文章编号 2095-1531(2014)03-0491-08

# Laser weapons-myths and prospects

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**Abstract**: The experience of designing strategic laser systems in the previous years and a strong belief in the attainability of the goal—the development of high-power laser weapons—help to significantly accelerate the pace of work in the field of new technologies. World press has recently published the articles where it was suggested that the anti-missile airborne laser project suffers cost overruns and delays or may fall victim to budget cuts. Just after that mass media immediately reported that the Pentagon refuses to develop combat lasers. As a result, there has appeared an epic set of myths about combat lasers. The task of this paper is to consider the most ridiculous statements and to reject them by sufficient analysis.

**Key words**: laser weapons; combat lasers; beam divergence; mirrors; reflectivity; interaction; continuous and pulsed lasing

# 激光武器—谬论与展望

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**摘要**:过去几年总结的战略激光系统的设计经验和实现高能激光武器发展目标的强大信念有助于加快新技术领域的工作步伐。World press 博客平台最近发布的文章表明,反导机载激光器项目遇到了成本超支和拖期的问题,可能会成为削减预算的牺牲品。随后,大众媒体立即报道了五角大楼拒绝研制作战激光器。因此,出现了一些关于作战激光器的谬论。本文旨在通过充分的论证与分析来反对这些谬论。

**关 键 词**:激光武器;对抗激光器;光束发散;反光镜;反射率;相互作用;连续和脉冲激光
**中图分类号**:TJ953 **文献标识码**:A doi:10.3788/CO.20140703.0491

**收稿日期**:2013-10-11;**修订日期**:2014-02-13
注:对应中文翻译内容可在《中国光学》网站文章目录下载

## 1 Introduction

The Wall Street Journal has recently published an article in which it was suggested that the anti-missile airborne laser(ABL) project suffers cost overruns and delays and may fall victim to budget cuts. Mass media have immediately happily reported that the Pentagon refuses to develop combat lasers. However, this euphoria seems very misleading, if not tougher.

Today, chemical lasers are being widely replaced by solid-state diode-pumped lasers. It is these lasers that the Pentagon counts on, because they are more compact, simpler and cheaper to use than chemical lasers. Besides, they are reliable, easily compatible(without any transformation of the output voltage) with nuclear and solar energy, allow for further scaling of output parameters, and the efficiency of their operations is significantly higher. Northrop Grumman Corporation has already presented a 105 kW solid-state laser and intends to significantly increase its output power by mono-module disk laser approach[3]. According to data from U. S., laboratories work is on the way to develop a prototype of a 500 kW laser. Subsequently, ‘hyperboloids’ will be truck-mounted [high energy laser technology demonstrator(HEL TD) program], ship-mounted [maritime laser demonstrator(MLD) project], and airborne [high energy liquid laser air defense system(HELLADS); a laser for F-35, B-1, CH-47 aircrafts)]. Another direction is largely supported by Raytheon, which stakes on fiber systems. A 50-kW laser weapon system (LaWS) will be integrated with the Phalanx Close-In Weapons System(CIWS) against anti-ship missiles and its land based version of Centurion C-RAM. In addition, the officials in the U. S. have recently reported on the progress of works on a combat free electron laser. At the same time, we should not forget about “Alpha” system(a laser with an output power of 4.5 MW), lying on the ground and waiting for the decision to be launched.

Bring solid-state lasers to megawatt powers takes time and considerable resources. However, the experience of designing strategic laser systems in the previous years and a strong belief in the attainability of the goal—the development of high-power laser weapons—help to significantly accelerate the pace of work in the field of new technologies. It should be noted, however, that tactical laser systems with lower power outputs have already been tested in the U. S. and now find applications in the army. All this testifies that the Pentagon experts clearly do not think about cancelling the promising laser programs. We are talking here about an effective system of disinformation. The report ‘Technology Horizons’ by the Pentagon refers to the global changes in the ‘rules of the game’ after the proliferation of ‘high energy weapons’, which will turn the traditional symbols of military power into outdated stuff like cannonballs and cavalry. And while the U. S. develops laser programs, many other countries show ‘laser apathy’. Incompetent bloggers and pseudoscientific workers, who had something to do with the laser program thirty years ago, speculate that ‘lasers

Fig. 1 Anti-missile airborne laser

are a bluff'. As a result, there has appeared an epic set of myths about combat lasers. Consider the most ridiculous of them.

## 2 Ten myths

### 2.1 Myth 1. Combat lasers have been developed for four decades with no progress in sight

Let us quote one of the Russian papers:"In the 1970s the Americans took a 150-ton Boeing-707 and 'stuck' a laser to it, which successfully burned small rockets. In the 2000s, they took a 350-ton Boeing-747 and 'stuck' a heavier and more powerful laser, which successfully burned larger size rockets. In 20 years they will buy in Ukraine a decommissioned "Antonov AN-225 Mriya" (640 tons), and here it is, the Death Star[1]. Yes, probably it will be able to shoot down a "Scud", and even a "Taepodong". However, only at the site, and once, no more.

Under the 150-ton Boeing-707, 'to which a laser was stuck,' is apparently meant a 137-ton Boeing KC-135 stratotanker based on the "707" of the first, modified in 1973 into NKC-135ALL [airborne laser laboratory (ALL)]. In 1983, a laser mounted on the aircraft shot down several Sidewinder air-to-air missiles at a distance of 5 km and

Fig. 2 Airbased military laser

some other 'little' things. What has changed since then? According to the above quotation only the size of the aircraft.

But what about the reality? Even the so-called 'megawatt' CW lasers in the 1980s did not emit light at megawatt power levels, they consumed more power. The 2.2-megawatt Miracle laser system, which later in the combat version was called a tactical high energy laser (THEL) ('MIRACLE' with the 'SEALITE' guidance system) did not possess a supernatural power. What to say about the earlier and five times weaker ALL. Has there been any progress since then? An ABL has a power of 1.1 MW and it is not the power to be consumed; this is the power in the beam. Thus, a 'more powerful' (50 times) laser was 'stuck' to a 350-ton Boeing... However, it should be understood that the actual capabilities of the laser rely not on the power as such, but on the concentration of the radiation, i.e., the ability of the 'guns' to emit not only a powerful, but also a narrow beam. The ALL had the level of the radiation concentration equal to $10^{13}$ J/(sr · s). An ABL has the level of about $10^{18}$ J/(sr · s)—that is, 10 thousand times higher.

These achievements are made up not only of the straight-line growth in the power. The last 30 years have seen a period of extremely rapid development of adaptive optics to compensate for the effects of atmospheric turbulence and laser path on the transmitted beam. In addition, the lasers of the same class are radically reduced in size. The first version of a THEL weighed 180 tons and could be hardly installed into six trailers. The laser used a hydrogen fluoride mixture which is very unfriendly to the environment. The second generation of advanced tactical lasers (ATLs) relies on oxygen iodine mixtures [so called chemical oxygen iodine lasers (COILs)] and is more compact. Finally, a new solid-state laser of Northrop Grumman weighs 1.5 tons, including the cooling system. In the future its weight is expected to be reduced to 750 kg. As a result, the land based version of the system consists of a heavy expanded mobility tactical truck (HEMTT A3), command post on a high mobility multipurpose

Fig. 3 Mobile laser system

wheeled vehicle and a towed single-axle trailer with the AN/MPQ-64 radar. At the same time, the U. S. works hard to convert the CW regime of the lasers in the pulse-periodic one, which will dramatically increase their range of actions.

Talks about the fact that "combat lasers have been developed for forty years and so they are hopeless," only show ignorance in technical matters. Breakthrough technologies are first tested for a few decades before the entry into a phase of maturity. Thus, aircrafts at the time of the first flight had almost 60 years of history—the first flying models were built in 1840 and the attempts to build full-size airplanes date back to 1868. It is, in fact, a classical scheme of development of any technology using new physical principles: First, a long 'incubation period' with no apparent practical results, and only then a 'great leap forward'.

### 2.2 Myth 2. Lasers cannot be used for a long time, usually they work several seconds

It is not so! In fact, chemical and solid-state combat lasers ensure continuous wave operation for minutes and tens of minutes. The next step in the development of high-power laser systems, of course, will be the implementation of a variable temporal structure of radiation in order to raise the peak radiation power for the ablation mechanism and to eliminate the effect of the screening of the target by plasma[2].

### 2.3 Myth 3. Energy of laser weapons is negligible compared to the fire arms

For comparison, the power of a 76.2-mm F-22 divisional gun (1936) is at 150 MW. This power is 150 times higher than that of the ABL! …… Besides, we ignore here the energy of the explosive in the shell, which is the same. Ponder upon this simple fact: A small ancient gun of the Second World for the price of scrap metal is hundreds of times more powerful than the ultramodern 'combat' laser weighing tens of tons and valued at over five billion USD. Only one shot from the ABL costs millions of dollars. And this shot comparable in energy with the burst of a machine-gun fire.

Such a comparison of the power achieved in 0.01 s with the power of CW light, and the 'proof' of inferiority of 'long-play' weapons (by using this comparison) contradicts even the school physics course. Let us try to compare everything in the correct way, i. e., by counting the energy sent to the target.

The muzzle energy of a 12.7 mm heavy machine gun is 15 – 17.5 kJ at a rate of 80 – 100 shots per minute. In other words, a 100 kW laser can be 'replaced' by three and a half heavy machine guns (6 000 kJ/min vs. 1750). But let us return to the gun. The muzzle energy of F-22 is 1.35 MJ, while the power of the ABL is 1.1 MW, i. e., 1.1 MJ per second. Thus, the laser shoots 48 'shells' per minute. By converting the MW power to the TNT equivalent, we will obtain 240 grams of explosives per second and 14.4 kg per minute, which corresponds to the content of 18 high-explosive shells from the same gun. However, the actual 'value' of the laser is higher. The matter is that even with accurate firing of firearms, most of the 'energy' goes not to the enemy, but dissipates. The reason for that includes a dozen factors (wind, fluctuations in humidity, air pressure and temperature, the Coriolis force, *etc.*), making the bullet or shell spread inevitable. A steady flux of photons flies to where it was sent, excluding the huge amount of unnecessary loss.

### 2.4 Myth 4. Efficiency of lasers is a few percent

In fact, the efficiency of combat lasers is about 20.6%, and this is not the limit. According to the RELI program, the efficiency is planned to be raised up to 25%. Fiber lasers, which are adapted by Raytheon for military applications, now have an efficiency of about 30%. The efficiency of firearms is 20% – 40%. At the same time, the efficiency of (smaller but steadily growing in power) solid-state diode-pumped systems is more than 50%, and soon it will approach its physical limit of 85%.

### 2.5 Myth 5. The laser beam has a huge diffraction divergence

Here we deal a physically insuperable law of diffraction, which states that the laser beam always diverges with an angle proportional to the ratio of the wavelength to the diameter of the beam. If we take a specific combat IR laser with a wavelength of 2 μm (this wavelength is typical of combat THELs, *etc.*) and a beam diameter of 1 cm, we obtain a divergence angle of 0.2 mrad (this is a small angular divergence; for example, standard laser pointers/rangefinders have a divergence angle of 5 mrad and higher). However, because of 0.2-mrad divergence the beam spot diameter will increase from 1 cm to 3 cm at a distance of 100 meters. That is, only 100 meters away the beam density will decrease (proportionally to the area of interaction) by 7 times. At a distance of a kilometer the density of the beam falls by 300 times.

Actually, a combat laser emitting a beam with the initial diameter of 1 cm is a fruit of an unhealthy imagination, not burdened with some knowledge in this area. In fact, when using the focusing optics the diffraction divergence is about $\lambda/D$, where $\lambda$ is the wavelength, and $D$ is the diameter of the mirror and also the initial beam diameter, tapering due to focusing as the beam approaches the target; a large beam diameter (meters in this case) provides a low diffraction divergence. In the case of the ABL the wavelength is 1.315 μm, and the diameter of the mirror is 1.5 m; by dividing one by the other, we obtain the divergence of about $10^6$ rad. In other words, at distance of only one kilometer the laser beam from the Boeing diverges by (oops-) 1 mm. At a distance of 200 km, the diffraction divergence will be 20 cm. The actual ABL beam divergence exceeds the diffraction limit by only 1.2 times.

### 2.6 Myth 6. One can easily be protected from laser weapons using, for example, an aluminum mirror

Yet another malapropism. Indeed, some metals may have near-100% reflection coefficients. First, however, these coefficients are not equal 100%. Thus, at a wavelength of 1 μm the reflection coefficient drops to 75% for most structural metals. A real missile after its launch will be also significantly contaminated with combustion products. Meanwhile, modern 'hyperboloids' emit light in the vicinity of 1 μm (the ABL has a wavelength of 1.315 μm). In this case, 25% of hundreds of kilowatts will be sufficient even in the cw regime to heat up and melt down the thin skin layer of the missile. Thus, reflectivity will decrease because the absorption of laser radiation increases rapidly with increasing temperature, and abruptly jumps after the start of melting. In the pulse-periodic regime the situation is even more favorable.

Besides, there arises also a 'childish' question: If the laser

Fig. 4 Water cooled mirrors

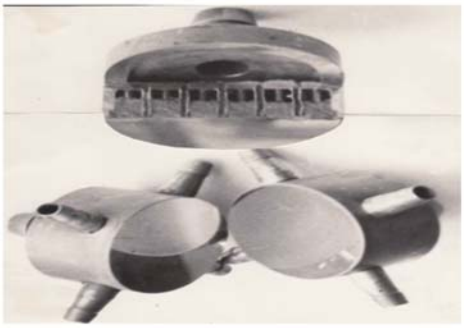

Fig. 5 Mirror with porous cooling system based on metal powder

beam can be focused and directed by a mirror, why cannot the same mirror protect us from the laser beam? In lasers use is usually made of multilayer dielectric mirrors that can reflect very much but in a very narrow range[4-5]. In other words, simple, effective and affordable protection from high-power lasers does not exist.

### 2.7 Myth 7. The problem of overheating of lasers cannot be solved

Four megawatts of heat, which can heat red-hot an aircraft and burn to the ground, are generated per each megawatt of laser power. The cooling system with the gas flow rate of 1 800 m/s (de Laval nozzle) is unable to release the generated heat from the fuselage.

In reality, the 'disposal' of the amount of heat in the megawatt units is quite trivial. Has anyone seen a red-hot diesel locomotive? Meanwhile, a decent diesel engine with a capacity of 2 MW releases more than 1 MW of heat into in the oil and cooling system. Far less easy is the problem of heat release from the limited volume of the laser weapon. In the case of a chemical ABL, the heated reaction products are simply blown out of the cavity by the well-known de Laval nozzle, and then liquid ammonia is used for cooling. Fairly cumbersome is the system with cryogenic components; however, it really is able to 'recycle' a very impressive amount of heat. Tactical solid-state lasers, which need more than 400 kW of heat to be released, do well without cryogenic refrigerators. Thus, the HELLADS makes use of a unique cooling technique; the circulation of a liquid releases excess heat outside the laser cannon. 'Remarkable also is General Atomics' advanced thermal energy storage device is capable of cooling directed energy weapons. Heat is stored in the 35 kilogram module by melting a wax-type phase change material. As a result, the HELLADS provides for the interception of missiles within two minutes at the specified cw power followed a thirty- second break.

### 2.8 Myth 8. High-power and compact energy sources for combat lasers do not exist

This is partially true: it is not yet possible to mount a 100 kW solid-state laser on anything less than a truck because of the need to have at hand a 500 kW generator and suitable capacitors. In fact, this is a real problem, which has nothing to do with fantasy. In practice, the hybrid version of the HEMTT (HEMTT A3), even in the basic version has a 350 kW generator, which can provide up to 200 kW. When the engine power is increased up to 371 kW, HEMTT A3 can produce 400 kW of continuous exportable power. A nice addition is the 1.5 MJ capacitor bank. In other words, where the bloggers fancy an electric power plant, in fact, there is a high-tech truck. However, the issue of energy in the space can be solved by other, more efficient ways.

Fig. 6 Mobile laser system

For example, well developed are nuclear power sources, solar energy, with its unlimited possibilities.

### 2.9 Myth 9. Every shot a laser is worth millions of dollars

In fact , one shot of the ABL

Fig. 7 Sketch space based laser system

costs 10 thousand USD, whereas the domestic 16 million rubles are the propaganda and exaggeration. This is comparable with the cost of a Fagot anti-tank guided-missile system. More complex anti-tank guided-missiles cost tens of thousands of dollars; for example, a Maverick air-to-ground missile for hitting targets ranging from a distance of a few thousand feet to 13 nautical miles at medium altitude costs 154 thousand USD, a Patriot missile—3.8 million USD. The cost of a shot from tactical lasers is less than from the ABL. Even in a hydrogen fluoride THEL it was 2 – 3 thousand USD; in this case, the laser used not hydrogen but deuterium which is quite expensive.

### 2.10 Myth 10. All the problems that can be solved with laser weapons, are easier and cheaper to solve by traditional means

This conclusion has already been proven to be ineffective; see, for example, at Israel's attempts to defend against missile attacks by Hamas missiles (the Iron Dome system). One interception costs 30 – 40 thousand USD. The cost of a rocket for a Grad multiple rocket launcher system is about 1 thousand USD, the cost of a Qassams rocket does not exceed 200 USD. Thus, the interception will be 40 – 200 times more expensive than the rocket launched by the enemy. In this connection Tariq abu Nazar, the Hamas spokesman, once said "if every rocket launch of our missilemen costs tens of thousands of dollars for Israelis, we will assume that the goal is achieved." As a result, some newspaper people accuse not developers of laser systems but those who are responsible for termination of the Israeli-American program. The Centurion missile defense system has not found wide application because of the short-range and great ammunition consumption.

## 3 Legends

Of course, this is not a complete list of the legends about lasers. Most of them are built on the same principle: either outrageous lie or painstaking making of a mountain out of a molehill. In fact, lasers on the battlefield are real and the army, which possesses such weapons, will receive an impressive advantage. Thus, the air force, able to actively defend against anti-aircraft and air-to-air missiles, will be much less vulnerable to air defenses. Thus, the development of laser technology is critically important not only for well developed countries. Combat lasers are an obvious asymmetrical response to the superiority of the precision weapons. The 'ideology' of the latter in a very rude manner is to ensure that instead of a dozen of shells, a guided munition (though much more expensive) is used to precisely hit a specific target, and to minimize collateral damage. However, such a scheme is particularly vulnerable to laser defense systems, which make no difference between an archaic shell for two hundred dollars and an expensive high-tech device or military equipment. The number of targets is not so great, and their cost is ten times higher than that of the most expensive laser 'shot'.

## 4 Afterword

It is already evident that the world has entered a new round of technological race. It does not depend on our wishes, it is the willing of time. Most developed countries, based on their technological advantages, are spending billions of dollars to develop high-tech next-generation lasers.

According to Japanese media, U. S. invested up to now more than 100 billion USD in the development of semiconductor laser pumping of solid-state lasers. The need to accelerate the development of high technology is the major topic of many political leader's speeches. It is important to note the opinions of Western experts, who say that today laser technology is one of the most effective ways to gain technological superiority in the world. And today, laser technology makes it possible:

(1) to provide a new level of development of industry, science and technology for your country, the revival of scientific and technological strength of the country on the basis of modern high-techs;

(2) to make your country a leader in the field of technical, scientific and technological progress;

(3) to revive a large number of enterprises in many sectors of industry, which are well known for their developments in previous years;

(4) to strengthen your country leading position in space and to ensure strategic and geopolitical priorities in the modern world; and

(5) to derive benefit from the sale of a wide range of laser programs, which is today comparable to the benefit from the sale of traditional products and resources.

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## 中文翻译：

## 1 简介

华尔街日报最近发表了一篇文章，提出反导弹机载激光器项目遇到了成本超支和延误的问题，可能会成为削减预算的牺牲品。大众传媒立刻兴奋地报道称，五角大楼拒绝开发作战激光器。然而，如果不强硬些，这种兴奋感似乎极具误导性。

如今，化学激光器已在很大范围内被二极管泵浦固体激光器所取代。五角大楼期待这些激光器，因为这些激光器比使用化学激光器更紧凑、更简单、更便宜。此外，这些激光器很可靠，与核能和太阳能很容易兼容（无需对输出电压进行任何变压），并且允许对输出参数作进一步的调整，其操作效率显然更高。诺斯罗普格鲁门公司已经提出了一种 105kW 的固体激光器，并计划大幅提高其输出功率。来自美国实验室的数据显示，目前正在开发一种 500kW 激光器样机。随后，“双曲面”将以卡车装载［高能激光技术演示器（HEL TD）计划］、船舶装载［海上激光演示器（MLD）项目］和空中机载［高能液体激光防空系统（HELLADS）；F-35、B-1、CH-47 飞机使用的一种激光器］的形式体现。另一个方向是由雷神公司提供大量资助并押注的光纤激光系统。50kW 激光武器系统（LaWS）将与对抗反舰导弹密集阵近战武器系统（CIWS）及陆基型百夫长 C-RAM 集成。此外，美国官员最近报告了自由电子作战激光器的进展情况。与此同时，我们也不应忘记一直搁置等待做出启动决定的“阿尔法”系统（输出功率为 4.5MW 的激光器）。


图 1 反导机载激光器

研发兆瓦级功率的固体激光器需要时间和大量的资源。然而，过去几年总结的战略激光系统设计经验和对实现目标强有力的信念有助于大幅加快大功率激光武器在新技术领域的工作步伐。然而，应当指出，低功率输出的战术激光系统已经在美国进行了测试，并在军队得到了应用。这一切都证明，五角大楼的专家们显然不会考虑取消这种大有前途的激光计划。我们在这里所说的是一种有效的虚假信息系统。五角大楼去年的报告“技术地平线”指的是全球“高能量武器”激增后“游戏规则”的变化，会将军事力量的传统符号变成像炮弹和骑兵那样过时的东西……。虽然美国制定了激光计划，但其他许多国家却表现出对“激光器的冷漠”。三十年前涉及到某些激光计划的不称职的博客

和伪科学工作者推测，“激光器是虚张声势”。结果，就出现了有关战斗激光器的大量谬论，认为这些都是最可笑的。

## 2 十个谬论

### 2.1 谬论 1：“作战激光器已研制了 40 年，但看不到任何进展。”

俄罗斯的一篇论文提到：“在 20 世纪 70 年代，美国人利用一架 150t 波音 707 飞机上搭载的激光器，成功击毁了小火箭。到了 21 世纪初，他们利用一架 350t 波音 747 飞机搭载的高重量、大功率激光器，成功击毁了尺寸更大的火箭。在未来 20 年间，他们将在乌克兰购买一架 640t 退役的‘安东诺夫 AN-225 Mriya’运输机，这架飞机在这里已是死亡之星[1]。是的，也许它就能击落‘飞毛腿’，甚至是‘大浦洞’。但只有在现场，只有一次，仅此而已”。

图 2 机载军用激光器

搭载激光器的‘150t 波音 707 飞机’指的是基于早期的‘707’飞机，即 1973 年经过改装的 137t 波音 KC-135 加油机。1983 年，搭载在飞机上的激光器击落了距离 5km 的数个“响尾蛇”空对空导弹和其他一些“小型”炮弹。

但实际情况怎样呢？即使 20 世纪 80 年代的‘兆瓦’连续波激光器不产生兆瓦功率的光，它们也会消耗很多的能量。2.2MW 的激光系统，被称为战术高能激光器（THEL）（‘奇迹’与‘海石’制导系统），并不具备超自然的力量。反导机载激光器具有 1.1MW 的功率，这不是消耗的功率而是光束的功率。因此，在 350t 波音飞机上搭载了‘更强大的’激光器……。然而，应该了解，激光器的实际能力不是依赖于这样的功率，而是取决于辐射密度，即不仅要求功率大，而且需要具有还很窄的光束。机载激光器的辐射密度水平为 $10^{13}$ J/sr·s。反导机载激光器的辐射水平约为 $10^{18}$J/sr·s -即高了 10000 倍。这些成就不仅仅是因功率的直线增长形成的。可以看出，过去的 30 年是对大气湍流的影响和发射光束的激光路径进行补偿的自适应光学发展极为迅猛的时期。此外，同类激光器的尺寸从根本上缩小了。最初的第一个战术高能激光器重 180t，刚刚能装入 6 辆拖车。激光器使用的氟化氢混合物会对环境造成严重的污染。第二代先进的战术激光器（ATL）工作物质为氧碘混合物［称为化学氧碘激光器（COIL）］，其体积较为紧凑。诺斯罗普格鲁门公司的新型固态激光器重为 1.5t，其中包括冷却系统。未来预计其重量将减少到 750kg。因此，陆基型系统由一个重型高机动性战术卡车（HEMTT A3）、高机动性多用途轮式战车上的指挥系统和装有 AN/MPQ-64 雷达

图 3 移动式激光器系统

的牵引式单轴挂车组成。同时，美国也在努力将激光器的连续波状态转换为脉冲周期状态，这将极大地增大其活动范围。

有关“作战激光器已研制了 40 年，但看不到任何进展”的说法，只能说明他们对技术问题的无知。突破性的技术在进入成熟阶段之前需进行几十年的试验。因此，首飞时的飞机已有近 60 年的历史，第一批飞行模型建于 1840 年，建立全尺寸飞机的尝试可以追溯到 1868 年。实际上，这是利用新的物理原理开发任何技术的一个经典方案：首先有一个很长的“潜伏期”，没有获得明显的实际效果，也只有这样才能产生一个“大飞跃”。

### 2.2 谬论 2：“激光器不能长期使用，通常只能工作几秒钟。”

事实并非如此！实际上，化学和固体作战激光器能确保连续波运转数分钟和数十分钟。当然，大功率激光系统下一步发展计划是实施辐射的可变时间结构，提高烧蚀机理的峰值辐射功率，利用等离子消除靶的屏蔽效应[2]。

### 2.3 谬论 3：“与射击武器相比，激光武器的能量可以忽略不计。”

1936 年研制的 76.2mmF-22 师属加农炮的功率为 150MW。这一功率比反导机载激光器的功率高 150 倍！……此外，我们在这里同样没有将炮弹内的爆炸性能量计算在内。思考这样一个简单的事实：一件第二世界的古代枪炮的废金属价格比重达数十吨，价值超过 50 亿美元的超现代化作战激光器高数倍。反导机载激光器仅发射一次的成本就高达数百万美元。这可与机枪一阵扫射的能量相比拟。

与连续波光功率比较，单次射击达到了 0.01 秒，‘长时间射击’武器的低劣‘证据’甚至与学校的物理课程相矛盾。让我们尝试以正确的方法，即通过计算向目标发送的能量进行比较。

12.7mm 的重机枪以 80-100 次/min 的速度射击时,枪口的能量为 15-17.5kJ。换句话说，一个 100kW 的激光器可以用三挺半重机枪（6000kJ/min）所“代替”。我们还是回到枪炮上。F-22 枪口能量为 1.35MJ，而反导机载激光器的功率为 1.1MW，即 1.1MJ/s。因此，激光器每分钟发射 48 发“炮弹”。将兆瓦功率转换成 TNT 当量，我们将获得 240g/s 和 14.4kg/min 的炸药，相当于同一枪炮 18 发高爆炮弹的重量。但是，激光器的实际“价值”也就越高。这个问题在于，即使枪炮的射击很准确，大部分的“能量”也不能射击到敌人，而是被消散。其影响因素主要有风速风向、湿度、气压和温度的波动、科里奥利力等，使子弹或炮弹不可避免地发生散射。光子的稳定通量飞到被发送的地方，不包括大量不必要的损失。

### 2.4 谬论 4：“激光器的效率为百分之几。”

事实上，作战激光器的效率约为 20.6％。根据 RELI 计划，预计效率将提高到 25％。光纤激光器的效率约为 30％，枪械的效率为 20％-40％。体积紧凑，功率稳步增加的固体二极管泵浦激光器的效率为50％以上，并且很快将接近其物理极限 85％。

### 2.5 谬论 5：“激光器光束具有巨大的衍射发散。”

这里我们采用的是物理上不可逾越的衍射定律，规定激光器光束始终以与光束波长-直径比成正比的角度发散。如果我们利用波长为 2μm（战术高能激光器的典型波长）、光束直径为 1cm 的特定作战红外激光器，我们将得到 0.2mrad 的发散角（这是小角度发散；例如，标准的激光器指针/测距仪具有 5mrad 及以上的发散角）。但是，对于 0.2mrad 的发散，光速斑点直径将以 100m 的距离从 1cm 增加到 3cm。也就是说，距离为 100m 时，光束密度将与相互作用区域成比例地减小 7 倍。距离 1km 时，光束密度将下降 300 倍。

实际上，作战激光器发射初始直径为 1cm 光束是没有掌握这方面知识的后果。事实上，使用聚焦光学器件时，衍射发散约为λ/D，其中λ为波长，D 为反射镜直径，也是初始光束直径，因波束接近目标是聚焦而呈锥形；较大的光束直径（在这种情况下为几米）提供低衍射发散。对于反导机载激光器，波长为 1.315μm，反射镜直径为 1.5m；通过计算我们得到约为 $10^{-6}$rad 的发散。换句话说，距离 1km 时，来自波音飞机的激光器光束发散仅为 1mm。距离 200km 时，衍射发散将为 20cm。实际的反导机载激光器光束发散只超过衍射极限 1.2 倍。

### 2.6 谬论 6：“一个人可以利用如铝反射镜等轻易地免受激光武器的危害。”

又是一个用词错误。事实上，一些金属可能具有近 100%的反射系数。但是，首先这些系数不等于 100%。因此，波长为 1μm 时，多数结构的金属反射系数下降到 75%。实际导弹发射后还将受到燃烧产物的严重污染。同时，反导机载激光器发出 1.315μm 波长的光。在这种情况下，数百千瓦的 25%，即使在连续波的状态下升温并熔化导弹的薄蒙皮层就已足够了。因此，反射率会因对激光辐射的吸收随着温度的升高而急剧降低，并在开始融化后突然降低。在脉冲周期状态下，情况甚至更有利。

图 4 水冷反射镜

此外，还出现了一个“幼稚”的问题：如果激光器光束可以聚焦并由反射镜引导，同一反射镜为什么不能保护我们免受激光器光束的危害呢？激光器通常是由多层介质镜组成，这些介质镜可以在严格定义的角度内反射多次 ，但仅限很窄的范围内[3]。另外，它们被冷却，不可能发射到目标的整个表面上。换句话说，对大功率激光器简单、有效的防护是不存在的。

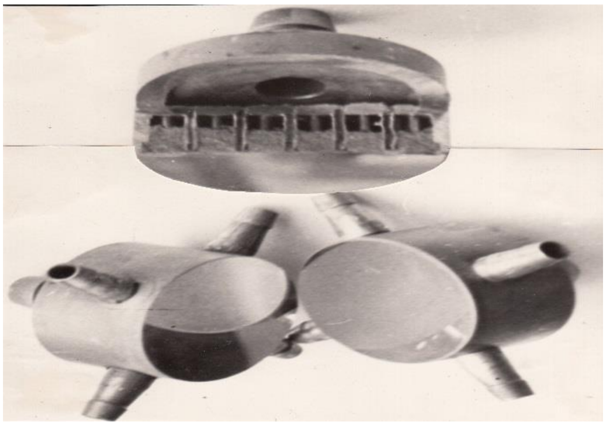

图 5 多孔冷却系统反射镜

### 2.7 谬论 7：“激光器过热问题不可能得到解决。”

可以加热使飞机燃烧落地的 4MW 热量，是由每 1MW 的热量产生的。气体流速为 1800m/s（德拉伐尔喷嘴）的冷却系统不能释放机身上所产生的热量。

在现实中，热量（MW）“处理”是微不足道的。有人见过烧红的内燃机车吗？同时，一台容量为 2MW 的柴油发动机，将 1MW 以上的热量释放到油和冷却系统中。释放激光武器有限体积内的热量是较为困难的问题。对于化学反导弹机载激光器，加热的反应产物通过已知的德拉伐尔喷嘴被直接从空腔内吹出，然后利用液态氦进行冷却。低温部件的系统比较麻烦。然而，这种系统确实能进行热量‘循环’。需要释放 400kW 以上热量的作战固态激光器，可以在不使用低温“制冷器”的情况下良好工作。因此，高能液体激光防空系统采用了独特的散热技术；液体的循环将多余的热量释放到“激光炮”以外。另外，值得注意的是，可冷却定向能武器的通用原子先进的热能储存装置。热量通过熔化蜡式相变材料储存在 35kg 的模块中。因此，高能液体激光防空系统在 30s 的间歇后以规定的连续功率在 2min 内提供导弹拦截。

### 2.8 谬论 8：“作战激光器的大功率紧凑型能源是不存在的。”

该论断中部分是真实的。100kW 固体激光器只能安装在卡车上，因为需要配套一个 500kW 发电机和适用电容器。实际上，这是一个现实问题，不存在任何幻想。在实践中，对于混合型的重型扩展机动性战术卡车（HEMTT A3），即使是基本型的，也需要有一个 350kW 发电机，可以提供高达 200kW 功率。发动机功率提高到 505 马力时，HEMTT A3 可产生 400kW 的连续输出功率，需要增加一个 1.5MJ 电容器组。换句话说，博客所谓的发电厂，实际上就是一辆高科技卡车。然而，能源问题可以通过其它更有效的方法进行解决。例如，研制核动力源、太阳能，这具有无限的可能性。

图 6 移动式激光系统

### 2.9 谬论 9：“发射一次激光价值数百万美元。”

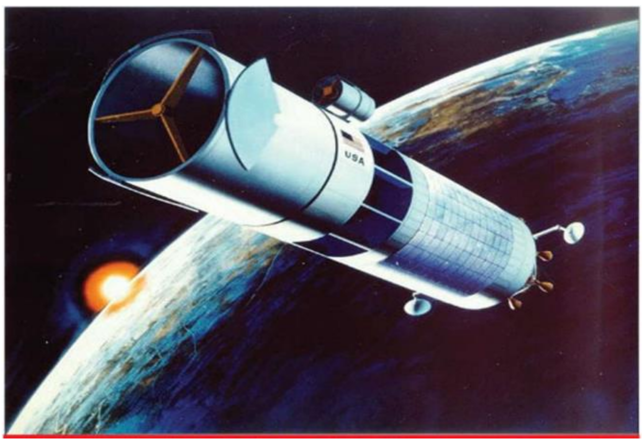


图 7 空基激光系统示意图

事实上，反导弹机载激光器每发射一次激光的费用为 1 万美元，而 1600 万卢布的说法是夸张的。这可与“柴捆”（Fagot）反坦克导弹系统的成本相比较。更复杂的反坦克制导导弹费用为数万美元。例如，打击目标的范围从中高空的几千英尺到 13 海里距离的特定空对地导弹的费用为 15.4 万美元，爱国者导弹为 380 万美元。作战激光器每发射一次的成本低于反导弹机载激光器。即使是氟化氢

战术高能激光器，费用也就是 2000-3000 美元。在这种情况下，反导弹机载激光器使用的不是氢，而是重氢，这是相当昂贵的。

### 2.10 谬论 10：“激光武器可以解决的所有问题，通过传统手段来解决都比较简单且价格低廉。”

这一结论已被证明是无效的。例如，以色列试图通过哈马斯导弹（“铁穹”系统）防御导弹攻击，一次拦截的成本为 30000-40000 美元。Grad 多级火箭发射架系统的火箭成本大约是 1000 美元，“卡桑”火箭的成本不超过 200 美元。因此，拦截成本比敌人发射火箭的成本高 40-200 倍。在这方面，哈马斯发言人塔里克·阿布·纳扎尔曾说过：“每发射一枚火箭花费以色列数万美元”。因此，一些报界人士不是指责激光系统开发商，而是那些负责终止以色列-美国合作计划的人员。由于距离短和弹药消耗量巨大，百夫长导弹防御系统而没有得到广泛的应用。

## 3 传说

当然，这不是关于激光器传说的全部内容。他们中的大多数都建立在相同的原则基础上：无论是离谱的谬论还是潜心制作的小题大做。其实，激光器在战场上是真实的，而拥有这种武器的军队将具有令人印象深刻的优势。因此，空军能主动防御防空和空对空导弹，大大减少空防弱势。所以，激光技术的发展不仅仅对发达国家是至关重要的。作战激光器是对精确武器的优越性做出的不对称回应。后者是要保证制导导弹（虽然昂贵得多）而不是十几枚炮弹精确打击特定目标，并最大限度地减少附带损害。但是，这种精确武器特别容易受到激光防御系统的攻击，使两百美元的古老炮弹与昂贵的高科技装置或军事设备没有区别。目标的数量并非那么大，其成本比大多数激光“发射”高出 10 倍。

## 4 后记

显而易见，世界已进入了新一轮技术竞赛。它不以我们的意志为转移，而是取决于时间。大多数发达国家正在根据自己的技术优势，花费数十亿美元来发展基于高新技术的下一代激光器。据日本媒体报道，美国至今在半导体泵浦固态激光器发展方面的投资超过 1000 亿美元。加快高新技术发展是许多政治领袖演讲的主要话题。西方专家认为今天的激光技术是获得世界技术优势最有效的方法之一。而在今天，激光技术使人们有可能：

（1）基于现代科技促进国家工业、科学和技术的发展跨上一个新台阶，实现国家科学和技术力量的复兴；

（2）使国家处于技术、科学和技术进步领域的领先地位；

（3）重振工业部门的大量企业，它们在过去数年的发展是众所周知的；

（4）加强国家在空间领域的领先地位，确保国际战略和地缘优势；

（5）从激光计划中获得利益，这是可与从传统产品和资源获得的利益相比拟的。