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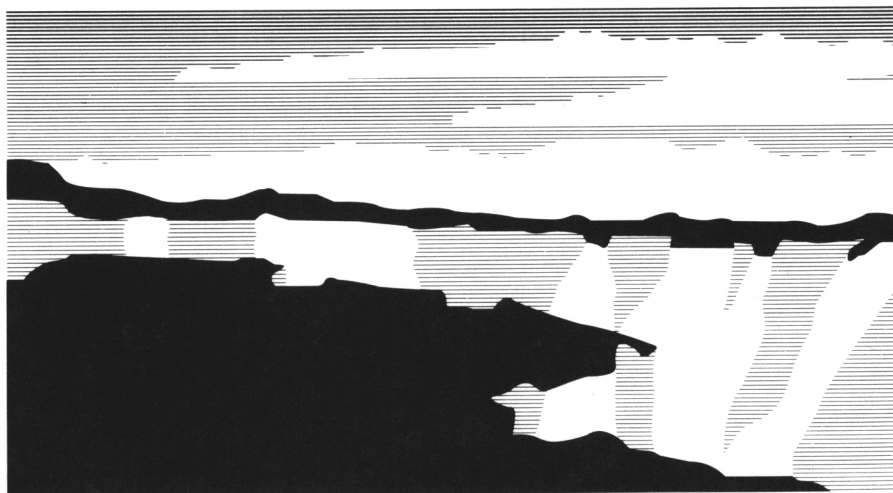
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Submitted to:

For discussions outside the Laboratory

Date: February 7, 2001

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SPACE BASED INTERCEPTOR SCALING

Gregory H. Canavan

Space Based Interceptors (SBIs) are small, smart rockets in space that can intercept missiles in boost before they can deploy countermeasures. This note discusses their scaling and that of their constellations with delays, peak velocities, and accelerations. Threats consist of one or more of the conventional $\approx 3g$ missiles widely observed in rogue threats. ICBM burn times of 250 sec, which are at the short end of those for missiles with that technology, are assumed to stress the defense. A range of delays for detection and release is studied.

SBIs have ranges adequate to address rogue ICBMs. They are not overly sensitive to 30-60 s delay times. Current technologies could support boost phase intercept with about 100 interceptors. Higher acceleration and velocity could reduce that number by factors of two to three. The SBI would be heavier and more expensive, but there would be fewer of them for an overall reduction in cost by about a factor of two. Improved technology makes constellations and costs relatively insensitive to SBI acceleration and velocity; however, the calculations below are based on simplified models that should be adequate for the discussion of trends, but not absolute values.

Interceptor ranges fall rapidly with theater missile range and burn time. Their constellations increase significantly for ranges under 3,000 km, even with advanced interceptor technology. Distributed launches demonstrate the improved absentee ratio for larger or multiple launch areas. SBI constellations increase with the number of missiles and the number of interceptors per missile. Economic estimates suggest that two SBI per missile plus a modest midcourse underlay is appropriate. Much of the SBI kinetic kill vehicle (KKV) technology is common to space- and surface based boost phase systems. It could have synergisms with improved midcourse intercept and discrimination systems.

Analysis. The threat missile burns for $T_{\text{burn}} \approx 250$ sec. The SBI is launched after time delay T_{del} , so its flight time is $T_{\text{flt}} = T_{\text{burn}} - T_{\text{del}}$. Accelerating at an average of A g's to a top speed V_{max} , takes time $T_{\text{acc}} = V_{\text{max}}/A$. If $T_{\text{acc}} > T_{\text{flt}}$, the SBI accelerates continually to

impact, which occurs at range $r = AT_{\text{flt}}^2/2$. For $T_{\text{acc}} < T_{\text{flt}}$, the SBI accelerates to V_{max} and then coasts to impact at range $r = V_{\text{max}}(T_{\text{flt}} - V_{\text{max}}/2A)$.

Each SBI can cover launches within an area πr^2 of its initial orbital trajectory, so the constellation required for uniform, single, whole-Earth coverage is $N = 4\pi R_e^2/\pi r^2$. It is assumed that the SBI has dry weight $M = 4$ kg, costs $K = \$0.5\text{M}$, has fuel with specific impulse $c = 3$ km/s, has an ideal rocket, and has launch costs $L = \$10\text{K/kg}$. Thus, the cost per SBI is $C = K + LMe^{V_{\text{max}}/c}$, and that of the constellation is NC .

Delay time is varied in Fig. 1 from 20 to 140 s for $V_{\text{max}} = 6$ km/s and $A = 4, 6$, and 8 g. Resulting ranges vary from 900-1,200 km for $T_{\text{del}} = 20$ s to 200-400 km for $T_{\text{del}} = 140$ s. Figure 2 shows the resulting constellation sizes, which are about 100 SBI for all A at $T_{\text{del}} = 20$ s and 400 to 1,400 km for $T_{\text{del}} = 140$ s. Constellations vary about a factor of two for expected delays of 30-60 s. The lowest acceleration SBIs are the most sensitive.

SBI Speed is varied in Fig. 3 for a delay time of 60 s, which stresses the defense. It shows that range is insensitive to maximum speed $V_{\text{max}} > 6$ km/s for low acceleration $A = 4\text{g}$, and to $V_{\text{max}} > 10$ km/s for $A = 6\text{g}$, but increases with slightly diminishing returns for all V_{max} for 8g. Figure 4 shows the resulting constellation sizes, which are large for $V_{\text{max}} < 6$ km/s but approach 160, 70, and 45 SBI for $V_{\text{max}} = 10$ km/s.

SBI weight is shown in Fig. 5. It approaches the dry 4 kg for $V_{\text{max}} \ll 3$ km/s, but increases exponentially for $V_{\text{max}} > 6$ km/s, where it is about 30 kg. Figure 6 shows the SBI cost on orbit, which increases from the $\$500\text{K} + 4 \text{ kg} \times \$10\text{K/kg} = \$540\text{K}$ of a zero propulsion unit to about $\$0.75\text{M}$ on orbit for a 6 km/s SBI. In this approximation, it is independent of acceleration, as it is assumed that improved technologies such as higher pump efficiency and mass fractions will make it possible to operate at higher acceleration and velocity without major penalties.

Constellation cost is shown in Fig. 7 for single, global coverage. Costs are for the hardware and launch costs discussed above. They range from $\$200\text{M}$ to $\$300\text{M}$ for 3 km/s SBIs. The minimum cost for a constellation of 80 4g SBIs is about $\$150\text{M}$ at 6 km/s; about $\$100\text{M}$ for 100 6g SBIs at 7 km/s, and $\$70\text{M}$ for 65 8g SBIs at 7 km/s. The 4 g curve resembles that for the previous SBI. The DAB SBI carried a cost of about $\$1\text{M}$

on orbit. The minimum in the 4g cost is fairly sharp. Costs increase rapidly for $V_{\max} > 6$ km/s due to the 60 s delay assumed. Shorter delays would reduce that sensitivity.

The minimum cost for the 8g SBI is about a factor of two lower than that of the 4g SBI. Higher acceleration only requires about half as many SBIs on orbit, and the cost per interceptor does not increase rapidly, as it is mostly in the KKV fixed cost. The cost curves for 6 and 8g SBI are much flatter than that for 4g. Operating 8g SBI in the range of 6 to 10 km/s would only cause about 20% penalties. Faster SBIs have smaller constellations but weigh more. The two effects largely offset one another.

Missile range R determines burnout velocity $V \approx \sqrt{gR}$ for less than intercontinental ranges. Thus, burnout times decrease as $T_{\text{burn}} = V/A_{\text{msl}} = \sqrt{gR}/A_{\text{msl}}$, where $A_{\text{msl}} \approx 3g$. For shorter ranges interceptor flyout times decrease as \sqrt{R} , which produces the ranges shown in Fig. 8. For interceptor $V_{\max} = 6$ km/s and $A = 4, 6$, and $12g$, they range from about 700 to 1,000 km at $R = 6,000$ km ($T_{\text{burn}} = 260$ s), which approach the previous ICBM results, to 200-400 km at $R = 2,000$ km ($T_{\text{burn}} = 150$ s). Figure 9 shows the resulting constellations. That for $A = 4g$ roughly doubles from 150 at 6,000 km to 290 at 4,500 km and doubles 3,300 km, after which it increases rapidly. That for $A = 6g$ doubles by 4,000 km and reaches 1,000 SBI by 3,000 km. The constellation for $A = 12g$ doubles by 4,000 km and reaches 500 by 2,000 km. Higher V_{\max} would not improve the lower acceleration SBIs, although $V_{\max} = 10$ km/s would reduced the 12g SBI constellation about 20% at 2,000 km. Constellation costs track these sizes directly. Thus, SBIs are cost effective for theater missiles with ranges down to about 3,000 km, but significantly less effective for shorter range missiles.

Distributed launch areas. 100 SBIs with 4 g and 6 km/s would provide single coverage of a point launch. Each SBI would cover $\pi r^2 \approx \pi(900 \text{ km})^2 \approx 2.5 \times 10^6 \text{ km}^2$ on the Earth's surface. The former Soviet launch area effectively an area $A = L \times W \approx 8,000 \text{ km} \times 1,500 \text{ km} \approx 1.2 \times 10^7 \text{ km}^2$. Both SBI overhead and those from a distance $< r = V_{\max} T_{\text{burn}} \approx 6 \text{ km/s} \times 500 \text{ s} \approx 3,000 \text{ km}$ away could reach missiles in boost or buses, which increases the fraction of the constellation available to engage to $f \approx (L + 2r)(W + 2r)/4\pi R_c^2$, significantly lowering the absentee ratio $1/f$.

The size of the uniform constellations of 6g SBI required for the simultaneous launch of 1,000 missiles are shown in Fig. 10. For 6 km/s SBI, intercept in a 300 s boost

would take about 13,000 SBI; intercept in boost and 300 s bus phase about 7,500. If the bus phase was extended 300 s, the number of SBI would drop to 5,000, for an absentee ratio of 5. For 600 s engagements, increasing V_{ma} to 10 km/s would reduce the constellation to 5,000 km, so there is a direct trade between speed and engagement time. Optimizing SBI inclinations to maximize coverage of the Soviet launch area increases the density there by factors of 2-3, which reduces the number of 6 km/s, 6g SBI needed for 600 s engagements to about 2,500, in rough accord with more careful analyses.

Multiple interceptors. Like ground-based interceptors, SBI constellations scale in proportion to the number of missiles launched simultaneously. The main difference is their absentee ratios, which favor ground basing for a few accessible threats and space basing for many threats, or ones not accessible to surface-based interceptors. If N interceptors are fired at each ICBM for reliability, both space and ground inventories increase in proportion to N times the number of ICBMs launched simultaneously.

With $P_k = 0.9$ interceptors, two SBI would achieve 99% expected damage of a ICBM. Firing a third SBI to get the next 0.9% is plausible for \$1M SBI, but unattractive unless the defense must operate only in short boost phases, where shoot-look-shoot is impractical. GPALS had two intercepts in boost phase, which required about 5,000 SBI according to the estimates above, and a midcourse underlay sized to intercept the 1% of the ICBMs that got through boost. For 1% leakage of 1,000 missiles, that would be about 10 weapons, which could be addressed with perfect discrimination by about 20 interceptors.

Synergisms. Ground- and space-based boost phase intercepts both appear to be feasible, but the technology is not now in hand for either, although it could apparently be developed more rapidly than generally thought. It appears that their key technologies are largely common. The very large fast boosters required for current EKV's are a drawback to ground-based systems as near-term options for midcourse and boost. The EKV is heavy in part because they are based on 90s technology, partly because they contain better sensors than needed to engage bright boosters—although they lack the active sensors needed to intercept thrusting targets.

It would appear possible to use the SBI KKV as the common front end for space and ground based boost phase intercepts, as their kinematic and sensory requirements are

similar. If a common KKV could also be used for midcourse intercepts, it would reduce the size of the booster required and the suite of sensors needed on the launch platform. It might also be useful as an upgrade to midcourse interceptors. Burros are basically SBIs with provision for external command and control and supervision. For a defense against rogues only, suppression is not expected, so hardening could be reduced or traded for more propulsion. If they were based on the previous generation of sensors, C2, propulsion, and electronics, it should be possible to share their operation with allies.

Summary and conclusions. SBI have ranges that are adequate to address rogue ICBMs. They are not overly sensitive to 30-60 s delay times. Current technologies would support boost phase intercept with about 150 interceptors. Higher acceleration and velocity could reduce that number by about a factor of 3 at the cost of heavier and more expensive KKV's. 6g SBI would reduce optimal constellation costs by about 35%; 8g SBI would reduce them another 20%. Interceptor ranges fall rapidly with theater missile range.

Constellations increase significantly for ranges under 3,000 km, even with advanced interceptor technology. For distributed launches, these estimates recover earlier strategic scalings, which demonstrate the improved absentee ratio for larger or multiple launch areas. Constellations increase with the number of missiles and the number of interceptors launched at each. The economic estimates above suggest that two SBI per missile with a modest midcourse underlay is appropriate.

The SBI KKV technology would appear to be common for space- and surface based boost phase systems, and could have synergisms with improved midcourse intercept and discrimination systems. While advanced technology could be helpful in reducing costs, particularly for short range theater missiles, current technology appears adequate for pressing rogue ICBM, accidental, and unauthorized launches.

Fig. 1. Range vs Tdelay

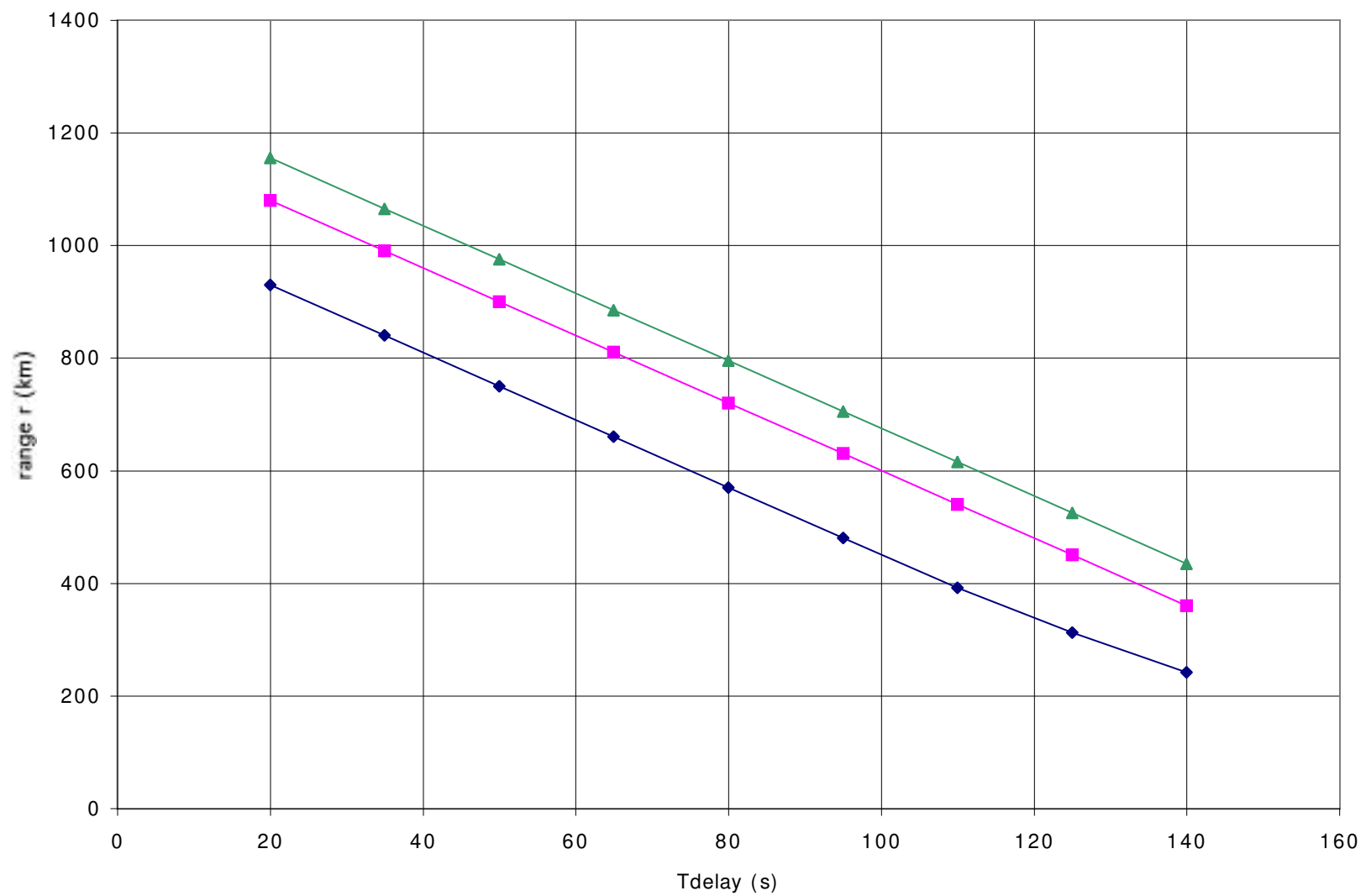


Fig. 2. Constellation size vs delay time

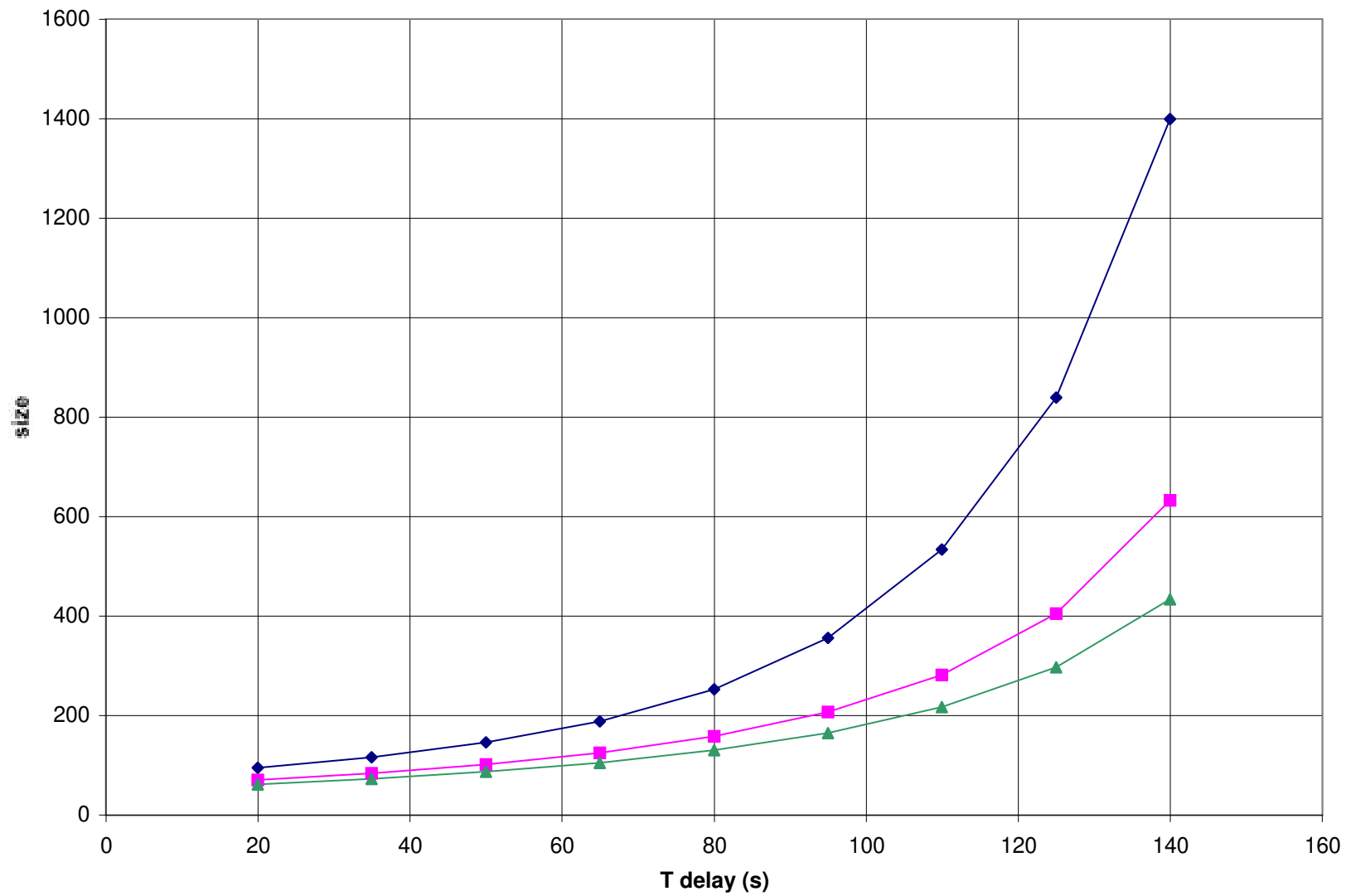


Fig. 3. SBI range vs Vmax
Tdelay = 60 s

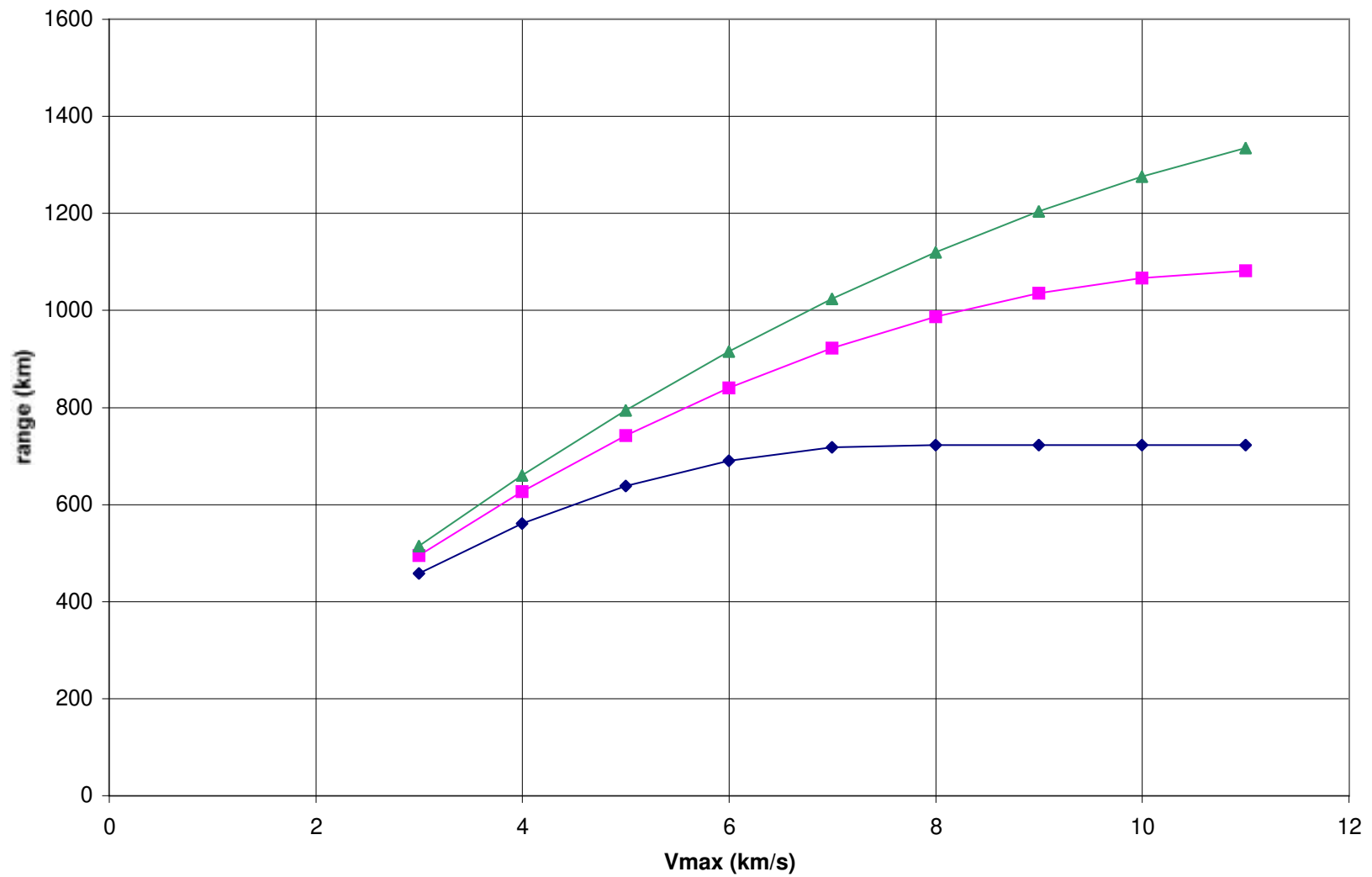


Fig. 4. Constellation size vs Vmax
Tdelay = 60 s

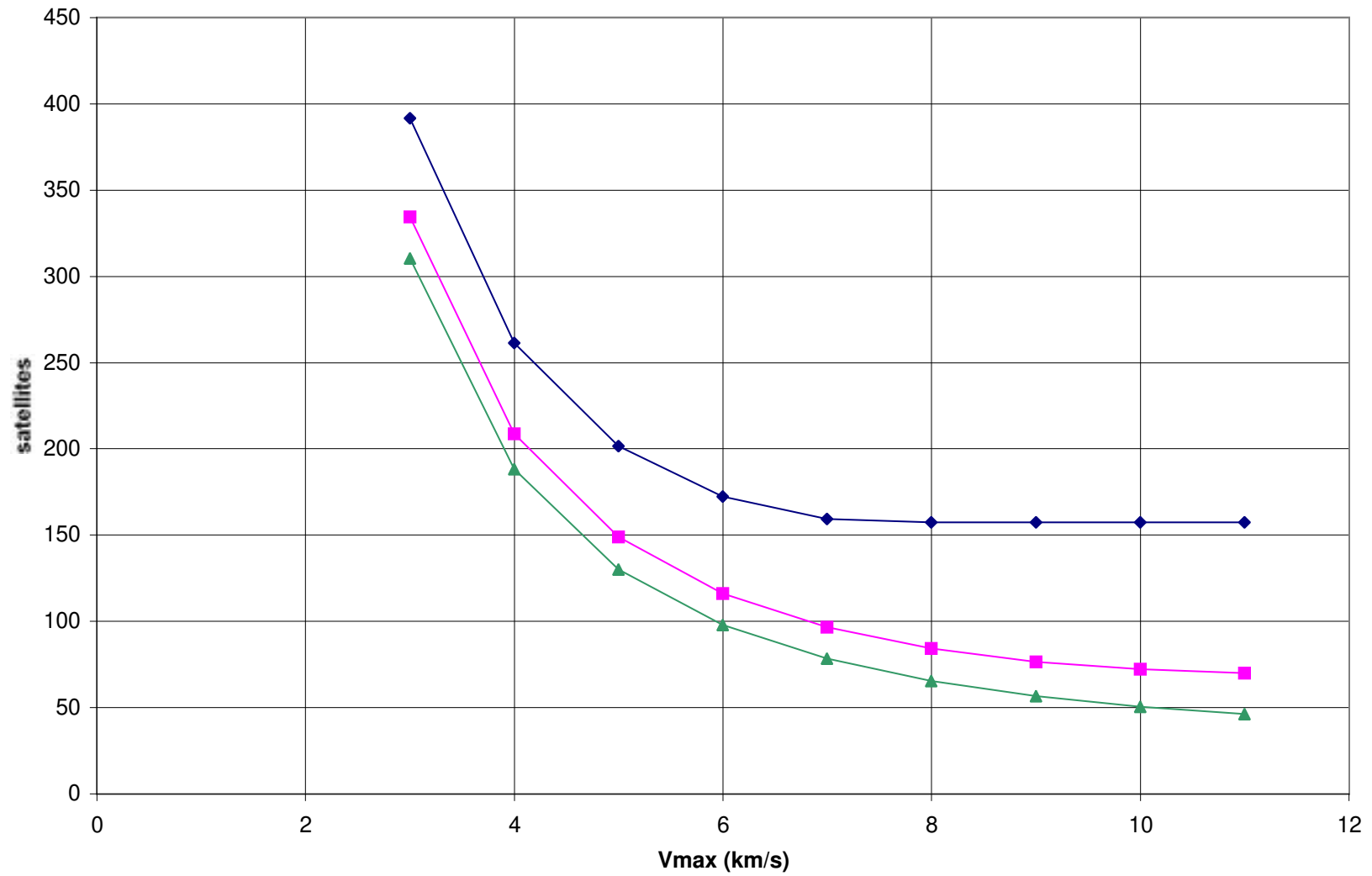


Fig. 5. SBI weight

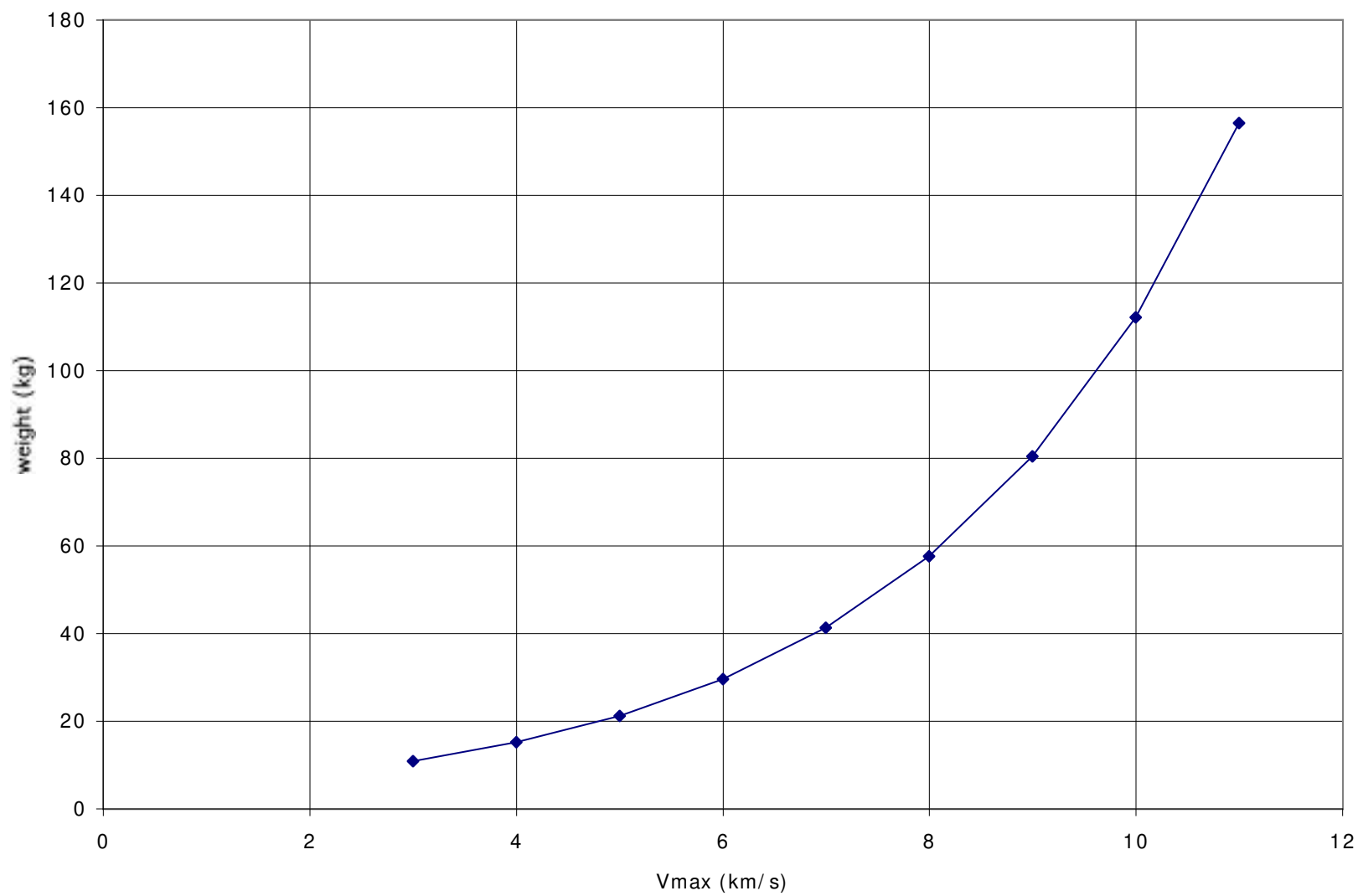


Fig. 6. KKV cost
\$10K/kg to orbit

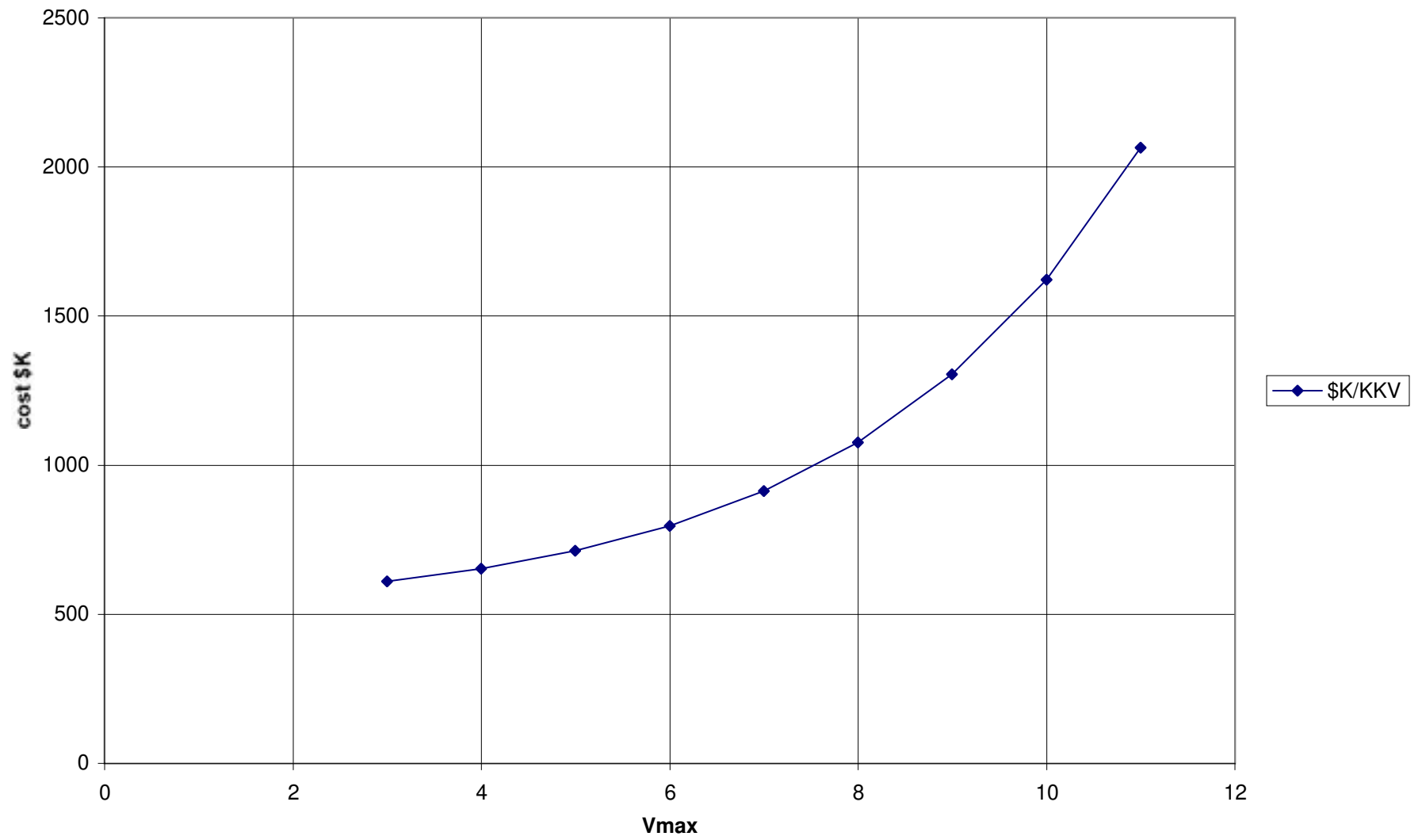


Fig. 7. Constellation cost vs Vmax
\$10K/kg to orbit

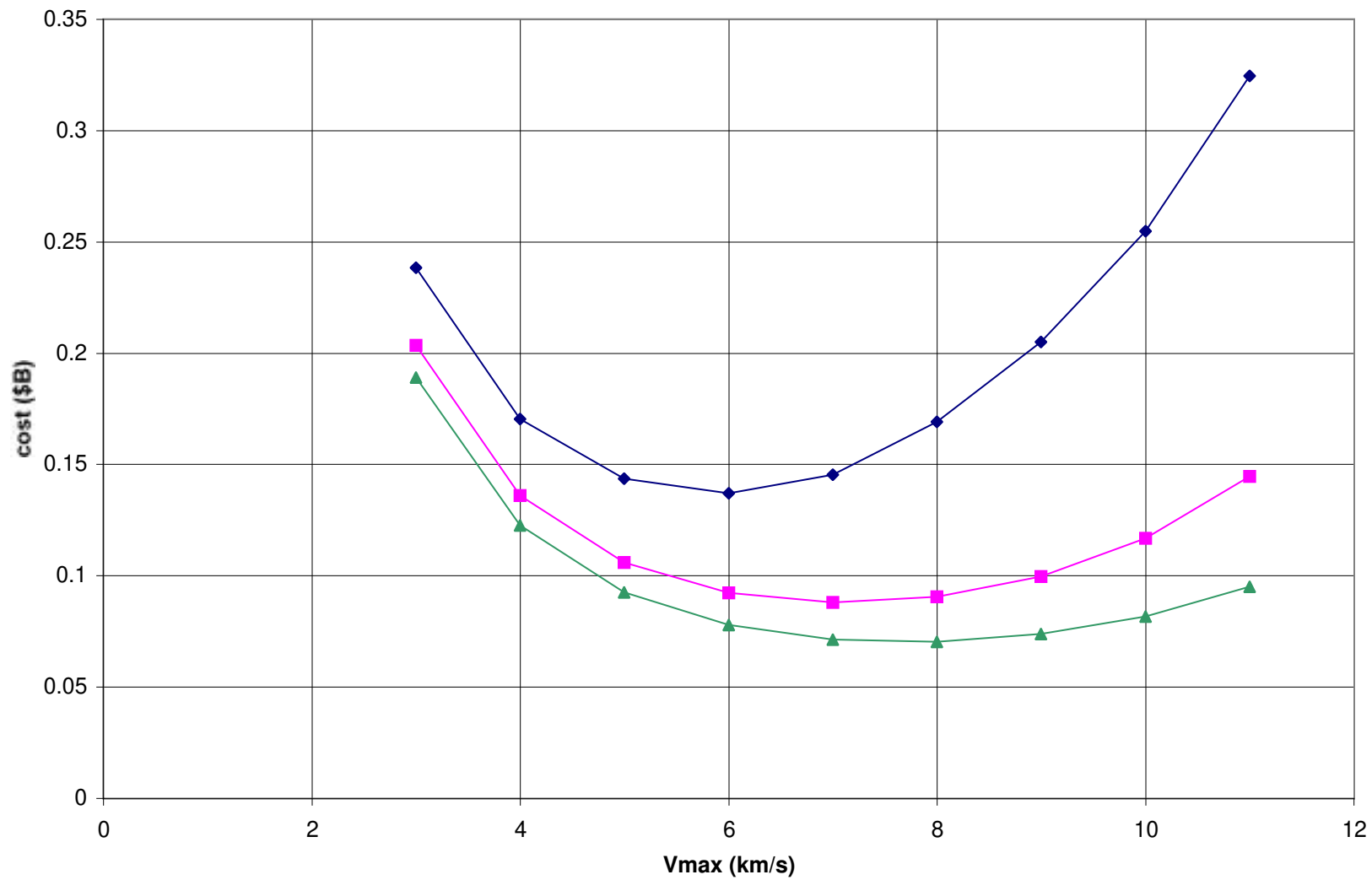


Fig. 8. Interceptor vs missile range

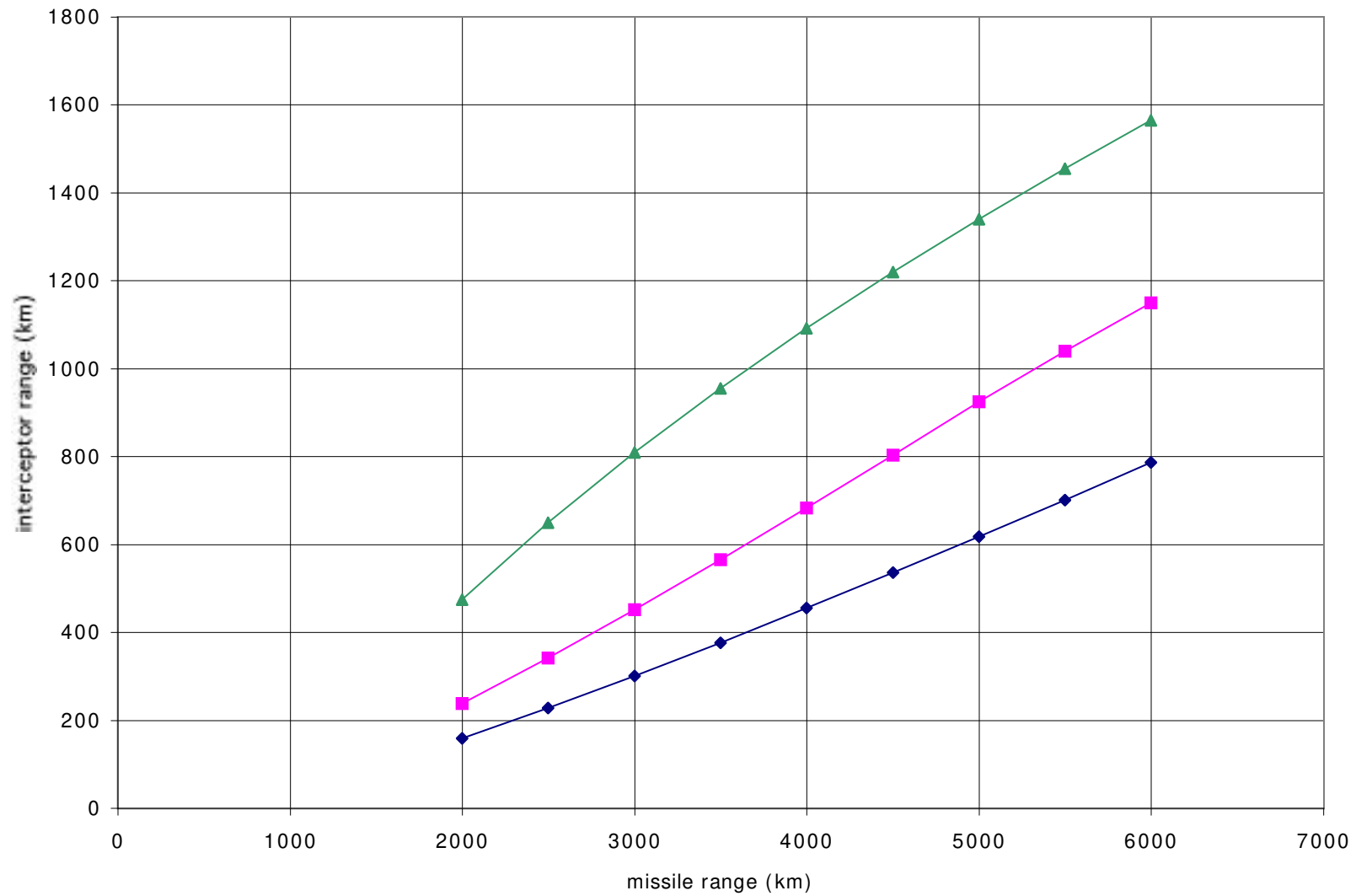


Fig. 9. Constellation vs missile range

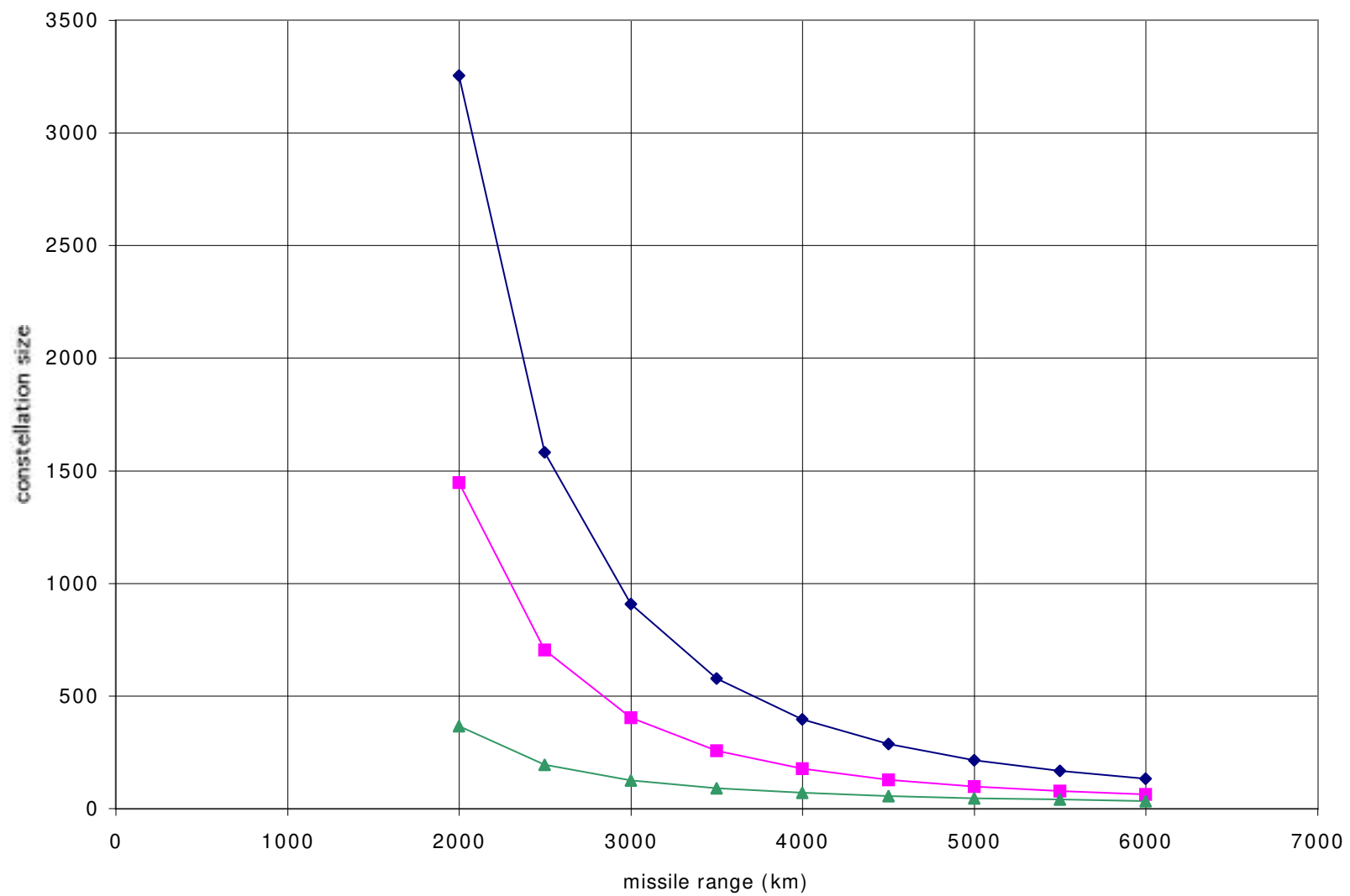


Fig. 10. Constellation for distributed launch

