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Comparison of Laser and Neutral Particle Beam Discrimination

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Comparison of Laser and Neutral Particle Beam Discrimination

Gregory H. Canavan

Los Alamos Los Alamos National Laboratory
Los Alamos,New Mexico 87545

COMPARISON OF LASER AND NEUTRAL PARTICLE BEAM DISCRIMINATION

by

Gregory H. Canavan

ABSTRACT

The relative ability of lasers and neutral particle beams (NPBs) to discriminate reentry vehicle (RV) and anti-satellite (ASAT) decoys is pivotal in assessing their relative worth as strategic defenses. This report evaluates their ability and assesses their relative contributions, concluding that NPBs can typically discriminate about 100 times as many objects as can lasers, and do so with significantly greater certainty.

I. INTRODUCTION

A key issue in comparing lasers and neutral particle beams (NPBs) for strategic defense is their relative ability to discriminate reentry vehicle (RV) and anti-satellite (ASAT) decoys. The former determines whether they can perform their primary mission effectively; the latter determines whether they can survive long enough to perform it. Although the physical bases for discrimination by lasers and particle beams are different, the mathematics that describes the effectiveness of each is the same for both. This report uses analysis derived for NPB discrimination to make a direct comparison of the number of decoys that lasers and NPBs could discriminate in midcourse, concluding that NPBs can discriminate significantly more objects, and do so with greater confidence.

II. LASER-DISCRIMINATION MECHANISMS

Lasers have some ability to discriminate by burning through decoys, producing observable temperature anomalies, or deflecting the decoys.

A. Burn-through

Because decoys must be light and thin to be effective, powerful laser beams could burn through them rapidly. If that produced an observable signal, the laser could quickly switch to another object without wasting much energy on decoys. For a 200-kg RV, a typical light decoy might have a mass of ≈ 2 kg. If the decoy area was $\approx 2\ m^2$, its surface areal density would be $\approx 0.1\ g/cm^2$. For typical materials with heats of vaporization $H \approx 10$ kJ/g it would require a fluence of about $J_d \approx 0.1\ g/cm^2 \cdot 10\ kJ/g \approx 1\ kJ/cm^2$ to burn through the decoy, which is about 5% of the 20 kJ/m^2 that would be needed to destroy a typical missile.

A 20-10 chemical laser, i.e., a P = 20 MW laser at wavelength w = 2.7 μm with a primary mirror of diameter D_o = 10 m, would have brightness $B = P(\pi/4)D_o^2/w^2 \approx 2 \cdot 10^{20}$ W/sr. At range r = 1,000 km it would take a time of about $t \approx J_d/(B/r^2) \approx 1\ kJ/cm^2/[2 \cdot 10^{20}\ W/sr/(10^6\ m^2)^2] \approx 0.05$ s to burn through a decoy, about 5% of the time it would take to burn through a missile. The burn-through time t is smaller than typical retarget times, which are $T_s \approx 0.1$ s, so at that range, discrimination would be limited by the rate at which the laser could retarget. At a range of 3,000 km, however, the burn-through time would increase as r^2 to ≈ 0.5 s, and discrimination would be limited by the rate at which the laser could kill decoys.

B. Onset of Ablation

The time to burn-through is essentially the time it takes the laser to begin eroding the surface, which is essentially the time required to melt it plus the time to ablate the material in its path. If from range r the laser delivers flux $F \equiv B/r^2$ and the decoys have an average reflectivity $R \approx 0.7$, heat of melting

$h \approx 1$ kJ/g, density $\sigma \approx 3$ g/cc, and thermal diffusivity $D \approx 0.1$ cm^2/s, then the time it takes to heat the front surface to melting is about

$$t_m \approx D[\sigma h/(1-R)F]^2 \quad , \tag{1}$$

which is $\approx 0.1\ cm^2/s(3g/cc \cdot 1kJ/g \div 0.3 \cdot 2 \cdot 10^4\ W/cm^2)^2 \approx 0.03$ s for the conditions above. This estimate assumes that D and other physical parameters remain constant throughout the melting, which may only be accurate to within a factor of two. At short ranges t_m would be smaller than the retarget time; at longer ranges it could become a significant fraction of the kill time. Thus, t_m should only be a few-percent correction to the burn-through time calculated above. If the decoys could, however, maintain low absorptivities, that could increase the melt time relative to the kill time.

C. Deflection

Burn-through is efficient relative to missile kill, but it still requires a significant amount of energy and time per object. An alternative is to measure the deflection of the object produced by the recoil of the blown-off material. It is known that high-power pulsed laser beams can produce impulse with a coupling efficiency of $C \approx 2 \cdot 10^{-5}$ N-s/J.[1] There are reservations about extrapolating this coupling to 0.01- to 0.1-s irradiations, and only limited data to support it. Moreover, there are countermeasures such as bulk absorption that could reduce C significantly. If, however, such coupling is obtained for longer irradiation times, a nearby object illuminated for 0.025 s by a 20-10 laser would develop a momentum of

$$I_o \approx 0.025\ s \cdot 20\ MW \cdot 2 \cdot 10^{-5}\ N\text{-}s/J \approx 10\ N\text{-}s. \tag{2}$$

A 10-kg decoy would develop a velocity of $\approx$ 10 N-s/10 kg $\approx$ 1 m/s, which is above the threshold for detection.[2] Deflection could give a measurable signal in an irradiation time

$$t_n \approx I_o/CP \approx 10\ N\text{-}s/[2 \cdot 10^{-5}\ N\text{-}s/J \cdot 20\ MW] \approx 0.025\ s, \tag{3}$$

which is $\approx$ 2.5% of the time required for kill. Although deflection is energetically preferred, it is sensitive to coatings of high reflectivity and other countermeasures because it operates at lower fluxes than pulsed lasers and somewhat lower fluences than continuous wave burn-through.

For objects at long ranges, the analysis is complicated because only a fraction of the laser radiation is deposited on the object. A mirror of diameter D_o focuses radiation of wavelength w into a spot of diameter $d_s \approx (w/D_o)r$ at range r. Thus, if the object has area $A << d_s^2$, the power deposited on the object is PA/d_s^2, and the time to produce impulse I_o is

$$t_1 \approx I_o/[C(PA/d_s^2)] = (I_o/CPA)(wr/D_o)^2 = (I_o/CAB)r^2. \quad (4)$$

The transition between the near- and long-range results occurs at $d_s^2 \approx A$. An interpolation formula that covers both limits is thus

$$t_d = (I_o/CPA)(d_s^2+A) = (I_o/CP)(Pr^2/BA+1) \ , \quad (5)$$

which has essentially the same scaling as the $t \approx J_d/(B/r^2)$ for burn-through. For deflection, however, the combination I_o/CA plays the role of a fluence to discriminate distant targets. Because $I_o/CA \approx 10$ N-s$/2\cdot10^{-5}$ N-s/J$\cdot$1 m$^2 \approx 5\cdot10^5$ J/m^2, the fluence for deflection is about 2-3% of the fluence to kill.

III. DISCRIMINATION KINEMATICS

The rate at which a laser can discriminate depends on the time it takes to discriminate a target and the time it takes to switch from one target to the next. If discrimination requires a fluence J_D, a laser can discriminate objects at range r in a time $J_D r^2/B$. Adding to that the retarget time, T_S, gives the total time required to discriminate an object and switch to the next, whose reciprocal is the laser discrimination rate, which is[3]

$$dN_D/dt = [(z^2+x^2)J_D/B + T_S]^{-1} \ , \quad (6)$$

where z is the distance from the laser to the objects to be discriminated, which are essentially in a plane perpendicular to their flight direction, and x is distance in that plane from the object to the point in it nearest to the laser. N_D is the number of objects discriminated up to time t. Simultaneous launches are the most stressing because they give the least time for discrimination. In them, the objects that penetrate the boost-phase defenses pass each laser in a plane of approximate lateral extent $W_M \approx 4{,}000$ km, the average of the widths of the launch and target areas. The plane's vertical extent should be $H_M \approx 1{,}000$ km, the maximum vertical dispersion of trajectories possible without excessive range penalties or dispersal of launch and arrival times. Thus, in midcourse the threat objects cover an area of $A_M \approx W_M \cdot H_M \approx 4\ \mathrm{Mm} \cdot 1\ \mathrm{Mm} \approx 4\ \mathrm{Mm}^2$, about half the current Soviet boost-phase launch area.

If D objects penetrated the boost defense, the average object density in the midcourse threat plane would be about $D'' = D/A_M$. If $M_M = 500$ missiles penetrated, each had $m = 10$ RVs, and each RV had $d \approx 10$ credible decoys, that would give $D = M_M m(d+1) \approx 500 \cdot 10\ 11 \cdot \approx 5 \cdot 10^4$ objects with an areal density of $D'' \approx 5 \cdot 10^4 \div 4 \cdot 10^6\ \mathrm{km}^2 \approx 10^{-2}\ \mathrm{km}^{-2}$. That gives an average spacing between objects of ≈ 10 km, so from a typical range of 1,000 km, average retargeting angles are under $\approx 10\ \mathrm{km} \div 1{,}000\ \mathrm{km} \approx 10$ mrad. These numbers and spacings represent a limited attack or a moderately attrited first wave. Because the Soviets have about 1,000 missiles, and ≈ 100 decoys per RV is credible against passive sensors, the number of objects could range up to 10^6. If so, the retarget angles would be even smaller.

As the plane of objects comes into range, each platform should start interrogating objects at the shortest range, i.e., those with $x \approx 0$, and progress out toward larger cross ranges as the objects come closer, continuing to irradiate objects at larger cross ranges until the objects pass and go out of range on the other side. Because there are D'' objects per unit area, by the time a laser cross range reaches x, it has irradiated about $\pi x^2 D''$ objects. Thus, the time derivative dN_D/dt in Eq. (6) can be replaced by the product of the object areal density and the rate at which the beam sweeps out area in the object plane, $D'' \cdot d(\pi x^2)/dt$. The trackwise range changes by $dz = Vdt$ in a time interval dt, where V is the closing velocity, so d/dt can be replaced by $V \cdot d/dz$ to produce

$$\pi dx^2/dz = (1/D''V)[(z^2+x^2)J_D/B + T_S]^{-1} \qquad (7)$$

for the rate of increase of area swept out. This result can be integrated over $-Z_M \le z \le Z_M$, where $Z_M \approx (2R_e h)^{1/2}$ is the maximum range set by the earth's curvature, which is $\approx$ 3,000 km for a h $\approx$ 1,000 km constellation, to determine the total area swept out per platform, which is

$$A_p = \pi x_M^2 , \tag{8}$$

where $x_M = x(z = Z_M)$. It takes a total of A_M/A_p satellites in A_M for all the threat area are to be covered, i.e., for all objects to be discriminated, assuming that the satellites are well distributed and do not overlap one another.

The total constellation size is $N = (A_M/A_p)/f$, where f is the fraction of the NPBs available for midcourse engagement. A phase-space estimate for f is

$$f = W_M L_M / 4\pi R_e^2 \approx 8\% , \tag{9}$$

where $L_M \approx 10{,}000$ is the length of a typical intercontinental trajectory. That value of f is, however, an underestimate, because it neglects the contributions from outside the threat tube. Satellites with effective ranges of thousands of kilometers that are at ranges of $x < -W_M/2$ or $x > W_M/2$ could contribute to midcourse discrimination. A rough geometric assumption that includes the exterior satellites out to a range of $\approx$ 1 Mm and ignores the rest increases f by a factor of (4 Mm+2 Mm)/4 Mm = 1.5 to about 12%. The calculations below assume an average f = 0.1. Combining N with f gives

$$N = (A_M/A_p)/(W_M L_M/4\pi R_e^2) = 4\pi R_e^2 H_M/A_p L_M , \tag{10}$$

which indicates that, within limits, the width of the threat area, W_M is less critical than L_M, so N depends primarily on A_p, i.e., the individual platform performance. Decreasing the launch area to a point could cut W_M and A_M roughly in half, but that sensitivity to launch area is much less than the order-of-magnitude sensitivity shown by boost-phase constellations.

IV. LASER-CONSTELLATION SCALING

The laser constellations needed to discriminate various threats can be evaluated by using the burn-through and deflections fluences of $J_d \approx 1$ kJ/cm^2 and Eq. (5), respectively, for J_D in Eq. (6). Figure 1 gives the size of constellations required to discriminate numbers of objects ranging from 10^4 to

10^6. The top curve is for a near-term laser brightness of $2 \cdot 10^{19}$ W/sr; the second curve is for bright $2 \cdot 10^{20}$ W/sr lasers. Both are for a burn-through fluence of 1 kJ/cm^2 and a retarget time of T_S = 0.1 s, the current goal. Bright lasers, i.e. B = $2 \cdot 10^{20}$ W/sr, the current program goal, would require ≈ 3 satellites in the battle or a ≈ 30 satellite constellation to discriminate ≈ 10^4 objects and ≈ 300 lasers to discriminate 10^5 objects. The constellations for B = $2 \cdot 10^{19}$ W/sr lasers are shifted up from those for bright lasers by a factor of ≈ 2.

The launch of 500 heavy missiles with 10 RVs each and 11 objects per RV requiring laser discrimination would produce a total of about 50,000 objects. Constellations of ≈ 50 satellites, i.e. the size required to engage most objects in the boost phase, could, as shown by the dashed line, reduce the number of decoys about 16,000 objects, or 30% of those penetrating the boost phase. That could improve the performance of adaptive downstream layers by ≈ 60%, which would be useful against limited or strongly attrited attacks.

The number of objects discriminated is limited by the laser retarget times. Retarget times of T_S = 0.1 s are adequate for killing ≈ 1,000 missiles but are not adequate for the 100- to 1,000-fold larger number of objects to be discriminated in midcourse. In midcourse, lasers spend much of their time retargeting between the soft targets, so the retarget times appropriate for kill dominate the time to discriminate each object. For large N, the cross range is small. If it can be neglected, to first order Eq. (6) can be approximated by

$$dN_D/dt = [z^2 J_D/B + T_S]^{-1} = [(Vt)^2 J_D/B + T_S]^{-1} \ , \qquad (11)$$

whose solution is

$$N_D = (B/JV^2C) 2\tan^{-1}(Z_M/VC) \ , \qquad (12)$$

where $C = (T_S B/JV^2)^{1/2} \approx (0.1 \text{ s} \cdot 2 \cdot 10^{20} \text{ W/sr}/10^7 \text{ J/m}^2)^{1/2}/8 \text{ km/s} \approx$ 180 s. The lasers are most effective at ranges ≤ 180 s·8 km/s ≈ 1,400 km. The number of objects inspected by each laser is ≈ $(B/JV^2C) 2\tan^{-1}(Z_M/VC) = (2 \cdot 10^{20} \text{ W/sr}/10^7 \text{ J/m}^2 (8 \text{ km/s})^2 \cdot 180 \text{ s})$ $2\tan^{-1}(3 \text{ Mm}/8 \text{ km/s} \cdot 180 \text{ s}) \approx 3{,}800$, so the total number of objects inspected by the ≈ 5 lasers in the battle would be about 19,000.

Figure 1 gives 16,000, about 15 % lower. The discrepancy stems from the omission in Eq. (11)'s of the crossrange, which for these conditions averages about $(x/z)^2 \approx 20\%$ of the total range.

If it is possible to reduce laser retarget times, their performance would, under the conditions of Eq. (12), improve by about a factor of $1/\sqrt{T_S}$. A 10-fold reduction in T_S would allow the lasers to address about 40,000 objects, a fair fraction of the total number of objects in lightly decoyed attacks. Even $T_S = 0.1$ s is, however, technologically demanding; shorter times could require development beyond that needed for the laser primary boost-phase mission. Laser performance in discrimination would also, again under the conditions of Eq. (12), improve as roughly $1/\sqrt{J}$ if the fluences needed to tag or burn through the decoys were reduced substantially from those assumed above. At present, however, there is incomplete information and little experimental information on the efficacy of countermeasures. Because discrimination occurs at fluences far below lethal ones, the attacker has a wider spectrum of techniques to block the measurement or use special materials to simulate RV signatures. Moreover, current conceptual configurations are retarget-time dominated. Under the approximations of Eq. (12), $N_D \alpha\ 1/JC\ \alpha\ 1/\sqrt{JT_S}$, so the impact of reducing the discrimination fluence would be reduced unless the retarget times were also reduced.

The constellation sizes for deflection can be determined by inserting the discrimination time of Eq. (5) in Eq. (6). The full substitution is $(z^2+x^2)J_D/B \rightarrow (I_o/CP)(P(z^2+x^2)/BA+1)$, which gives

$$dN_D/dt = \{(I_o/CP)[P(z^2+x^2)/BA+1] + T_S\}^{-1} . \qquad (13)$$

The result is shown in the third curve of Figure 1, which lies about a factor of 2 below the curve for burn-through. The reason is again retarget time. Discrimination by deflection is also retarget dominated, so the lower fluence required has little impact on the number of objects discriminated. The transition from filling to overfilling the objects occurs at $z_t \approx (BA/P)^{1/2} \approx (2 \cdot 10^{20}\ \mathrm{W/sr} \cdot 1\ \mathrm{m}^2/2 \cdot 10^7\ \mathrm{W})^{1/2} \approx 3{,}000$ km, so for most of the object trajectories, Eq. (13) can be simplified to

$$dN_D/dt \approx \{(I_o/CP + T_S)\}^{-1}, \tag{14}$$

so that the number of objects discriminated is about

$$\begin{aligned} N_D &\approx (2Z_D/V)/(I_o/CP + T_S) \\ &\approx (2 \cdot 3 \cdot 10^6 \text{ m/8 km/s})/(2 \text{ kg}\cdot\text{m/s}/2\cdot 10^{-5}\text{N-s/J}\cdot 20 \text{ MW}+0.1 \text{ s}) \\ &\approx 750 \text{ s}/(0.005 \text{ s}+0.1 \text{ s}) \approx 7{,}150 \text{ objects/satellite}, \end{aligned} \tag{15}$$

and the 5 satellites available could ideally interrogate ≈ 36,000 objects. Figure 1 gives 25,000 objects, which is 30% less than the ideal 36,000. That is due to z_t being ≈ Z_D for these conditions, which reduces the interrogation rate by ≈ 50% at both ends of the trajectory. Because I_o/CP ≈ 5% of T_S, the reduced fluence for deflection would have no impact unless T_S were reduced by about a factor of 100.

V. NPB-CONSTELLATION SIZES

NPBs discriminate on the RV mass, which decoys cannot afford to match. A fluence of ≈ 10 kJ/m^2, which is a factor of about 100 below the fluence for laser burn-through, gives a neutron signal above any expected background, permitting unequivocal discrimination. The constellation sizes required can be determined by using a discrimination fluence of 10 kJ/m^2 in the integration of Eq. (6). The fourth and fifth curves down in Figure 1 show the constellation sizes for NPBs with B = $2 \cdot 10^{19}$ W/sr, a nominal high-brightness platform, and T_S = 1 to 10 1 ms, which bound the retarget values currently thought to be practical for NPBs. For T_S = 10 ms, 5 NPBs in the threat tube could discriminate ≈ 350,000 objects; a constellation of 125 NPBs could discriminate the maximum threat of 10^6 objects. For T_S = 1 ms, each NPB in the threat tube could discriminate about 380,000 objects, so that only about a 25-NPB constellation would be needed to discriminate the full threat.

NPBs of attainable brightness with detectors of modest size and stand-offs appear to be capable of discriminating highly decoyed threats. The constellations needed are appropriate for both boost and midcourse engagements and for both discriminating decoys and engaging the weapons found, giving costs per discrimination significantly lower than those of the objects discriminated. NPB constellations have significant margin against the dilution of threat RVs in more decoys. Because of this ability to discriminate and kill, NPBs should be survivable and effective.

VI. EXTENSIONS

The sections above compared laser and NPB discrimination for platforms of fixed size. The estimates are thought to err in favor of the lasers, e.g., continuous wave lasers are assumed to couple to decoys as well as pulsed lasers, although their coupling could be much lower, and materials that absorb laser energy in depth could essentially eliminate impulse coupling. The $2 \cdot 10^{20}$ and $2 \cdot 10^{19}$ W/Sr brightnesses assumed for lasers and NPBs, respectively, are the nominal goals of their current developmental programs. Absent reverses, lasers and NPBs of those performance levels should be available for deployment within roughly the first decade after the initial deployments of strategic defenses.

Figure 1 shows that nominal laser constellations of about 30 satellites could discriminate $\approx 10^4$ objects, and that for the same conditions NPBs could discriminate $\approx 10^6$ objects, which indicates that NPBs are roughly a factor of 100 more efficient in discrimination. Because $\approx 10^4$ objects is the minimum number of discriminations of interest, lasers of nominal brightness have no significant discrimination capability. Changing the laser interaction fluences would impact that conclusion little. Lasers are dominated by retarget time, for which the calculations above used about the minimum thought to be attainable.

Laser discrimination has been advocated on the basis that absentee lasers over the pole could provide some "free" interim midcourse discrimination, but that is in a sense double counting. Lasers would not be over the pole unless a significant penalty was paid to put them there; the optimal inclinations for laser boost phase intercepts are closer to the 50^o-60^o latitude of the missiles. The calculations above indicate that their interim discrimination capability would not be significant, so that penalty would probably not be paid.

It has been noted that smaller, less bright platforms might be deployed earlier to offset the degradation of effectiveness of kinetic interceptors by fast, compact boosters.[4] Lasers of brightness $2 \cdot 10^{19}$ W/Sr could be useful for providing additional boost phase kill potential.[5] According to the Figure 1, a constellation of 50 such lasers could discriminate ≈ 7,000 objects, about 45% of the number a $2 \cdot 10^{20}$ W/Sr lasers could discriminate. That level could suffice for entry-level or highly attrited threats, but it could be saturated by even moderately decoyed threats. Modest lasers do not appear to be useful for discrimination.

Lasers brighter than the nominal $2 \cdot 10^{20}$ W/sr platforms assumed could discriminate more effectively. Calculations have been performed of the discrimination potential of $3 \cdot 10^{21}$ W/sr lasers.[6] Those high-brightness calculations can be compared with the above results. High-brightness calculations of impulse deflection of 1% mass carbon phenolic decoys produce $N_D \approx 20,000$ deflections per laser. For 10 lasers in view that gives ≈ 200,000 decoys, which agrees closely with the 240,000 decoys from other high-brightness calculations.

Lasers of ≈ $3 \cdot 10^{21}$ W/sr brightness could see and irradiate decoys throughout most of midcourse. That would require deploying them at altitudes of 2,500-3,000 km, but their brightness could give them enough range so that those altitudes would not degrade their performance significantly. That range would enable them to irradiate objects throughout midcourse, which would increase their engagement time by a factor of ≈ 2. Long ranges would also allow more lasers to contribute from the sides of the threat tube, which should increase the constellation's absentee ratio by factor of ≈ 2 over that of $2 \cdot 10^{20}$ W/sr lasers. It is sometimes assumed that brighter lasers could also be retargeted more rapidly by a factor of ≈ 2. If all these potential advantages materialized, the brighter lasers should perform better by a factor of $\approx 2^3 = 8$.

Figure 2 shows the result of integrating Eq. (13) over the whole trajectory for B varying from $3 \cdot 10^{19}$ to $3 \cdot 10^{21}$ W/sr, T_S = 0.05 s, and 200,000 decoys, a typical threat in companion analyses. The top curve is for $T_S = 0.1$ s; the bottom curve is for $T_S = 0.05$ s, the faster retargeting time assumed for brighter lasers in some analyses. For low brightness the number of lasers is in the hundreds, as in the figure above. Reducing T_S does, however, drop the total constellation size from a few thousand lasers down to about 1,500.

By $3 \cdot 10^{20}$ W/sr, the number drops to about 450 for $T_S = 0.1$ s and 300 for 0.05 s. By $3 \cdot 10^{21}$ W/sr, it drops to 50-90 satellites, as the two curves come closer together. The overall scaling reflects the fact that 8 times the discrimination rate of the $2 \cdot 10^{20}$ W/sr lasers gives $\approx$ 25,000 decoys per laser or $\approx$ 250,000 decoys total, which is in close accord with the $\approx$ 240,000 discriminations for high-brightness lasers in the companion calculations. These scalings and levels have also have been confirmed by others.[7]

Thus, the analyses are largely consistent. Their differing conclusions as to the usefulness of laser discrimination result from the brightnesses of the lasers assumed. High-brightness lasers could, when available, discriminate useful numbers of decoys with acceptable constellation sizes. Smaller lasers, however, have longer dwell times and limited ranges, which forces them to lower altitudes, where their ranges are limited by earth curvature. That produces 8-fold lower absentee ratios and engagement times and hence the insignificant discrimination rates discussed above.

Intermediate brightnesses would produce intermediate levels of discrimination. Discrimination rates for nominal brightness lasers would be marginal for current threats; discrimination rates for intermediate brightness would not produce significant levels of discrimination. The interpretation of the two limits is that very bright lasers could, when available, be of value for discrimination, but modest lasers would not be.

VII. SUMMARY AND CONCLUSIONS

A key issue in comparing lasers and NPBs is their relative ability to discriminate decoys. Because decoys must be light to be effective, bright lasers could burn through light decoys rapidly, starting at fluences of $\approx 1\ kJ/cm^2$. If continuous lasers can generate impulse efficiently, the ≈ 10 N-s needed to deflect decoys usefully could be delivered in a few milliseconds. The fluence to discriminate even distant targets with deflection is only a few percent of that needed to kill them by burning through. The kinematics of laser and NPB discrimination are similar; the difference in their effectiveness is primarily due to the different fluences needed for their distinct interaction mechanisms.

Constellations of ≈ 50 bright lasers required to engage targets in the boost-phase could discriminate 15,000 to 25,000 simultaneously launched objects. That could be useful against limited attacks or ones that were severely attrited by boost-phase defenses, but they would not be effective against fully decoyed attacks, which might involve 200,000 to 1,000,000 objects.

Lasers are dominated by their retarget times; the calculations above used the minimum attainable. Lasers brighter than the mid-term $2 \cdot 10^{20}$ W/sr platforms assumed could discriminate more effectively than smaller ones, because they could see and irradiate decoys throughout midcourse from orbits far from the threat tube. High-brightness lasers could, when available, discriminate useful numbers of decoys with acceptable constellation sizes. That is not, however, the case with nominal lasers, whose long dwell times and limited ranges force them to lower altitudes. That produces much higher absentee ratios and shorter engagement times, which reduces their discrimination rates to insignificant levels. Thus, very bright lasers could be effective in discrimination, once they were available, but the levels required for impact are such that they might not be available when needed.

NPBs discriminate on mass, which decoys cannot afford to match. A fluence of $\approx$ 1 J/cm^2, a factor of $\approx$ 100 below laser burn-through, gives a neutron signal above and expected backgrounds, which should support unequivocal discrimination. NPBs can also switch much more rapidly from one target to the next. Constellations of a few tens of nominal NPBs could discriminate 350,000 to 3,000,000 objects. There appears to be a transitional discrimination role in which lasers deployed for boost-phase lethality could provide interim, partial discrimination. NPBs, when available, could then discriminate the full threat.

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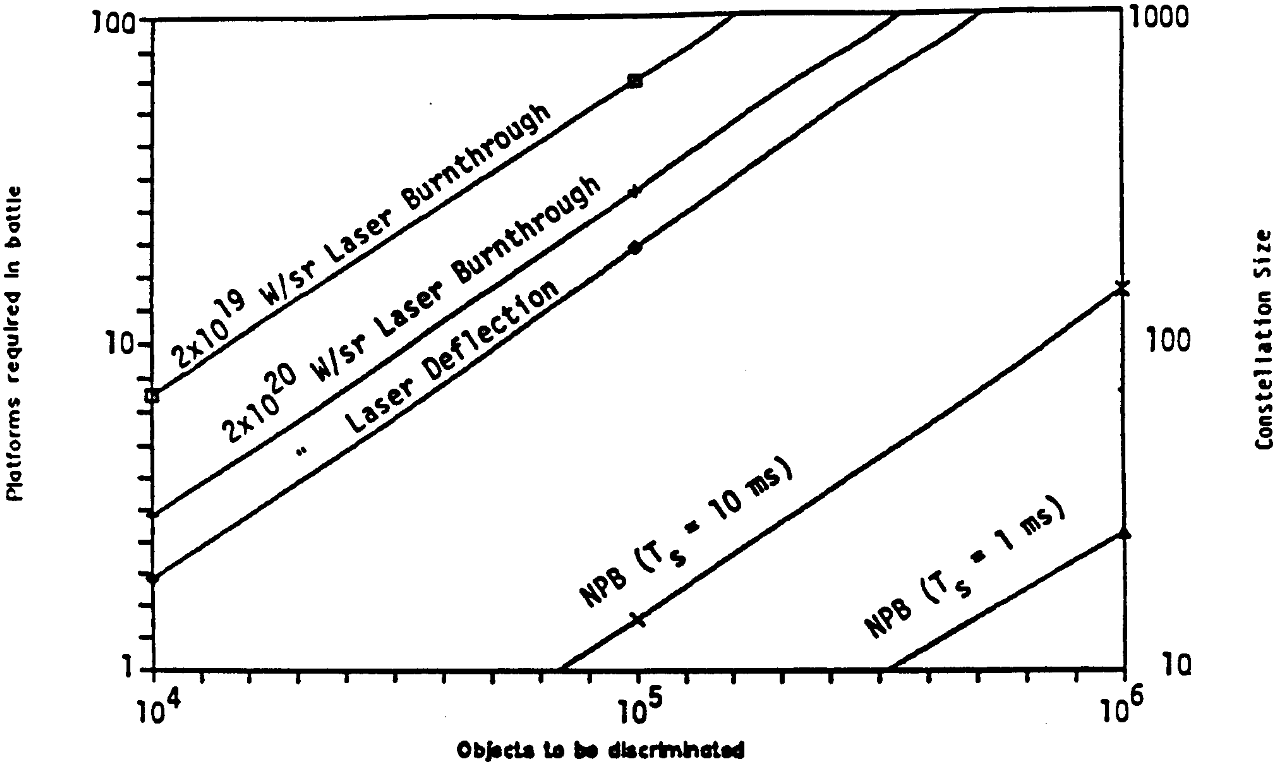

Fig. 1. **Constellation sizes required for discrimination of varying numbers of decoys.**

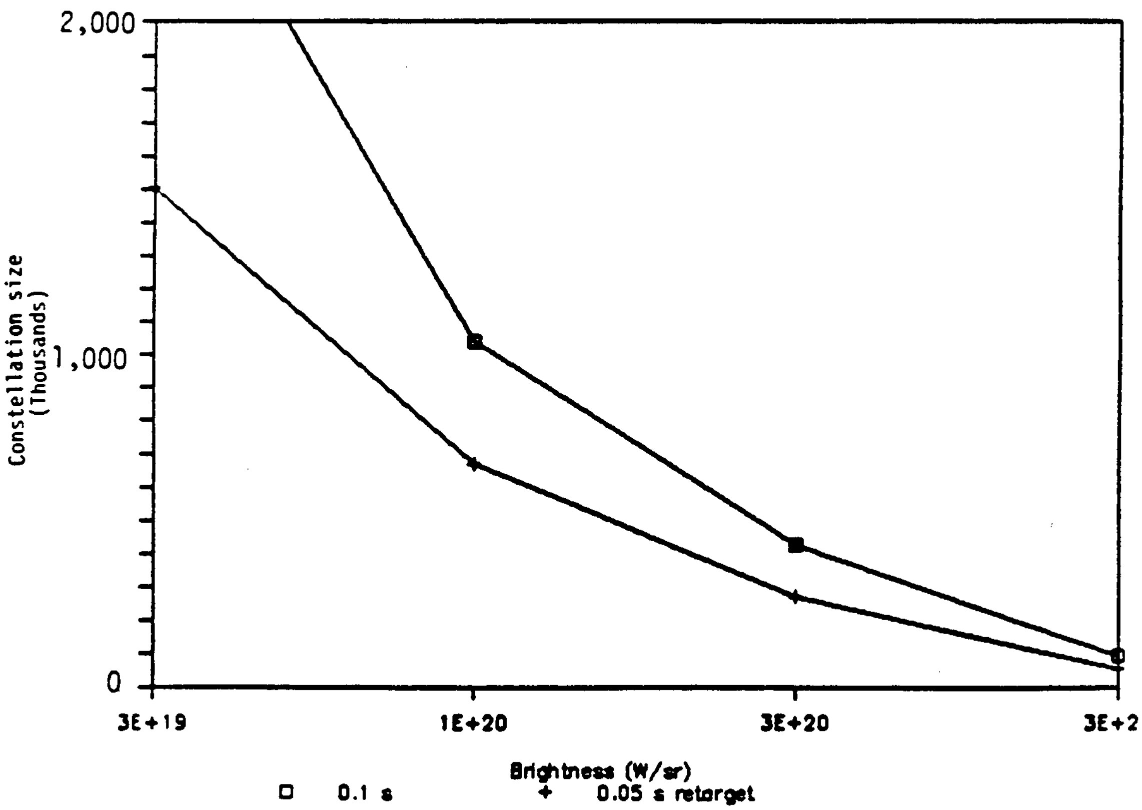

Fig. 2. Brightness and retarget time.

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