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Defending the Defenders: Brilliant Pebble Defense Against Pop-up Neutral Particle Beam Suppression Attacks

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DEFENDING THE DEFENDERS: BRILLIANT PEBBLE DEFENSE AGAINST POP-UP NEUTRAL PARTICLE BEAM SUPPRESSION ATTACKS

by

Gregory H. Canavan

ABSTRACT

Pop-up neutral particle beams (NPBs) can suppress brilliant pebbles. For attrition attacks, modest shielding should suffice, although the pebbles' survivability could be degraded. NPBs are difficult to negate once operational; it appears necessary to destroy them during ascent. Doing so effectively would require the prompt destruction of all heavy launches from missile launch areas.

I. INTRODUCTION

Pop-up NPBs can be used to suppress space based-interceptors (SBIs), of which the smallest and most survivable designs are the "brilliant pebbles."[1] The extent of suppression depends on the attack. For attrition, modest shielding should suffice, but during the ingress of SBIs toward missile intercepts, the pebbles' survivability could be degraded. NPBs are difficult to negate once operational; it appears that it could be necessary to destroy them during ascent or during the delay time during which they were activated. Doing so effectively would require prompt destruction of all heavy launches from missile launch areas.

II. ATTRITION

Attrition by on-orbit NPBs is discussed in "Survivability of Space Assets in the Long Term," which dismisses it as no more effective than that by on-orbit lasers or kinetic-energy interceptors.[2] The reason is that it is more effective to shield than to irradiate. In the absence of NPB suppression, SBIs would minimize their shielding to minimize their kill package and total masses. The additional material required to shield against a 100-MeV beam is about 100 kg/m^2. A 200-MeV beam, which would probably be too big to pop up but might be orbited, would require $\approx$ 400 kg/m^2.[3] If $\approx$ 30% of the SBI's $\approx$ 0.1 m^2 frontal area was vulnerable, the total shielded area would be $\approx$ 0.03 m^2. That would require $\approx$ 100 kg/m^2 x 0.03 m^2 $\approx$ 3 kg of shielding for 100-MeV beams, or $\approx$ 12 kg for 200 MeV.

If the SBIs could hide behind their shields while they were being irradiated and then discard that shielding mass when they flew out to intercept the offensive missiles, the cost impact of pop-up NPB would be $\approx$ 10-30% effect, which is large but tolerable. The added mass would largely be bulk material, whose cost would essentially be only that of launch. Thus, attrition by on-orbit NPBs need not be a problem.

III. SUPPRESSION

Penalties are larger if the SBIs must remain shielded en route, as when facing NPBs popped up to suppress them. Shielded SBIs' velocities would drop 25-50%, which would reduce their availability by a factor of 2 to 4. Coverage could be restored by adding SBIs, but that would cause a two- to four-fold decrease in the cost-effectiveness of each. Restoring SBI performance would increase the total mass on orbit by a factor of 2 to 4.[4] These penalties would be particularly severe if the SBIs' decoys were also discriminated.[5]

In addition to shielding penalties, convergence reduces SBI survivability, because during ingress their distance from the pop-up NPBs decreases along with the distance to the missiles. The rate and radius at which the SBIs are killed depend on their hardness and number. The brightness needed to keep hardened SBIs out of the launch corridor corresponds to a few 100-MeV pop-ups.[6] It would not appear feasible to negate pop-up NPBs once they were operational; it appears necessary instead to destroy them during ascent or before they are activated.

IV. DEFENDING THE DEFENDERS

The pop-up NPBs could probably start irradiation at an altitude of h_m = 120-130 km.[7,8] Current SBIs could intercept down to ≈ 100 km. Thus, the SBIs could intercept the pop-up missiles if they were within range. If their maximum range is R and their areal density is $N'' = zN/4\pi Re^2$, where N is the number of SBIs, Re is the earth's radius, and z ≈ 2 is the concentration of the SBI constellation possible over the missile launch area, then the number of SBIs within range is $\pi R^2 N''$. Requiring that there be at least one SBI in range for intercept gives

$$N = 4Re^2/zR^2 \approx 2(Re/R)^2 \qquad (1)$$

as the SBI constellation size below which the gaps between satellites could be large enough to prevent intercept. For a current absentee ratio of 20%, intercepting ≈ 1,000 missiles would require ≈ 1,000/0.2 ≈ 5,000 SBIs, which would give a spacing of $\surd(2Re/N)$ ≈ 160 km. Successful deployment of the pop-up NPBs would require smaller ranges.

The pop-up NPB booster is assumed to accelerate vertically with acceleration a_b to velocity V and then coast for the time t_a required for vibrations to damp down, the beam to align, and power to be generated. For modest accelerations and long t_a, the total engagement time is

$$t_e = V/a_b + t_a, \qquad (2)$$

for $h_m \le V^2/2a_b + V\cdot t_a$, where $V^2/2a_b$ is the burnout altitude and Vt_a is the approximate distance the pop-up drifts during activation. For high accelerations and short t_a, the engagement time is

$$t_e = V/a_b + (h_m - V^2/2a_b)/V, \qquad (3)$$

where $(h_m - V^2/2a_b)/V$ is the approximate time the pop-up drifts after booster burnout.

For a defender velocity v, acceleration a_d, and time to decide whether to attack of t_d, the maximum range is

$$R = v \cdot \cos\theta \cdot (t_e - t_d - v \cdot \cos\theta / a_d), \qquad (4)$$

where θ is the angle that the defender accelerates downward from the local horizontal, which is determined by

$$\theta = \sin^{-1}[\delta h / (t_e - t_d - v/a_d)], \qquad (5)$$

where δh is the distance below the constellation's perigee that the SBI must descend to reach h_m.

V. RESULTS

Figure 1 shows the critical constellation sizes from Eq. (1) as functions of the time to activate the NPB for booster burnout velocity V = 3 km/s, defender velocity V_d = 6 km/s, and decision time t_d = 10 s, the rough value determined by signal, clutter, and automatic processing. The top curve is for a booster acceleration of 4 km/s, a typical current value; the lower ones are for the faster 6-, 8-, and 10-g that could be developed during this time period.

The lowest curve for 4 g's decreases monotonically with t_a from about 800 SBIs at $t_a = 0$ to about 400 at 30s, the range that seems plausible from ground experiments. The curve for 6 g's increases from 800 to 1,500 SBIs as t_a decreases from 30 to 10 s. For lower values it is insensitive to t_a, in accord with Eq. (3). The curves for 8 and 10 g's increase to maxima of ≈ 2,100 and 2,800 SBIs. Only the largest accelerations would impact the SBIs for these nominal conditions, because they are already closely spaced to meet the near-term threat.

Figure 2 shows how the SBI constellation size varies with booster burnout velocities from 3 to 6 km/s. For the lowest accelerations, higher velocities reduce constellation size, because they delay burnout. For 8 g's there is a rough maximum of about 2,800 SBIs at 4 km/s, and for 10 g's there is a maximum of about 5,000 SBIs at 5 km/s. Both are in accord with the high acceleration limit of Eq. (3), which gives an optimal velocity from the pop-up's point of view of $\sqrt{(2a_b h_m)}$. The maximum for 10 g's is 5,000 SBIs, which approaches the actual constellation size.

The SBI constellation altitude and altitude change impact N through Eq. (5), which is shown in Fig. 3 for nominal parameters. For $\delta h \leq 150$ km, or constellations below ≈ 275 km, there is about a factor of 4 to 5 impact on constellation size, which comes about because any vertical velocity increment subtracts from the SBIs' horizontal velocity and hence their range. For $\delta h \geq 150$ km the impacts vary. For 4- and 6-g boosters, they are modest; for 8-g boosters, the constellation size is doubled by $\delta h = 200$ km; and for 10-g boosters there is no solution for $\delta h \geq 150$ km.

The SBIs' main offset is velocity. Figure 4 shows the effect of increasing SBI velocity from 6 to 12 km/s. For small a_b the effect is slight; for large accelerations the effect is larger, particularly for small increments. For 10 g the reduction between 6 and 8 km/s is ≈ 30%. Larger increments produce smaller reductions.

The SBIs' main liability is decision time. The nominal 10-30-s times used above are about the minima expected for fast machine decision making. With longer times or human involvement, the times could become much longer. Figure 5 shows the impact of t_d on N. For 4 g's the impact is apparently slight, although the curve turns up sharply at $t_d \approx 70$ s. For 6 g's increasing t_d from 10 to 30 s roughly triples N. For 8 g's, N increases about 7-fold to 7,000 SBIs from 0 to 30 s. For 10 g's there is no solution beyond $t_d \approx 20$ s. The several minutes needed for human intervention would impact the defenses strongly.

VI. SUMMARY AND COMMENTS

Attrition attacks do not seem to be much of a concern; modest shielding should suffice. If SBIs can discard their shielding before intercept, NPBs would have a 10-30% effect. Penalties are roughly 2-4 times larger if the SBIs must remain shielded en route, as when facing NPBs popped up to suppress them. It does not appear feasible to negate pop-up NPBs once operational; it appears necessary to destroy them during ascent or before they are activated. That should be possible for nominal parameters, because the SBIs are already closely spaced to meet near-term threats.

Suppression is possible, but it imposes some awkward constraints. Perigees must be fairly low, and velocities could usefully be somewhat higher than in current designs, but the largest problem is decision making. There is just enough time for automatic decision making; human intervention could preclude intercept altogether. To be effective, the defense of the defenders would have to automatically intercept any large launch from within or from 500-1,000 km around the missile launch areas. While technically feasible, this could be opposed. Thus, the problem with pop-up NPBs would appear to be less the stressing threat they pose than that they bring the man-in-the-loop issues that were thought to be a long-term issue for SBI effectiveness into the near term as a determinant of SBI survivability.

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Fig. 1. Constellations vs suppression current

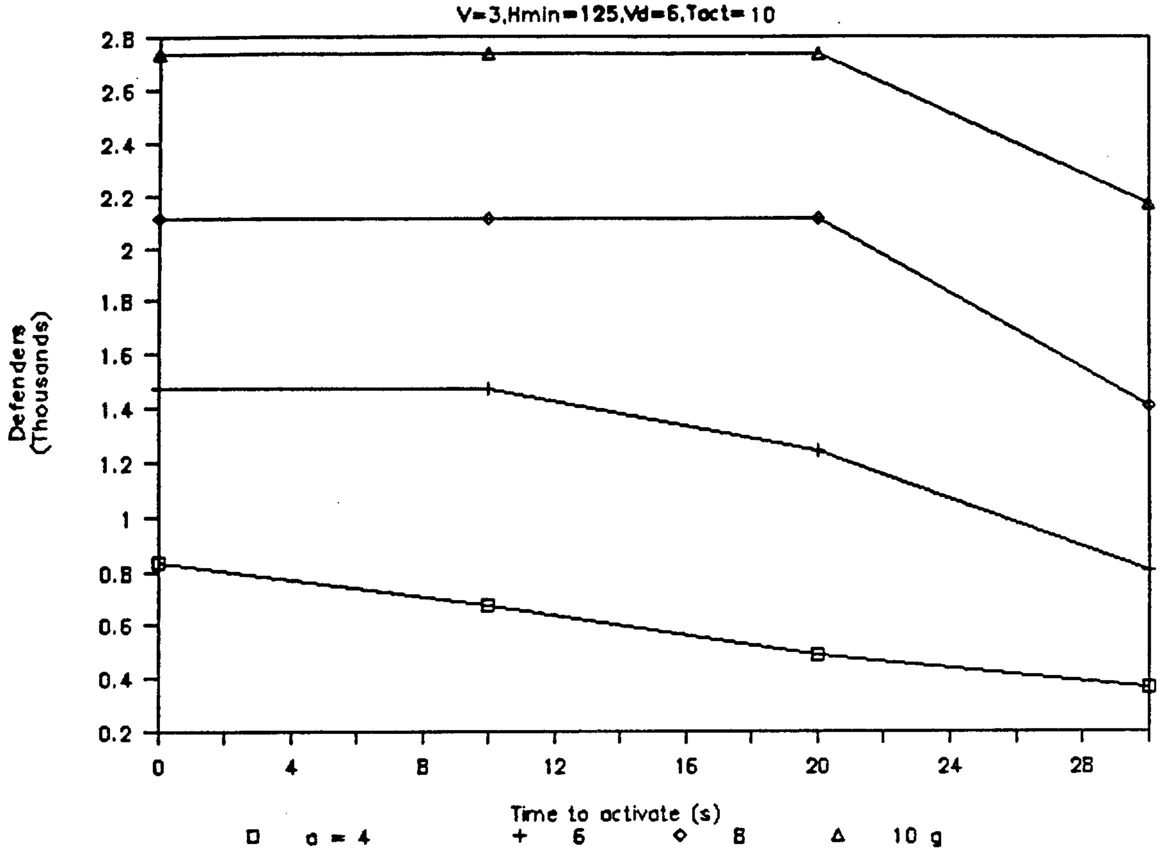

Fig. 2. Constellations vs booster velocity

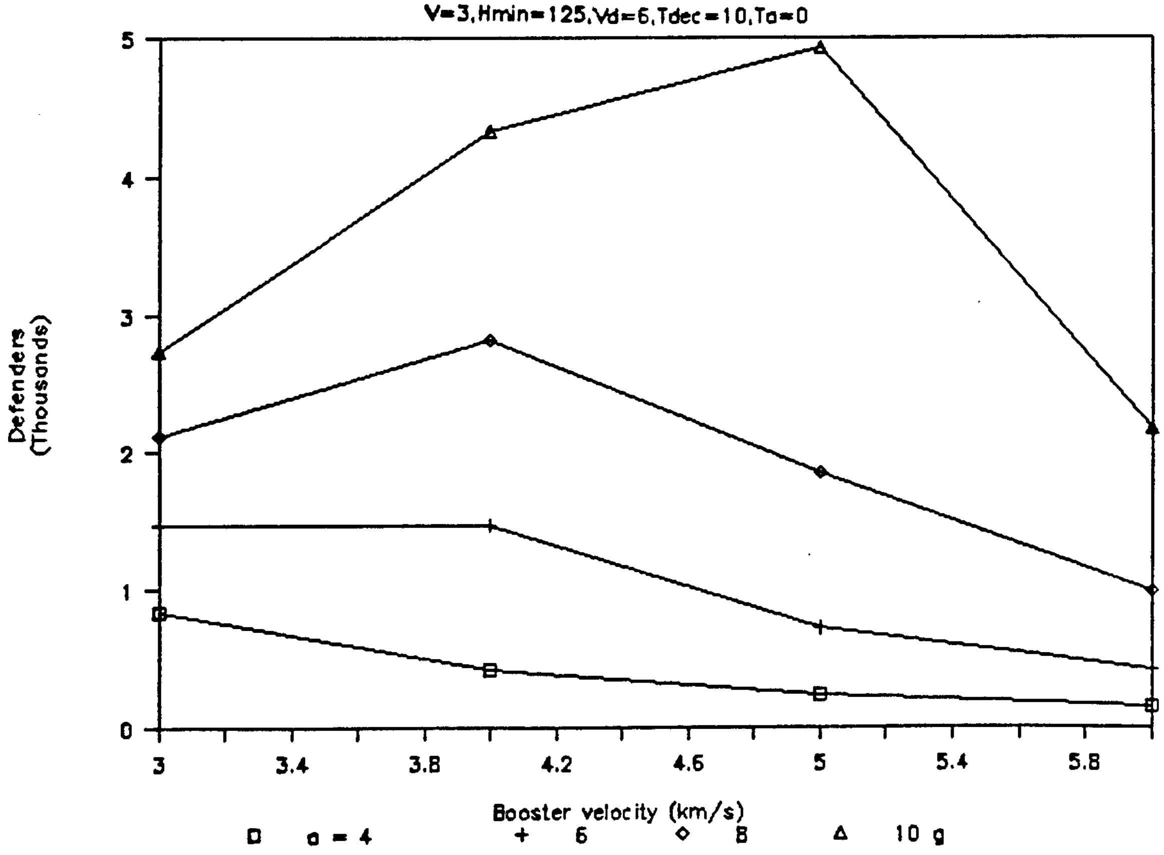

Fig.3. Constellations size vs altitude change

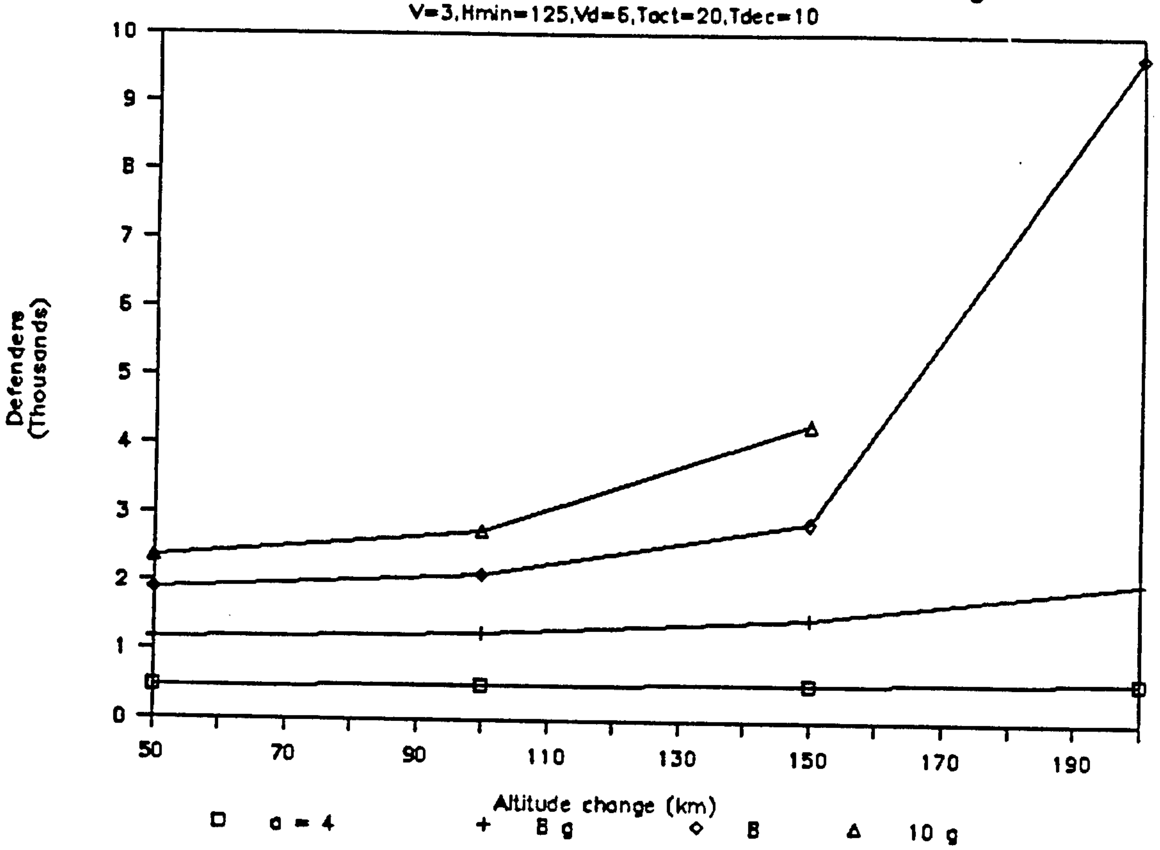

Fig.4. Constellation size vs defender velocity

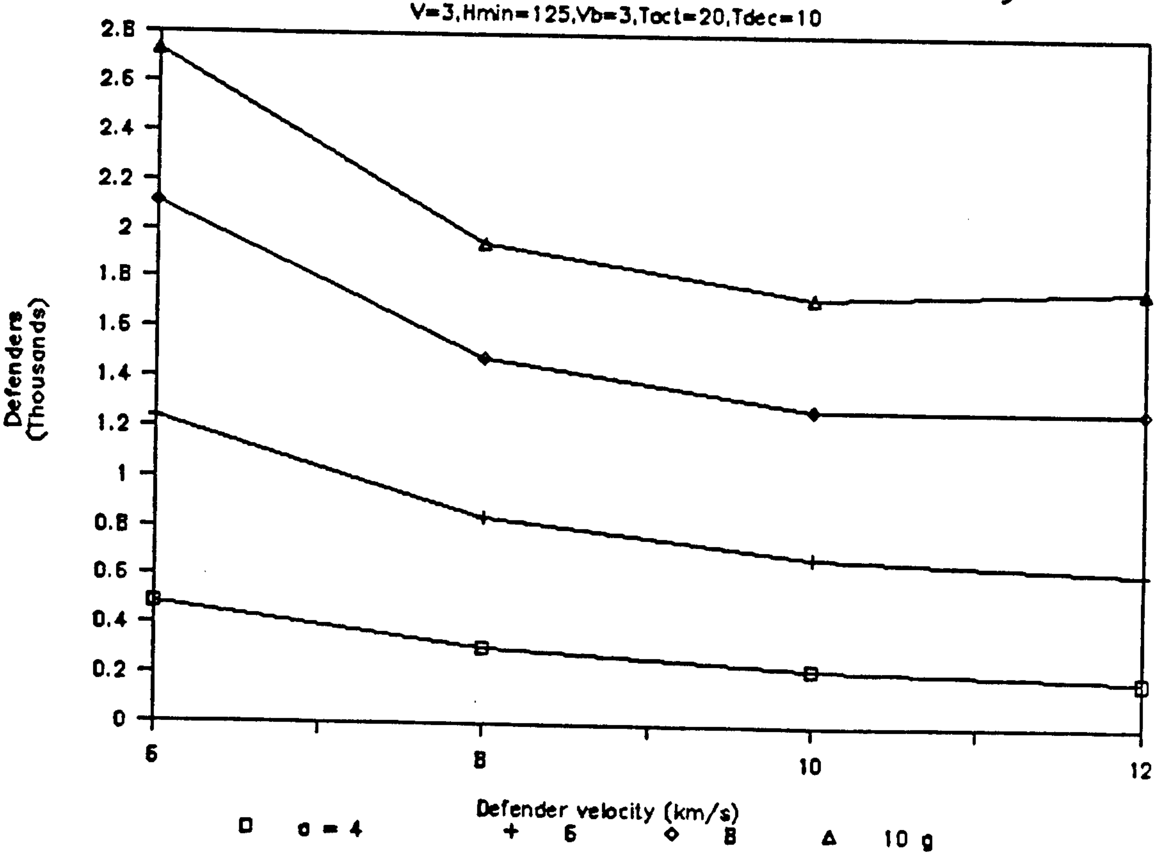

Fig. 5. Constellation size vs decision time