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Space Development: The Strategic Implications

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ABSTRACT

Space Based Industries will be stimulated by the development of the Ballistic Missile Defense (BMD). The BMD will require a space logistics capability far in excess of what the Space Shuttle can provide. This increased logistics base will aid Space Based Industries to grow by providing low cost work areas, transportation, and raw supplies. In return these industries will develop manufacturing in space. This will lead to using off-earth resources, the moon and the asteroids, and eventually to the building of self-sufficient space settlements. These space settlements will in turn be of significant military importance.

This paper consists of my own engineering estimates based on simple calculations and is not the official Air Force assessment. It is assumed that the laser becomes the key element in President Reagan's proposed Ballistic Missile Defense (BMD).

The first step to determining the requirements of a Laser BMD is to address the question of hardening the targets to laser fire. The three most well known means of hardening are rotating the missile, use of an ablative coating on the missile, and mirroring the missile.

The intention of rotating the missile is to distribute the laser energy over a greater surface area. The rotational rate is limited by the strain that is placed on the missile. At one revolution per second a 3.09 meter diameter missile is subjected to six gravities of centripetal acceleration. This rotational rate, 10 meters per second, is insignificant to the velocity of the missile, between one to two kilometers per second, at the time of laser firing. The capability of the laser to hit a particular spot is accomplished by firing in so brief a period that the missile barely moves. The effects of rotating the missile are therefore negligible.

The laser beam will first encounter the ablative coating on the missile. This material will carry away the thermal energy that strikes the missile. One kilogram of phenolic nylon will quench 9 Megawatt-sec of energy. The thickness of the ablative coating is a function of the amount of energy that strikes the missile and the surface area that the energy covers.

Beneath the ablative coating would lay a mirror finish. This mirror would reflect most of the laser energy from the missile. A thin film of silver would greatly reduce the amount of energy absorbed by the missile's skin. Polished silver would absorb only 7% of the energy compared with 15% for polished aluminum. A square meter of the missile's skin is roughly 2.7 kilograms of aluminum. To raise this mass to its melting point requires 1.5 million joules. An input of 22 million joules is needed to reach this point against the mirror defense. The energy that is absorbed by the missile acts to vaporize fuel in contact with the skin or to raise the temperature of the skin, weakening the structure. The failure mode is the same, the internal pressure ruptures the missile's skin.

Any increase in weight in the missile must be compensated by either accepting reduced capability in the missile, enlarging the missile, or making significant strides in propulsion or material science. Each kilogram of armor added to the missile subtracts roughly three kilotons of explosive power. The largest Soviet missile is estimated to have a payload of 7,000 kilograms, equivalent to a 20 Megaton warhead.
This missile would be useless if its payload was carried as armor. This missile has a surface area of 300 square meters. When covered by 23 kilograms of ablative material it has a laser hardness of 207 Megawatt-Sec. per square meter. Added to the mirror defense this would produce an ultimate laser hardness of 229 Megawatt-Sec. per square meter. A Ballistic Missile Defense built to this requirement would provide a threat so severe that future missile systems would be discouraged. This will free the United States from the threat of a quick nuclear strike. As U.S. defense capability grows other Nations will be forced into a similar stance. The policy of Mutual Assured Destruction (MAD) will be replaced by a policy of National Defense.

The laser is a cassegrain configured device. The laser energy exits via a window to strike the small mirror. The small mirror reflects the energy onto a larger mirror which then focuses the laser light into a cone with its tip on the target. Adaptive versus fixed optics permits the focus to change as the range to target changes. This permits the energy of the laser to be placed on as small a surface area (ie. spot diameter) as possible based on the limits imposed by diffraction. The spot diameter is equal to the laser wavelength times the target distance divided by the large mirror's diameter.

The mirrors are not perfect reflectors and typically each absorbs 7% of the laser energy. The small mirror is cooled by fluids. The surface area of the large mirror permits it to be passively cooled. The energy that enters the mirror is transported by conduction into a thermal ballast. This thermal reservoir allows the laser to be pulsed. The energy is stored for gradual release in the period that the laser is inactive. A high emissivity coating (.97) radiates this heat into space. The Black Body equation can be used to estimate the output power of the laser per unit area. It merely requires assuming a critical temperature. Using 642 degrees C, roughly two thirds of the melting point of silver, allows an output of 500 kilowatts per square meter of mirror.

The overall efficiency which includes the mirrors would be 8.6%. The bulk of the waste heat is carried away in the exhaust of the spent fuel.

The laser Battlestations appear as a string of circles moving in polar orbit with the earth rotating beneath them. Additional strings are added until a series of circles cover the equator. As these circles move towards a pole they begin to overlap until they coincide over the pole. These circles are the footprint within which the laser can assure destruction of the target. This configuration is the most effective use of the Battlestations. It concentrates the lasers over the poles where the most difficult targets, the warheads, make their closest approach to the lasers, yet this configuration maintains coverage of the missiles during their vulnerable boost phase as well as providing the capability to attack the warheads at re-entry. The defense can be made stronger by using different types of weapons at these points. The laser though best suited for the boost phase intercept would still provide support at the warhead apogee and re-entry points.

The orbit of the Battlestation is taken to be 1,500 kilometer. This places the Battlestations outside the normal flight path of the missiles and aids in the identification of high priority targets that are a threat to the Battlestations. The Battlestations are placed in three polar orbits separated by 60 degrees. Each orbit contains six Battlestations. Assuming the Earth is a perfect sphere 12,800 kilometers in diameter, each Battlestation must cover a circle 6,700 kilometers in diameter. This requires an effective slant range of 3,700 kilometers.

To meet the 229 Megawatt-Sec. per square meter illumination requirement, a laser is needed with a fifteen meter diameter mirror, an output of 85 Megawatts, and a mass of 150,000 kilograms. Eighteen units must be provided in polar orbits.

There are two solutions for placing this mass on orbit. The Battlestations can be handled as an ordinary satellite. This would require developing a Heavy Lift Launch Vehicle (HLLV). The complexity of the Battlestation can be reduced by having Man at the site for deployment and periodic maintenance. This would be done by developing a Manned Orbital Transfer Vehicle (OTV) that would be launched from the Space Shuttle.

This is a poor solution. It's unlikely that the U.S. will follow the BMD with a space
program equally as large, yet the large payload capacity of the HLLV would limit it to such a program. After eighteen operational flights this new launch vehicle would be consigned to the rubbish heap. Additionally, this option would use the Space Shuttle inefficiently. In carrying the Manned OTV the Shuttle would be transporting mainly fuel at a cost of $1000 (1983$) per pound. The cost to manufacture the fuel is roughly fifty cents per pound.

The alternative method is on orbit assembly. The most expensive element would be developing the polar orbit space station. Initially the space station would serve as a research and development laboratory for the BMD. Once the design is established the space station would be used for assembly, checkout, and repair of the Battlestations. After the Battlestations are placed into their orbits the space station will continue to serve as a maintenance depot.

An Orbital Transfer Vehicle (OTV) is necessary to transfer the battlestation from the 300 kilometer assembly orbit to the final orbit of 1,500 kilometers. Giving the OTV a Manned capability allows it to be more versatile. The Manned OTV can provide on-site maintenance, a rescue capability, and offer a highly mobile platform for space operations. The space station makes it possible to base the Manned OTV on orbit. This permits the Manned OTV to grow beyond the confines of the Space Shuttle allowing it to far greater carrying capacity and use of advanced concepts such as Aerobraking. The Manned OTV's development and hardware costs would be amortized over its working lifespan. This makes its chief asset the fuel brought from earth.

A new launch vehicle must be built to supplement the launch capability of the Space Shuttle. This new vehicle should cost little to develop, take little time to build, cost less than the Shuttle to operate, and somehow complement the Shuttle's operation. This miracle can be built. It is the Semi-Reliable Logistics Vehicle. This is a simplified rocket designed for mass production. It uses existing technology to reduce its development time and cost. It lowers its operating costs by reducing its reliability. It is useless for valuable satellite or astronaut traffic. It is designed to handle low cost, easily replaced items such as fuel, food, water, air, and off-the-shelf parts. Roughly two thirds of the Battlestation can be shipped into orbit using this vehicle. The Battlestation uses 30,000 kilograms of a sand bag type armor designed to absorb projectiles or be released as a smokescreen when under laser fire. One thousand seconds of laser operation requires 76,000 kilograms of Hydrogen/Fluoride fuel. If transporting the liquid Fluorine is found to be too hazardous for this vehicle, the cost savings would be so great that the Fluorine could be transported in a biologically benign form and processed on orbit. This would be similar to the shipping of Chlorine in the form of Sodium Chloride.

The fifteen meter diameter laser mirror must be carried into orbit in sections. Preferably these sections should be as large as possible. This will drive the development of an Aft Cargo Compartment. This is a cylinder eight meters in diameter and six and a half meters long attached to the rear of the External Tank. Carrying the External Tank into orbit presents no problem. The tank is normally carried to within 98% of orbital velocity. If the energy intensive jettison maneuvers are omitted the Space Shuttle's carrying capacity increases by taking the tank into orbit with the tank already on orbit it would be natural to develop its resources. The tank contains 5,000 to 7,000 kilograms of residual Hydrogen/Oxygen fuel. This figure increases if the Shuttle flies light, as is a common practice. The tank consists of two airtight aluminum containers, massing about 26,000 kilograms, covered by an organic insulator of roughly 8,000 kilograms.

After the Ballistic Missile Defense is complete this equipment will remain. The Aft Cargo Compartment will permit larger communications satellites to be carried into orbit. Commercial space station modules will carry out deployment, checkout, and repair of these satellites. The Commercial space station will also conduct research, development, and manufacturing. The Semi-Reliable Logistics Vehicle will reduce the cost of supplies to orbit by a factor of ten. This will reduce the cost of using Man on orbit, provide easier access to the higher orbits, and allow a broader range of products to be economically manufactured in space. The weight limitation on satellites will be eliminated by on orbit assembly and the space based Manned OTV. Reliability of the satellites will increase with on orbit checkout while the complexity of the satellite will decrease with periodic on site maintenance. The result will be cheaper, less complex satellites that will be more reliable and longer lived.

The most significant item though will be the resources of the External Tank. There currently exists no cost to carrying the tank into orbit. By offering the tank at a token price the government can provide an incentive
to industry to develop this raw material into productive tools. The tanks will provide nearly a million kilograms of material each year. Yet, this is a limited resource. The tank cannot be carried into orbit for its own value. It must hitch a ride with a more valuable payload. By learning to handle the raw resources of the External Tank, industry will open the door to handling the raw material of off-earth resources such as the moon and the asteroids.

Space Based Industries will grow which will mean greater competition for resources. As the prices of these resources rises, industries will make investments to lower their costs. Primarily, this will be towards increasing the capability of the Space Transportation System. However, some speculative money will be spent on developing the products, processes, and transportation to make use of off-earth resources. The first use of off-earth resources will be viewed as a high risk venture. This risk will be minimized by keeping the investment low.

If a major source of Hydrogen is discovered on the moon, then lunar resources will be the first used. This will incur only a minor development effort on the Manned OTV. Failing the discovery of such a Hydrogen source, then earth approaching asteroids are the next likely targets. The Solar Sail would be the logical commercial choice for such deep space operations. It has a high payload to weight ratio, uses no reaction mass, is long lived, and most importantly it can be manufactured on orbit using the resources of the External Tank. The first product to be derived from off-earth resources will probably be oxygen. It would have widespread use in fuel, life support, and manufacturing, and being a consumable it would be in high demand. Magnetic separation could be used to concentrate ferrous oxides at the asteroid. The Solar Sail would return to earth orbit where the oxygen would be liberated under heat. The iron as well would command a high price.

As processing avenues open up, the demand for off-earth resources will increase. A lower starting cost, due to using asteroidal resources, will lead to the development of lunar resources using a magnetic catapult. Asteroidal and lunar materials will depress the need for materials launched from earth. Fewer launches will be made resulting in increased costs for the remaining launches. The increased cost for earth resources will force Space Based Industries to become even more dependent on off-earth resources until the cost of operating in space will be made independent of launch costs.

Once Space Based Industries are committed to using off-earth resources, the situation takes on the form of a goldrush. The low cost materials will allow Space Based Industries to expand and even compete against Earth Based Industries. Competition will be fierce as companies attempt to stake out marketing territories. This expansion will require large numbers of personnel on orbit. Many of these people will be attracted by the novelty of working in space. Once the novelty wears off, the companies face the problem of retaining trained personnel. This is not unusual where work is carried out in remote areas. The key problem is isolation. The best solution so far is to transport complete families into the area. Transport costs are high in remote areas and space transportation will be far higher. As with any remote area, the transporting of families will be practical only if most of their support can be derived at the site.

The movement of families into space will begin with the growing of food in space. Export industries will help to support local industries. A parachute industry will exist to deliver metals and finished products to earth. A by-product of this industry will be cloth for local tailors. The small population base is a handicap to centralized production of consumer goods. Many products though can be handmade. While this would be a luxury on earth, it will be a necessity in space. Small cottage industries will form to compete against everyday items imported from earth. The cost of living in the space settlement will be high, but this will be compensated by the high value of the goods and services that the space settlement provides. As the population of the settlement grows, the economy will turn more inward. The return from export goods will be shared by a greater number, hence less money will exist per person. However, the greater population base will support a wider production of goods. The space settlement will become more self-sufficient and less money will be spent on imports. Additionally, the greater number of people will allow centralized production, further decreasing the cost of local products. There will always exist some basis for trade between the space settlement and earth, but the space settlement’s economy could become so closed that the loss of such trade would be trivial. The settlement would be as pleasant a place to live in as any metropolitan city on earth.

There exists also a military side to the space settlement. As the space settlement grows more self-sufficient, its population will grow and additional space settlements must be built. The space settlements will be
like islands in space, some will be separated by mere minutes of travel while others will be separated by months of travel. The military strength of such settlements should not be doubted. Because of their position and resources, the space settlements will have control over the earth’s access to space. A likely industry of space will be the production and delivery of Nickel and Titanium on the order of tens of thousands of tons to earth each year. With such a transportation capability, the space settlements would be able to attack any enemy on earth. The space settlements will share our own heritage and love for personal freedoms. As a democracy, the U.S. can accept the development of such independent city-states. Can a dictatorship say the same? To exist, the space settlement must become self-sufficient, independent of another’s rule. To be of value, the space settlement must have an industrial capability, but such a capability can be used as a weapon. As the settlement grows, new settlements will form and the risk of rebellion increases. Would a dictatorship accept this?

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