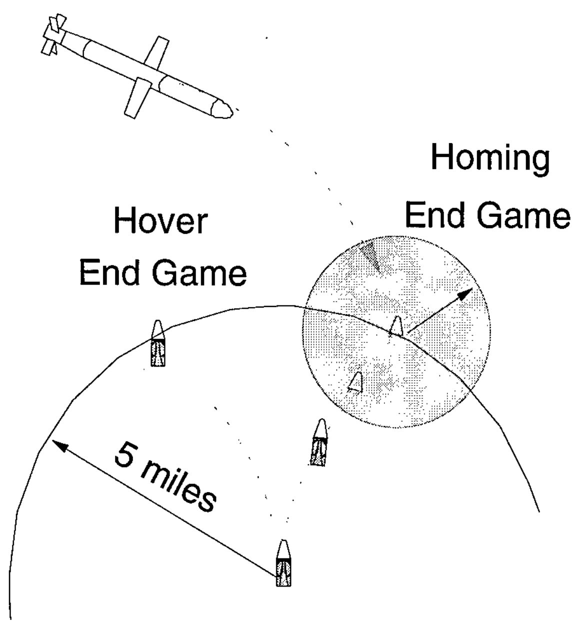

Figure 2. Each PMI has an approximately hemispherical intercept volume having a diameter of about 10 miles. Two endgame approaches: hover/wait and active homing, are illustrated.

As illustrated in Figure 2, each PMI can reach and defend against cruise missiles and other threats anywhere within the 5-mile hemispherical volume. The time required to traverse the maximum defended radius/altitude is about 25 seconds. Available and emerging cruise missile defense cueing sensor techniques (laser, passive EO, radar, acoustic, etc.) should provide lead times generally in excess of 25 seconds.

Two different PMI endgame approaches are included in our design trade (Figure 2). In the simpler and lower cost approach, the PMI, after it reaches the predicted threat impact basket, would hover in-situ, acquire the threat with an onboard sensor, perform minor position adjustments, and impact/destroy the threat. Further trades for this design concept include incorporation of proximity-fused warheads such as the explosively formed penetrator (EFP) warhead and deployed skirt mechanisms for increasing the collision cross-section. A more complex endgame concept includes substantial divert/control capabilities that enable the PMI to move in any desired direction and home on the target for a kill. This can be done by incorporating the homing capabilities on the PMI itself (unitary design) or on a small separable KKV (Figure 3). This PMI endgame design

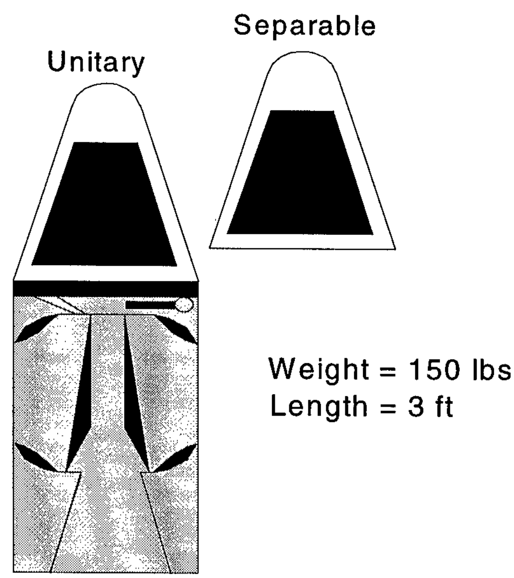

Figure 3. The PMI preliminary design has a weight under 150 lb and length under 3 ft. Trade options include unitary or a separable KKV.

concept is more complex and costly, but has larger defended volumes and is more robust against advanced threats such as those with maneuver capabilities, or when the cueing sensor performance deteriorates for whatever reason.

For CM and other threats of interest, the PMI sensors should achieve acquisition ranges in excess of several miles, thus providing the PMI with final divert times of over 10 seconds, which are sufficient to remove cueing sensor and PMI flyout errors of half a mile or more.

The PMI onboard sensors, together with specially developed algorithms will provide some discrimination and IFF capability for the endgame. Two additional features are traded/incorporated in the PMI design to further reduce the risk of friendly kills. One is an onboard transmitter/receiver that will interrogate the potential target for a predetermined coded message. The other is continued communications from a control station which could issue a last-minute over-ride order to disengage.

PMI preliminary design, major subsystem/component functions, characteristics, and packaging will be described in the following Section. Evaluation of and predictions for the performance of PMI in a representative cruise missile defense scenario will be presented in Section 3. A summary of our results and some concluding remarks will be presented in Section 4.

PMI Design

The baseline PMI design leverages mature technologies and products to reduce development time, cost, and risk. Shown schematically in Figure 4, the PMI propulsion uses the mature advanced axial solid stage (ASAS) motor that have been successfully developed and applied in BMDO programs. Peak velocities of the PMI are less than Mach 2, thereby avoiding numerous potential, severe aero-thermal environmental complications and

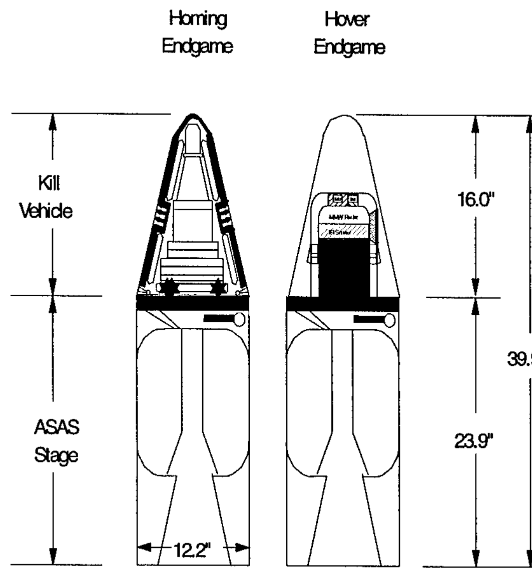

Figure 4. Schematic of PMI with ASAS motor propulsion and hover endgame and homing endgame front-end options.

risks that are often associated with hypersonic projectiles. The two PMI endgame design options, hover and homing, are also shown schematically in the figure.

The standard ASAS motor is 12.5 inches in diameter and is capable of imparting a total impulse of over 20000 lb.-sec. The nominal burn time of this motor is just over 14 sec but this time can be modified if required. This motor has a propellant weight of 74 lb. and a total weight of 100 lb. It is a single, perforated grain design with an electro mechanical actuated thrust vector control (TVC). A standard attitude control system is used to control the PMI during the flyout.

PMI flyout trajectory simulations were performed in order to determine the intercept volume. These trajectories were computed using the ASAS total impulse of 20350 lb.-sec and a burn time of 14.5 seconds. Both the carrier vehicle ballistic coefficient and launch angle were varied parametrically. Figure 5 presents velocity and altitude as a function of range for a launch angle of 65 degrees. Also noted on the figure are time,

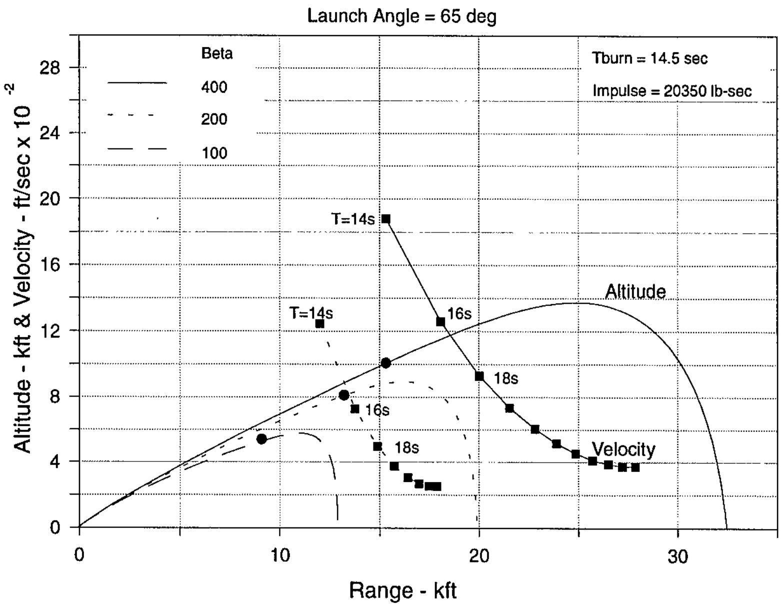

Figure 5. Representative PMI flyout trajectory with standard ASAS motor at 14.5 sec burnout and 65 degree launch angle.

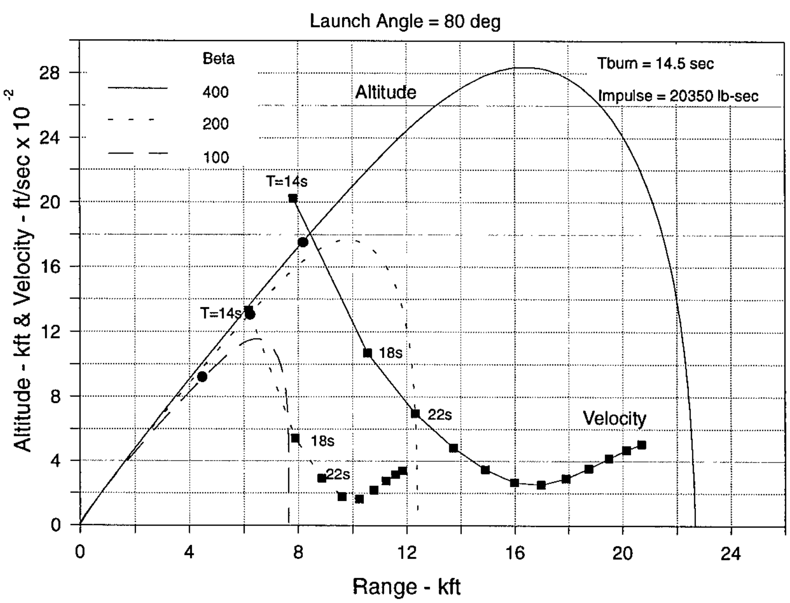

Figure 6. Representative PMI flyout trajectory with standard ASAS motor at 14.5 sec burnout and 80 degree launch angle.

marks at every two seconds . It can be seen that for a ballistic coefficient of 400 lb./ft^2, the maximum altitude is approximately 14 kft and the range is just above 25 kft.

A similar plot is shown in Figure 6 for a launch angle of 80 degrees. In this case the peak altitude is greater than 28 kft but the range at this time is only 16 kft. If the burn time was increased for the same impulse motor it is possible to achieve a longer range for a small loss of altitude. Figure 7 shows this effect for a launch angle of 80 degrees and a burn time of 21.75 seconds.

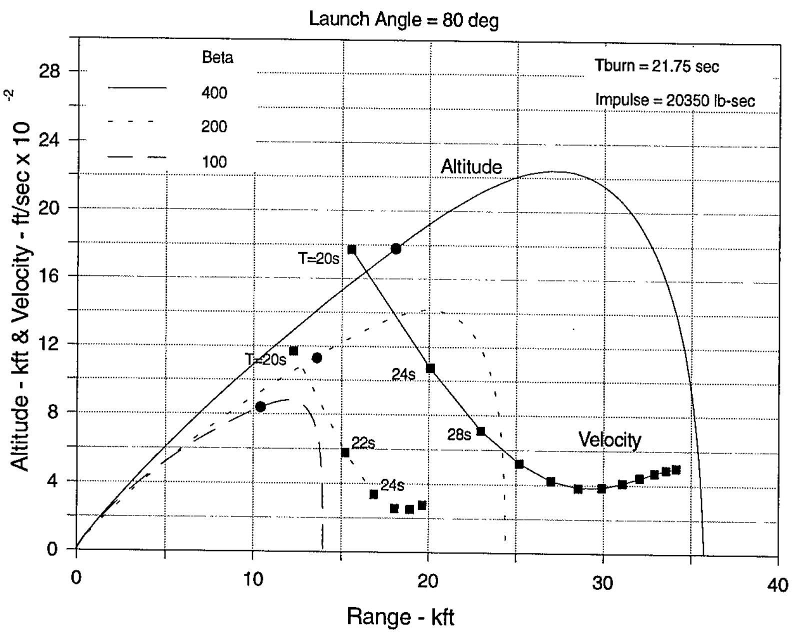

Figure 7. PMI flyout trajectory with ASAS motor at 21.75 sec burnout and 80 degree launch angle.

Illustrated in Figure 8, the active homing endgame design option configuration is a biconic with an integrated divert and attitude control system (DACS)/aeroshell. Key elements of this DACS/aeroshell concept include tanks for propellant/pressurant, divert thruster and nozzle geometry, ACS, and any required thermal protection system. This integrated airframe eliminates parasitic weight and volume and results in an efficient packaging of the required subsystems. The DACS/airframe weight is less than 20 lb. and internal components weigh about 18 lb, resulting in a total kill vehicle weight of just under 40 lb. The ballistic coefficient of this configuration is 400 lb/sq ft.

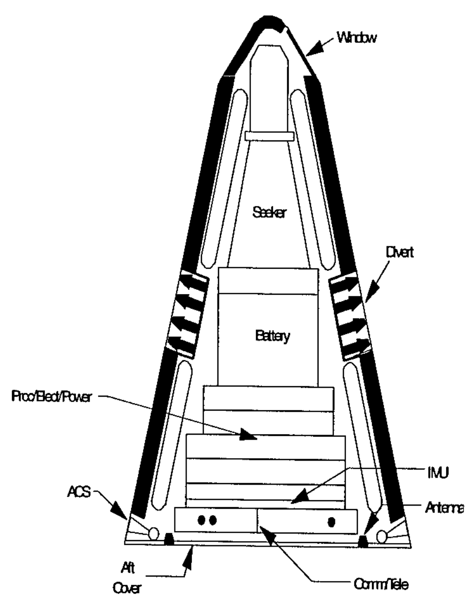

Figure 8. Schematic of active homing endgame design option front-end kill vehicle.

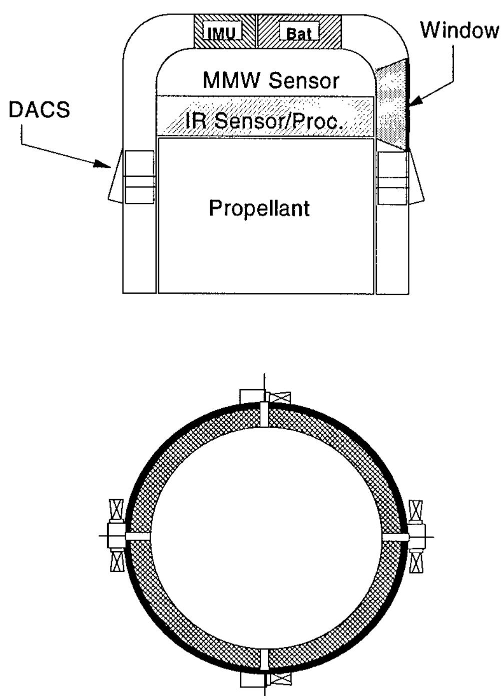

Figure 9. Schematic of hover endgame design option front-end kill vehicle.

The hover endgame design option configuration, illustrated in Figure 9, is enclosed in a shroud to minimize the flyout aerodynamic drag. The kill vehicle is cylindrical in shape and has a length and diameter of less than 12 inch. The total weight is just under 50 lb. The propulsion system for the hovering, translation and attitude control functions is encased in the shell. An inertial measurement unit (IMU) is also housed at the top of the unit. The ballistic coefficient of this carrier vehicle configuration is 350 lb/sq ft. A front end hover vehicle with a more aerodynamic shape packaged on the booster without a shroud is also a trade-off for this design concept.

A very promising candidate technology for the PMI front-end kill vehicle propulsion system is the integrated platelet approach that integrates the DACS elements into the PMI aero-shell, resulting in a light-weight and highly efficient propulsion system. All the design concepts put forth in this paper utilize a single guidance and navigation package that resides in the front-end hover or homing kill vehicle. This unit performs both flyout and endgame guidance and control functions. The guidance and navigation package consists of an onboard miniaturized GPS receiver and an IMU in conjunction with sensor inputs. The GPS/IMU package also provides directional references for the onboard sensors. Micromechanical IMUs weighing less than 1 oz. that are being developed are an attractive candidate for use on the PMI. IMU alignment is required prior to PMI launch for proper initialization of PMI position and attitude. Alignment using GPS signals with multiple antennas on the PMI and/or its support structure would preserve the autonomy of the PMI system. Additional analysis and trade-off are needed to assess the required/achievable accuracies of the GPS and other alignment approaches.

The baseline design for the sensor onboard the PMI also leverages mature technology derived from past programs and products such as Endo LEAP, Advanced Interceptor Technology, THAAD, and smart munitions. Anticipated sensors include mmw and EO. Design trade and development considerations would include evaluation and incorporation of advanced/emerging sensor and processing technologies and components for further miniaturization and performance enhancement. Examples of candidates to be considered include

- highly integrated sensor-processor approaches such as "3-D smart sensor" and "sensor on a chip".
- CMOS activated-pixel sensors.
- uncooled infrared detector arrays.

Target kill is accomplished either by direct impact or by another kill/negate mechanism. A trade-off exists among hit-to-kill, stand-off warhead, particulate clouds, etc. Such warhead technology is well-developed, has been used successfully in a number of smart submunitions.

System Performance

The performance of the PMI system for the cruise missile defense missions shown in Figure 1 depends on numerous factors that characterize the mission scenario and the major elements, in particular, the cruise missile, the cueing sensor, and the PMI. A system effectiveness model and the corresponding computer code called PMIPERF have been developed to evaluate and predict the performance of the PMI system. As illustrated in Figure 10, the key cueing sensor parameters are the predicted target location uncertainty and the time between target cueing and arrival of the cruise missile at the PMI location. Key PMI parameters include the distance between neighboring PMIs, PMI commit/activation response time, PMI flyout/propulsion characteristics, and kill vehicle sensor and divert characteristics. The direction of the approaching threat relative to the PMI positions and threat position prediction uncertainties are treated statistically by Monte Carlo sampling and averaging.

Representative results for the hover endgame option are shown in Figure 11. In this case the inter PMI distance is 10 km, the threat altitude is 3 km, and the system response time is 5 sec. After a threshold cueing time of about 35 sec, the probability of target intercept increases rapidly to useful levels for practical values of target position cueing uncertainty. Similar results for the more capable kinetic kill vehicle homing endgame option are shown in Figure 12. Target intercept probabilities are higher than those for the hover option even though the target cueing location uncertainties are higher in this case. Requirements on cueing sensor lead time and accuracy may be relaxed if in-flight target update (IFTU) is included in the architecture.

These and similar results can be used to analyze and optimize design trade, mission planning, BMC4I planning, and resource and allocation, including the number and placement of the PMIs deployed and the type, performance, location of the cueing sensors required.

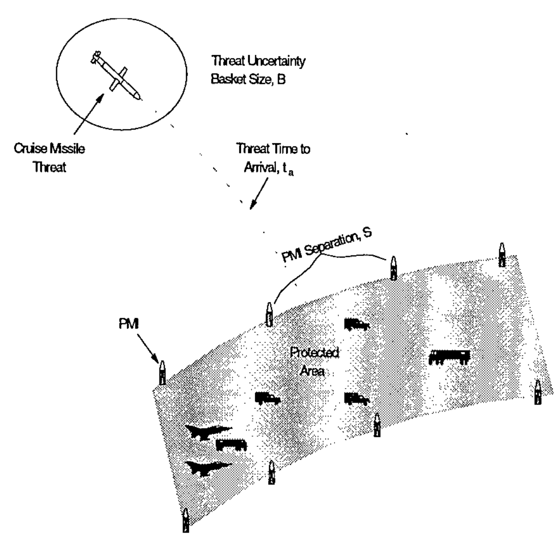

Figure 10. Key elements and parameters in modeling PMI system effectiveness

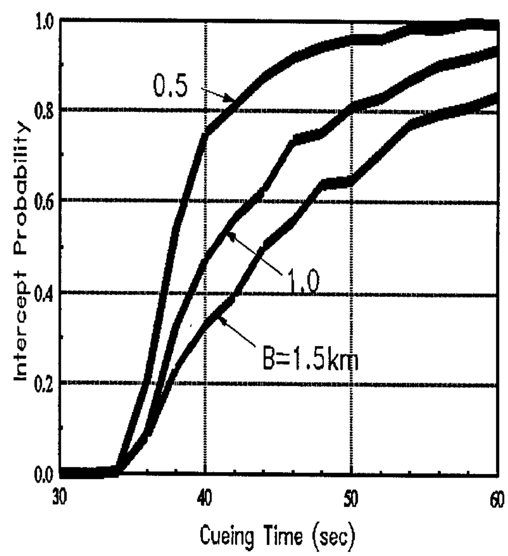

Figure 11. Probability of cruise missile intercept by a single PMI for the hover endgame option. The parameter B is the cueing uncertainty in the predicted target position

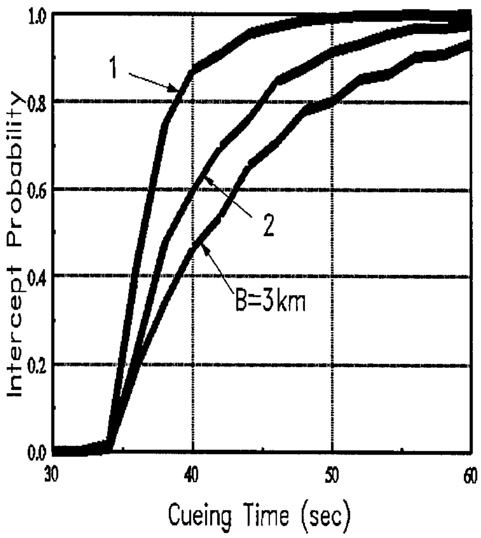

Figure 12. Probability of cruise missile intercept by a single PMI for the homing endgame option for several values of the cueing uncertainty in the predicted target position

Summary

A ground based portable miniature interceptor (PMI) design, weighing about 150 pounds, appears to be an effective defense against cruise missiles. The architecture and CONOPS incorporate an appropriate cueing sensor. Initial PMI conceptual design leverages mature technologies and components to reduce system development cost, time, and risk. Initial deployment analysis indicates PMI placement at about 10 miles apart along the defended perimeter, each PMI being capable of defending an approximately hemispherical volume of about 5 miles in radius. A system performance model has been developed and results indicate that substantial target intercept probabilities can be achieved for representative cruise missile defense scenarios provided that appropriate target cueing information is available. The present design, analysis, and results can be incorporated into an expanded CMD design and CONOPS development process that includes more detailed characterization of the cueing sensors and the cruise missiles.