SPACE
{Editorial Insights}

Space Engineering and Technology

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Abstract: Space engineering and technology encompasses the leading-edge development of advanced engineering systems that push the frontiers of technology to allow humans to explore beyond the earth's atmosphere and eventually the entire cosmos. First, the readers are provided with an introduction to the scope of space engineering and technology, and the history of space technology development. Next, the research and development areas of current interests and higher priorities are elaborated. Finally, some suggestions for future space and technology development are offered.

Keywords: Space, Engineering, Technology Development, Space Exploration, Space Travel, Cosmos.

Introduction

Space engineering and technology is a specialized field that focuses on the generation of concepts, design, development, building and construction, testing, launch, deployment, control, and operation of space systems and technologies related to space exploration, satellite communications, and space-based research and development. Space engineering is different from other engineering fields because it demands a higher level of technical expertise and specialized knowledge of the unique challenges and conditions that exist only in the space environment. These challenges and conditions include various gravity levels from microgravity, reduced gravity, and then to hyper gravity, extreme temperature fluctuations, the vacuum of space, solar thermal radiation, high levels of nuclear radiation, and the constraints to design systems that can function independently in space without the support of Earth-based infrastructure. So far, space research and development has made significant contributions in scientific, engineering, and economic advances, including the development of satellite communications, GPS and other global navigation systems, Earth observation satellites, human spaceflight and robotic exploration of the solar system.

The extension of human space exploration from a low earth orbit to a high earth orbit, then to Moon, Mars, and possibly asteroids and moons of other planets is NASA's biggest challenges for the new millennium. A major integral part to this is space engineering and technology that enables human space travel and exploration.

Engineering and technology for space is important because it enables us to explore and understand the universe in which we live. Space engineering and technology play a vital role in our ability to study other planets and celestial bodies, gather scientific data about the universe, and advance our understanding of the laws of physics and the nature of the cosmos.

Space-based technologies are on the rise. As we have evidenced for the past sixty years, satellites have enriched our life by transforming our capability to monitor, navigate and communicate across the globe. However, the satellite overpopulation in valuable lower earth orbits has become a concern. And future space-based stations, solar stations, space travel and research spacecraft will only increase the volume of space activities. In this article, we will address the directions and options of space research and technology development for the optimal design, building, operation, and management of space-based technologies to facilitate a healthy, productive, and sustainable space environment.

Space technology, encompassing the tools and techniques utilized for exploration and operations beyond Earth's atmosphere, has revolutionized our understanding of the universe and significantly impacted daily life on our planet, contributing to advancements in communication, navigation, weather forecasting, and scientific research, while simultaneously presenting complex challenges and ethical considerations regarding its development and use.

With the rapid development of science and technology, our understanding of the universe and our place in it is constantly expanding. As we explore new frontiers in space, we are also developing new technologies that can be used for a variety of applications here on Earth. In this essay, we will discuss the role of space technology in our lives and how it is changing the way we live and work. We will also explore some of the challenges associated with space technology and how we can overcome them.

History of Space Technology Development

The history of space technology development is closely related to space exploration activities. It began with the early visionaries who first dreamed of reaching the moon, planets and stars. Those forerunners have continued through the years with the development of infrastructures of space exploration technologies.

The first giant step in space technology was the successful launch of the world’s first man-made satellite, Sputnik 1, by the Soviet Union in 1957. This first move was almost immediately followed by the launch of Explorer 1 by the United States in 1958, which marked the beginning of the Space Race between the two superpowers during that era. In 1961, Yuri Gagarin became the first human being to journey into space aboard Vostok 1. On May 5, 1961, astronaut Alan Shepard became the first American — and the second man — to travel in space when he launched a 15-minute, sub-orbital flight aboard NASA's Mercury spacecraft Freedom 7. John Glenn was the third American in space and the first American to orbit the Earth, circling it three times in 1962. While in 1969 Neil Armstrong made history as the first man to walk on the Moon. In fact, during nine Apollo missions, 24 astronauts (all Americans) went to the Moon, and 12 of them walked on it. The last crewed mission to the Moon was Apollo 17, taking place between 7 and 19 December 1972. It was a 12-day mission and broke many records, the longest space walk, the longest lunar landing and the largest lunar samples brought back to Earth. As space technology continued to evolve, Appollo program was followed by the Space shuttle program. From the first launch on April 12, 1981, to the final landing on July 21, 2011, NASA's space shuttle fleet flew 135 missions and helped construct the International Space Station (ISS). The ISS is a multi-nation construction project that is the largest single structure humans ever put into space. The ISS is a testament of space technology at its best. The construction of ISS began in 1998 and the first long-term residents, Expedition 1, arrived on 2 November 2000. So far, more than 270 astronauts have visited ISS. As NASA and commercial companies continue to push the space technology fronts, human space exploration would soon be knocking on Martians’ door.

Areas of Interest and Importance

A part of the primary goal of this journal is to faithfully, rigorously, and extensively document significant achievements in space engineering and technologies along with applications. Also, we hope to lead the rapid integration and technological breakthroughs of interdisciplinary work in the space field, and to build a high-level academic platform for discussion, cooperation, technological progress and information dissemination among researchers, professional engineers, and scientists. The articles we publish will advance mankind’s exploration of the frontiers of space and witness the vigorous development of space engineering and technology.

All manuscripts addressing the aspects of research and development of space engineering and technology that enable spaceflight, space habitation, and space exploration, and also facilitate the operation in space environments, including planetary surfaces are welcome. Examples are given below:

- Spacecraft system design
- Space guidance, navigation and control
- Power and propulsion in space
- Advanced materials for space applications
- Robotics and AI in space
- In-space manufacturing
- Space environmental control and life support systems
- Space transformative and disruptive technologies
- Efficient and safe utilization of cryogenic propellant fluids in thermal management, power and propulsion, and life support systems of a spacecraft during space missions
- Cryogenic propellant fluid and thermal management
- The transport, handling, and storage of cryogenic fluids in reduced gravity and microgravity conditions
- Cryogenic fluid long-term storage in space
- Materials science and manufacturing for space technology
- In-situ resource utilization on moon and mars
- Space biotechnology and applications
- Rocket propulsion and Combustion
- Space environmental monitoring and contamination control
- Sustainable space exploration, environmental impact, and responsible resource management
- Space traffic management and control
- satellite communication and positioning, such as space cybersecurity, on board data handling,
- space environment surveillance and tracking, such as moving object detection and characterization
- in-orbit manufacturing and construction
- in-orbit refueling, space docking systems
- Space pollution reduction and clean up: recycling, debris remediation and removal
- Space waste treatment technology
- space pollution treatment, including light pollution, dust pollution
- Space eco-system design
- sustainable propulsion, including propulsion sensors, fuels, deflection

In July 2024, NASA published a report entitled: Civil Space Shortfall Ranking 2024 (https://www.nasa.gov/wp-content/uploads/2024/07/civil-space-shortfall-ranking-july-2024.pdf)
This comprehensive document identifies and prioritize nearly 187 critical technology areas spanning 20 technology categories that require further development to support future space exploration, science missions, and other stakeholder needs. The ranking integrates input from a wide range of stakeholders across the aerospace community, marking a significant step towards aligning technology development efforts and investments. The top 100 areas are listed below for your reference.

1. **Advanced Habitation Systems -** Environmental Monitoring for Habitation, Fire Safety for Habitation, Radiation Countermeasures (Crew and Habitat), Radiation Monitoring and Modeling (Crew and Habitat), Food and Nutrition for Mars and Sustained Lunar habitation., Water and Dormancy Management for Habitation, Crew Medical Care for Mars and Sustained Lunar, EVA and IVA Suit System Capabilities for Mars Missions, Earth Independent Human Operations within Habitat Elements, Logistics Tracking, Clothing, and Trash Management for Habitation, Crew Health Countermeasures – Non-Exercise, Crew Exercise and Sensorimotor Countermeasures.

2. **Advanced Manufacturing -** In-Space and On-Surface Manufacturing of Parts/Products from Surface and Terrestrial Feedstocks.
3. **Advanced Materials & Structures -** Micrometeoroid-Robust Protection of In-space Observatories, Thermal and Vibrational Isolation for ultra stable Science Payloads,
4. **Autonomous Systems & Robotics -** Robotic Actuation, Subsystem Components and System Architectures for Long-Duration and Extreme Environment Operation, Robust, High-Progress-Rate, and Long-Distance Autonomous Surface Mobility, Autonomous Guidance and Navigation for Deep Space Missions, Sensing for Autonomous Robotic Operations in Challenging Environmental Conditions, Robotic Mobile Manipulation for Autonomous Large-Scale Logistics, Payload Handling, and Surface Transport, Metrics and Processes for Establishing Trust and Certifying the Trustworthiness of Autonomous Systems, Autonomous Planning, Scheduling, and Decision-Support to Enable Sustained Earth-Independent Missions, General-Purpose Robotic Manipulation to Perform Human-Scale Logistics, Maintenance, Outfitting, and Utilization, Autonomous Vehicle, System, Habitat, and Infrastructure Health Monitoring and Management, : Robotic Mobility for Robust, Repeatable Access To and Through Extreme Terrain, Surface Topography, and Harsh Environmental Conditions, Intelligent Multi-Agent Constellations for Cooperative Operations, : Intuitive and Efficient Human-Robot Interaction for Safe Teaming and Remote Supervisory Control, Robust Robotic Intelligence for High-Tempo Autonomous Operations in Dynamic Mission Conditions.
5**. Avionics -** High Performance Onboard Computing to Enable Increasingly Complex Operations, Extreme Environment Avionics, Foundational Technologies for Future Avionics Devices and Systems, Next Generation Avionics Architectures.
6. **Communication & Navigation -** Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications, Deep Space Autonomous Navigation, High-Rate Communications Across the Lunar Surface, High-Rate Deep Space Communications.
7. **Cryogenic Fluid Management -** In-space and On-surface, Long-duration Storage of Cryogenic Propellant, In-space and On-surface Transfer of Cryogenic, Fluids, Prediction Modeling of Cryogenic Fluid Dynamics and Operations, Cryogenic Liquefaction.
8. **Dust Mitigation -** Passive Dust Mitigation Technologies for Diverse Applications, Active Dust Mitigation Technologies for Diverse Applications, Advanced Modeling and Test Capabilities to Characterize Dust Effects on Hardware.
9. **Entry, Descent & Landing -** High-Mass Mars Entry and Descent Systems, Navigation Sensors for Precision Landing, Terrain Mapping Capabilities for Precision Landing and Hazard Avoidance, Advanced Algorithms and Computing for Precision, Landing, Entry Modeling and Simulation for EDL Missions, Aerocapture for Spacecraft Deceleration and Insertion, Assessment and Validation Capabilities for Integrated Precision Landing Systems, Characterization of Plume Surface Interaction.
10. **Excavation, Construction & Outfitting -** Robotic regolith manipulation and site preparation, Excavation of granular (surface) regolith for ISRU commodities production.
11. **In-Situ Resource Utilization -** Extraction and separation of water from extraterrestrial surface material, Perform resource reconnaissance to locate and characterize resources and estimate reserves, Extraction and separation of oxygen from extraterrestrial minerals, Produce propellants and mission consumables from extracted in-situ resources,
12. **In-Space Servicing, Assembly & Manufacturing -** Broad and dependable supply chain for space-qualified robotic hardware, electronics, and associated software, Surface Mating Mechanisms, In-Space Transfer of Electric Propulsion Propellant, Enable commercially-provided Rendezvous, Proximity Operations, and Capture (RPOC) products and services, In-Space & Surface Transfer of High-Pressure Gases
13. **Orbital Debris -** Mitigation of New Orbital Debris Generation, Remediation of Small Debris.
14. **Power -** High Power Energy Generation on Moon and Mars Surfaces, Power Management Systems for Long Duration Lunar and Martian Missions, Power for Non-Solar-Illuminated Small Systems, High-Power, Long-Distance Energy Transmission Across Distributed Surface Assets, Power and Data Transfer in Dusty Environments, Energy Storage to Enable Robust and Long Duration Operations on Moon and Mars.

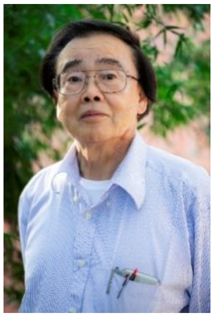
15. **Propulsion -** Nuclear Electric Propulsion for Human Exploration, Nuclear Thermal Propulsion for Human Exploration, Solar Electric Propulsion - High Specific Impulse, Mars Ascent Vehicle Propulsion, Sub-kW and kW Class Electric Propulsion Systems.
16. **Sensors & Instruments -** Advanced Sensor Components: Imaging, Situational Awareness Sensors and Tools for Astronauts, Quantum Sensors That Use Atoms, Ions, and Spins, Quantum Sensors That Use Photons.
17. **Small Spacecraft -** Small Spacecraft Propulsion, Autonomy, Edge Computation, and Interoperable Networking for Small Spacecraft, Access Beyond LEO for Small Spacecraft, Rendezvous, Proximity Operations, and Debris Remediation using Small Spacecraft.
18. **Surface Systems** - Surface-based lunar logistics management for near/mid-term missions, Surface-based food management for sustained lunar evolution, Surface-based fluid management for sustained lunar evolution, Surface-based fluid management for near/mid-term missions, Surface-based lunar logistics management for sustained lunar evolution, Autonomous on-surface maintenance and repair for sustained lunar evolution, Common tools for on-surface maintenance and repair for reduced crew interaction, Dissipation of electrical charge on surface assets
19. **Thermal Management Systems -** Survive and operate through the lunar night, Conditioned stowage to maintain science and/or nutritional integrity, Cryogenic cooling for science instrumentation, High temperature heat rejection for nuclear applications, Long-life thermal control for surface suits capable of extreme access, Advanced thermal modeling capabilities.
20. Miscellaneous - Protect Earth from Destructive Natural Impacts, (Planetary Defense), Enhanced Access to Orbital and Suborbital Space for Flight Demonstration and Test, Space Situational Awareness, Planetary Protection.

Suggestions for future space technology development

In my opinion, the future of space technology will still be driven by the needs such as more reliable, faster, and safer transport vehicles for deeper space travel. As a result, new propulsion technologies such as nuclear and solar powered engines will enable faster and more efficient travel through space, making it possible to reach deep-space destinations in time frames relatively shorter than human life spans. On the spacecraft control and robotic instrumentation, with the increasing availability of powerful computing resources and AI intervention, we will be able to develop more sophisticated spacecraft control systems, allowing for greater autonomy and flexibility in flight operation. We also need the development of new materials and manufacturing techniques for the building of lighter, stronger, and more durable spacecraft, making them more survivable in harsh conditions of space. The increasing commercialization of space travel and exploration will lead to the development of new markets and business opportunities, providing new windows for economic growth and expansion. The continued miniaturization of electronics will allow for ever smaller and more efficient spacecraft, making it possible to explore even the most remote corners of the universe. The advent of artificial intelligence and machine learning will speed up for the development of advanced and smart spacecraft, capable of making decisions on their own in response to challenging and difficult conditions. Internation collaborations instead of space race, competition or even space war will advance space technology at much greater rates. The promotion for international partnerships will create new opportunities for collaboration and knowledge sharing, contributing to the advancement of space technology worldwide.

Conclusion

Space engineering and technology have played an important role in our understanding of the universe and fundamentally affected our daily life on Earth, providing solutions to global needs in many aspects of human lives. Space technology has also revolutionized the way we live and work. It has provided us with new ways to communicate, navigate, and explore our universe. Space technology has also made it possible for us to better understand our planet and its resources. As we continue to develop new space technologies, we will be able to make many of our dreams come true. As we continue to explore the cosmos, future advancements in space technology will pave the way for many scientific discoveries and inventions that eventually enable human habitation beyond our planet.



Dr. Jacob Nan-Chu Chung is currently the Andrew H. Hines, Jr./Progress Energy Eminent Scholar Chair Professor at the University of Florida. He joined the University of Florida in 1998 after 19 years on the faculty at Washington State University. Dr. Chung holds both B.S. and M.S. degrees in Nuclear Engineering and had spent 6 years working as a nuclear reactor safety engineer in the industry before receiving his Ph.D. in Mechanical Engineering from the University of Pennsylvania in 1979. Dr. Chung's research activities have been in the general areas of fluid mechanics and heat transfer. Dr. Chung is a co-author for a book entitled "Transport Phenomena with Drops and Bubbles". He has authored and co-authored over 230 archival journal papers and received the College of Engineering Research Excellence Award in 1988 at Washington State University. He was awarded the University of Florida, Herbert Wertheim College of Engineering, Doctoral Dissertation Advisor/Mentoring Award in 2008. He also received the 2014 ASME Heat Transfer Memorial award. Recently, he was awarded the "2023 Exceptional Public Service Medal" by NASA for his pioneering contribution to space cryogenic propellant thermal management. Dr. Chung has served as a technical consultant to the Battelle Pacific Northwest National Laboratory and the Hewlett-Packard Corporation. Dr. Chung is a Fellow of the American Society of Mechanical Engineers.