DOI 10.15302/J-SSCAE-2017.05.013

Prospects for the Promotion and Application of Defense Disruptive Technology in Developing the Space Industry

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Abstract: This paper begins by making a qualitative selection of defense disruptive technologies. It considers the features of various defense disruptive technologies and establishes an index evaluation system to carry out a quantitative analysis of the major ones. Based on this, this paper identifies major defense disruptive technologies that can have a huge impact on the space industry. These are expected to greatly improve the efficiency of the space industry, significantly reduce research cost, and lead to a considerable improvement in the current level of space technology.

Keywords: disruptive technologies; space; efficiency; cost

1 Overview of disruptive technology

Disruptive technology (DT) is that which for a different approach is used and which will exert a disruptive effect on existing traditional or mainstream technological approaches. From the perspective of technical attributes, DT can be an original innovation based on a new principle, integrated innovation based on existing technology, or transfer and innovative application of a mature technology.

DT emphasizes the effect, that is, the action effect of such technology, of its disruptiveness. Therefore, a DT is not necessarily a new technology, but may be a new application with a disruptive effect. The space industry is a high-tech field integrated with many disciplines. Space activities involve materials, electronic information, manufacturing, energy, medicine, and many other disciplines, hence disruptive technologies have application potential in the space industry. Disruptive space technology needs to be evaluated from the perspective of overall system performance improvement.

Disruptive space technology is a transformative technology that can greatly improve the efficiency of space systems or significantly reduce research costs. With features of innovativeness, perceptiveness, breakthroughs, and profound influence, it is also a technology that will have an important influence on the space industry, space science research, and even in the military space sector.

2 Qualitative selection and quantitative analysis of DT

2.1 Qualitative selection of DT

Twelve major areas of disruptive technologies have been determined by means of information investigation, questionnaire survey, discussion, and interviews.

Fifty disruptive technologies were selected by consulting, sorting, and analyzing nearly 50 research reports from 2009 onwards, both at home and abroad [1–3]. Questionnaires regarding these 50 technologies were distributed to experts for them to judge, accept, reject or add to. In total, 82 questionnaires were

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Received date: August 3, 2017; **revised date:** September 25, 2017

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Funding program: CAE Advisory Project "Prediction Research On Major Disruptive Technologies that Cause Industrial Change" (2016-ZD-12)

Chinese version: Strategic Study of CAE 2017, 19 (5): 074–078

Cited item: Luan Enjie et al. Prospects for the Promotion and Application of Defense Disruptive Technology in Developing the Space Industry. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2017.05.013

distributed and 75 responses gathered. Twenty-five technologies were selected and ranked after statistical analysis. Finally, 12 major disruptive technologies were chosen by focusing on the technology, deep analysis, and comprehensive integration by means of meetings, expert seminar and interview, and internal discussion.

These 12 technologies are quantum technology, terahertz technology, graphene technology, negative-refractive-index materials technology, autonomous and unmanned technology, cyberspace technology, super-high energetic materials technology, and brain-computer interface technology, additive manufacturing technology, directed-energy technology, counterspace technology, and hypersonic vehicle technology.

2.2 Quantitative analysis of DT

The establishment of a DT-index appraisal system is conducive to performing quantitative research into disruptive technologies, and finding new methods for analysis.

2.2.1 Composition of DT index system

The index system is composed of the primary index, secondary index, and index weight.

Technology basement, paradigm, performance, application, and technical restriction are taken as the primary index in the appraisal system. Technology basement index—B (basement) indicates technology input and R&D. Technology paradigm index—F (form) indicates the approach to realizing and implementing emerging technology. Technology performance index—P (performance) indicates the technical characteristics. Technology application index—S (scale) indicates the scale and influence of the application, and technology restriction index—R (restrict) indicates the possibility of technology implementation. If T (technology) is used as the evaluation for a certain DT, the function of T is established preliminarily and simplified, i.e. $T=f(B, F, P, S, R)$.

For 5 primary indexes B, F, P, S, R, 18 secondary indexes B_i, F_j, P_k, S_l, R_m are set, of which $i=1, 2, 3, 4, 5, 6$; $j=1, 2, 3$; $k=1, 2, 3, 4, 5$; $l=1, 2$; $m=1, 2$; each can be scored quantitatively, as shown in Table 1.

The weight is set preliminarily to define its scope. Technology "basement" is a macro-level index with strong subjectivity, and its weight can be lowered; for the technology paradigm index, its weight is reduced; technology performance is the core index, and its weight is increased; technology application is the prediction for the future, and its weight is decreased. The final index weight setting is shown in Table 2.

The shared weight for F_1, F_2, F_3 is 0.08.

Table 1. Secondary index of DT-index appraisal system.

Primary index	Secondary index	Meaning of secondary index
Basement	National strategic policy (B_1)	Frequency of technology occurrence in technical strategic planning, technical vision, and technology roadmap issued by the state and all services
	Think-tank strategic policy (B_2)	Frequency of technology occurrence in technical documents and reports issued by well-known think-tanks or consultation agencies
	Commercial strategic policy (B_3)	Frequency of technology occurrence in DT documents and reports issued by news media and commercial institutions
	Number of research institutions (B_4)	Number of state-owned institutions developing the technology
	Number of industrial companies (B_5)	Number of defense industry companies and commercial companies developing the technology
	Number of universities (B_6)	Number of universities developing the technology
Form	New scientific principle (F_1)	Novelty of brand-new scientific principles adopted by the technology
	Application of existing principle (F_2)	Re-application feasibility of existing scientific principles of the technology
	Technical integration (F_3)	Technical integration effect
Performance	Damage and destruction performance (P_1)	Upgrade rate of damage and destruction performance and other key indexes compared with existing technologies
	Speed and dimension performance (P_2)	Upgrade rate of speed and dimension and other key indexes compared with existing technologies
	Technical performance in electronic information field (P_3)	Upgrade rate of key indexes of related technologies in electronic information field compared with existing technologies
	Technical performance in biological/brain field (P_4)	Upgrade rate of key indexes of related technologies in biological/brain field compared with existing technologies
	Technical performance in energy, power, material fields (P_5)	Upgrade rate of key indexes of related technologies in energy, power, material fields compared with existing technologies
Scale	Military (S_1)	Number of potential military applications
	Civilian and commercial (S_2)	Number of potential non-military applications
Restrict	Technical possibility (R_1)	Possibility for implementation, current restrictions
	Technical rate (R_2)	Rate for implementation, or expected time spent

Firstly, weighted sums of each secondary index in the primary index of a DT were computed, and then the scores of the 5 primary indexes were added together to get the score of the DT, as follows:

$$T=f(B, F, P, S, R)=\sum(B_iW_{Bi}, F_jW_{Fj}, P_kW_{Pk}, S_lW_{Sl}, R_mW_{Rm})$$
$$=\sum B_iW_{Bi}+\sum F_jW_{Fj}+\sum P_kW_{Pk}+\sum S_lW_{Sl}+\sum R_mW_{Rm}$$
$$(i=1, 2,\ldots, 6;\ j=1, 2, 3;\ k=1, 2, 3, 4, 5;\ l=1, 2;\ m=1, 2)$$

2.2.2 Verification of DT index system

This index appraisal system can be used to calculate the scores of 12 major disruptive technologies and five typical non-disruptive technologies. The sensitivity and rationality of the index system could be verified by comparing the computed scores.

The five non-disruptive technologies include, oil made from seawater, aluminum combustion chamber technology, nuclear thermal rocket technology, guided bullet technology and adaptive variable cycle engine technology, whose scores are 2.68, 2.93, 1.87, 2.06, and 3.05 respectively.

The scores of 12 major disruptive technologies are between two and five. The technology with the highest scores among the 12 major disruptive technologies under development is brain-computer interface technology, with a score of 4.607. The technology with the lowest score among 12 major disruptive technologies was counterspace technology, with a score of 2.537 (the full score is 5 points).

Fig. 1 shows the scores of the five non-disruptive technologies and 12 major disruptive technologies.

The scores of disruptive and non-disruptive technologies are relatively concentrated, reflecting the sensitivity of the index system. The relatively high scores of the disruptive technologies show that, in general, the index appraisal system has rationality.

Of the disruptive technologies, brain-computer interface technology has the highest scores. It has received significant attention in various countries and has been given considerable focus, with a clear technology application prospect and a wide range of applications. The technology with the next-to-last score in 12 disruptive technologies was counterspace technology, which obtained a low score in the technical performance index, affecting the final scores. Hypersonic vehicle technology, with the lowest overall score, obtained a low score in the technology paradigm because it is an earlier mature technology principle (1938) and had a slow technology upgrade rate, thus affecting the final score.

3 Application of DT in space sector

Among the 12 major disruptive technologies currently under development, quantum technology, graphene technology, terahertz technology, additive manufacturing technology, and hypersonic vehicle technology have considerable application prospects

Table 2. Index weight setting.

Index	B						F		
Secondary index	B_1	B_2	B_3	B_4	B_5	B_6	F_1	F_2	F_3
Weight	0.04	0.03	0.02	0.03	0.03	0.03		0.08	

Index	P					S		R	
Secondary index	P_1	P_2	P_3	P_4	P_5	S_1	S_2	R_1	R_2
Weight	0.08	0.08	0.12	0.12	0.1	0.05	0.05	0.07	0.07

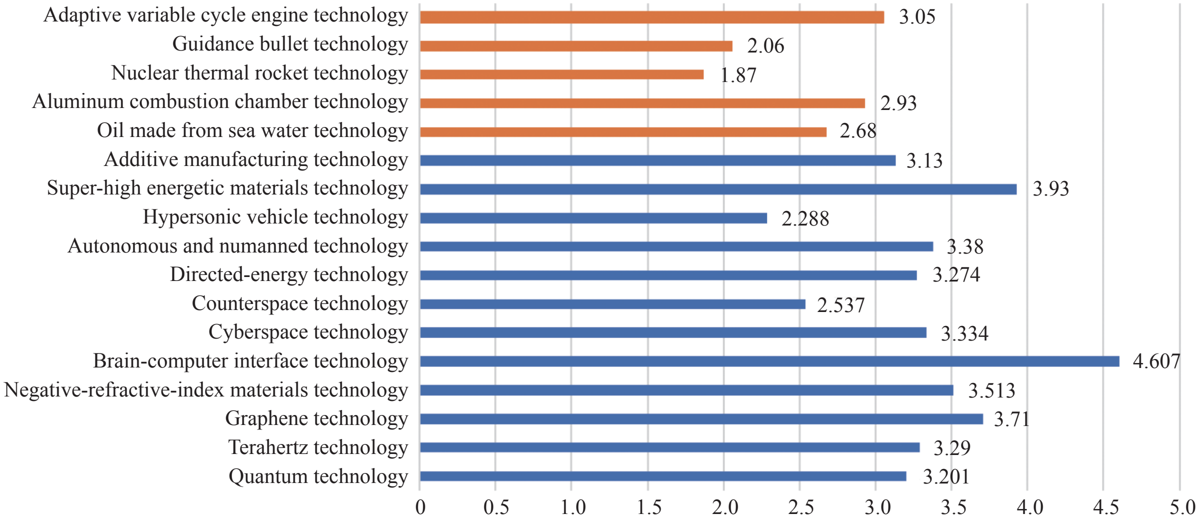

Fig. 1. Scores of the five non-disruptive technologies and 12 major disruptive technologies.

in the space sector. According to their technical characteristics, these technologies can be divided into three categories:

3.1 The new discovery and new application of quantum and graphene technologies are expected to greatly improve system performance

Quantum technology is a technical application based on quantum theory, which mainly includes quantum communication, quantum calculation, and quantum precision measurement. Quantum communications, utilizing the quantum state of the photon to load and transmit information with large throughput capacity and fast transmission speed, is another revolution in the history of communications, after the telephone and optical communications. It can realize key distribution and is resistant to any hacking because of its inseparable single photon as the information carrier and non-cloning quantum state, thus ensuring its encrypted information cannot be deciphered. Quantum communications between satellites and the ground can be realized in the future space sector as an important link in the wide-area quantum communications system. Quantum computation can realize a leap in computing power using the superposition property of the quantum state. It has a parallel calculating ability that is missing in classic computation and can accelerate some important classic algorithms (Fig. 2), providing a brand-new method of solving large-scale computing problems. Quantum precision measurement combines traditional physical principles with the quantum effect. It can greatly increase the precision or sensitivity of measurement. For example, a quantum inertial system composed of gyroscopes, accelerometers, and atomic clocks using quantum technology may replace satellite navigation or traditional inertial navigation.

Graphene is a 2D crystal (Fig. 2) spun off from graphite materials, composed of carbon atoms with a thickness of only one layer of atoms and featuring semiconductor and metal properties. It is a new type of material of the thinnest and toughest nanometer size with the highest electrical and thermal conductivities and is prominent in mechanical, electrical, thermal, and optical performance; it is regarded as the “King of New Materials.” Graphene is expected to replace silicon as the base material of the next generation of electronic components, and to be applied in high-performance integrated circuits and new Nano-electronic devices. In the space sector, graphene materials may be used to make a “space elevator” cable up to tens of thousands of meters long. Moreover, graphene can also be widely applied in new rockets and carbon-fiber vehicle shells and in other fields.

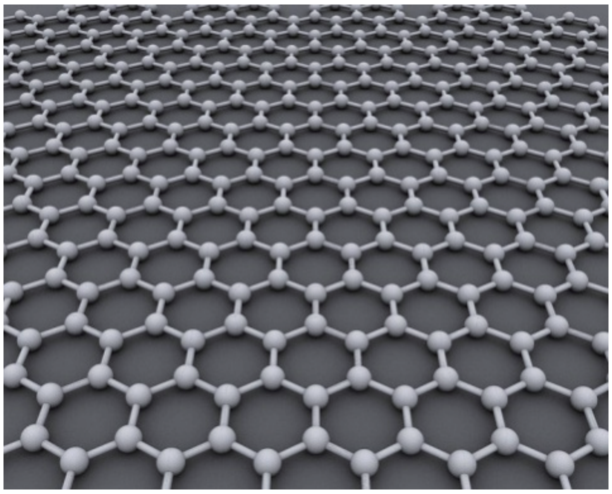

Fig. 2. Microstructure of graphene.

3.2 The innovative applications represented by terahertz and additive manufacturing technologies enable a leapfrog progress of subsystems and components

Terahertz is an electromagnetic band between microwave and infrared. It has unique characteristics different from other electromagnetic waves. However, in the last century, there was no effective detection and generation method for Terahertz. In this century, with the development of Terahertz wave source devices, amplifiers, and power devices, Terahertz is widely applied.

For example, because the wavelength is shorter than that of microwaves, a terahertz radar can detect a smaller target and effectively counteract the stealth technology that is effective only in a specific frequency range, which brings a new breakthrough to the anti-implicit technology. Terahertz is suitable for high-speed data communication and communication in the space environment as it has the advantage of wave bandwidth. Terahertz wave can be transmitted without loss in outer space. On one hand, the transmission rate of data communication between satellites can reach 25 to 250 Gbit/s. Even if the transmission rate is 25 Gbit/s, it is 27 times that of the current microwave bandwidth. On the other hand, the wave beam is wide so can be easily aligned enabling miniaturization and planarization of the antenna system.

Additive manufacturing (3D digital printing) technology is an innovative technology that turns a digital model into a 3D entity by increasing materials layer by layer, which is completely different from the traditional material decreasing, processing and forming manufacturing concept, thoroughly changing the traditional manufacturing technology path. In the space sector, additive manufacturing technology has been applied, providing technical means for realizing in-orbit maintenance of spacecraft. It is expected to realize in-situ manufacturing in space as a large structure would be difficult to be transported by carrier rocket [4]. For example, the required parts can be made directly on the space station without relying on carrier rockets and spaceships to transport the parts produced in advance on the ground to the space station (Fig. 3). Additive manufacturing technology is expected to be the main manufacturing mode of in-situ manufacturing in space, providing support for space stations, manned

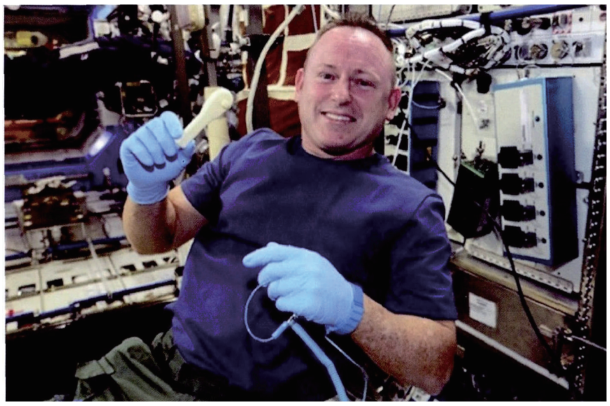

Fig. 3. An astronaut in the International Space Station shows the socket wrenches produced using additive manufacturing technology.

lunar-landings, manned Mars landing, and other manned space missions in the future. In addition, the technology provides a new manufacturing method for small parts of launch vehicles and satellites. For example, during the development of the Space Launcher System (SLS) heavy rocket in the United States, additive manufacturing technology is widely used to produce parts, such as the injector, turbine pump, and exhaust cover plate of the core level and upper-level engine. In 2014, Aerojet Rocketdyne successfully used this additive manufacturing technology to produce the MPS-120 modular propulsion system that can be used for CubeSat propulsion and conducted ignition tests.

3.3 The technical integration and innovation represented by hypersonic vehicle technology provides a new technical approach for system-level and task-level space system frameworks

Hypersonic vehicle technology is a comprehensive system of technological innovation enabling flight at fine times the speed of sound, integrated with aerodynamic, structures, propulsion, thermal protection, guidance control, and several other technologies. The vehicle powered by a hypersonic air-breathing engine or composite engine, which can realize long-range flight at hypersonic speed in the atmosphere, near space and in the trans-atmosphere, is the strategic target of aerospace technology. As a hypersonic vehicle is further development and combined with other space technology, the long-standing sky flight dream—taking off from the runway and flying directly into space—will be achieved. Airborne craft will be able to freely maneuver in and out of the atmosphere. They can perform various space tasks, such as low-cost air transportation, quick response to launch or recycle satellites, anti-satellite operations, and reconnaissance and surveillance. The technology enables rapid and precision strikes globally, opening up a new technical approach and new method of safer, more reliable, economic, and rapid access to space.

4 Conclusions

DT in the field of space has gradually experienced three stages: unique technology, leading technology, and sharing technology. The development of such technology is characterized by highly cross function, convergence, and collaboration. In the new round of scientific and technological revolution, the trend of technology convergence among industries is becoming more and more obvious. Technological advances and breakthroughs in other industries will profoundly drive the development of disruptive technologies. The development of DT in the field of space can fully absorb technological breakthroughs and achievements in other industries.

At the same time, the research on the disruptive technologies, such as quantum, terahertz graphene, additive manufacturing technologies show: ① DT in the field of space has significant influence and drives the development of components, systems, and subsystems; ② DT is mainly used in several critical fields, such as information, power, and material manufacturing. Therefore, counterspace [5], space transportation, and deep space exploration will become major breakthroughs in the future.

China, as an important force in the field of space technology, needs to accelerate technological innovation in the future more than other countries. Therefore, improving the ability of independent innovation has become a very urgent strategic task. The development of DT has become an important driving force in the space industry. Pre-deploying and developing disruptive technologies helps improve the international competitiveness of the space field and guarantee the sustainable development of enterprises.

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