Outer Space: Innovation, Security, and Sustainability

This editorial is based on "Musk's SpaceX has taken significant leaps in space exploration" which was published in Livemint on 21/10/2024. The article brings into picture the transformative advancements in space technology, highlighting the shift from expendable rockets to reusable spacecraft led by private companies like SpaceX.

For Prelims: Reusable spacecraft, Falcon Heavy mission, Starlink, Low-Earth orbit , Japan's SLIM mission, NASA's Artemis, India's Mangalyaan, UAE's Hope probe, NASA's Perseverance rover, International Space Station,Defence Space Agency, Mission Shakti, James Webb Space Telescope, Russia's 2021 ASAT test, 1967 Outer Space Treaty, Indian Space Policy 2023.

For Mains: Recent Developments Shaping Space Sector Across the Globe, Key Issues Arising Out of Advancement in the Space Sector.

From **Neil Armstrong's historic lunar steps to SpaceX's revolutionary 'chopsticks' catching its descending booster,** humanity's space ambitions have taken quantum leaps in innovation and cost-effectiveness. The paradigm shift from **expendable rockets to reusable spacecraft,** pioneered by private players like **SpaceX**, has dramatically reduced launch costs while expanding possibilities for space exploration. As **India strengthens its own space capabilities through ISRO** and emerging private players, the focus must be on fostering a robust R&D ecosystem that can drive similar technological breakthroughs.

What are the Recent Developments Shaping Space Sector Across the Globe?

- **Commercialization of Space Launch Services:** In the past 4 years, SpaceX has launched **13 human spaceflight missions**, safely flying 50 crewmembers to and from Earth's orbit, reducing launch costs to approximately **$67 million per Falcon Heavy mission.**
    - SpaceX demonstrated **reusable rocket technology** by launching one of its **Falcon 9 boosters** for the 20th time recently.
    - This commercialization has dropped launch costs, with the cost of heavy launches to **Low-Earth orbit (LEO)** has drastically come down **from $65,000 per kg to just $1,500 per kg**, according to an estimate from McKinsey.
    - Space tourism initiayibes like , Blue Origin's New Shepard launched **six crewed flights before its 2022 incident.**
        - Billionaire **Jeff Bezos** embarked on a brief journey to space during the inaugural crewed flight of his rocket, New Shepard.
        - Plans for private space stations are advancing, with **Axiom planning its first module launch in 2026**.
- **Rise of Small Satellite Constellations**: **Starlink** leads with over 6,000 operational satellites as of **September 2024**, providing internet to over 2.3 million subscribers across 60+ countries.
    - **Amazon's Project Kuiper plans to launch 3,236 satellites by 2029**.

    - **OneWeb, post-merger with Eutelsat,** has deployed 634 satellites for global coverage.
    - **China's Guowang** constellation plans **13,000 satellites**, marking the entry of state actors into the mega-constellation race.
- **Moon Mission Renaissance:** India's Chandrayaan-3 achieved a historic soft landing near the lunar south pole in **August 2023,** making it the fourth country to achieve this feat.
    - **Japan's SLIM mission demonstrated precise landing capabilities in January 2024. NASA's Artemis program has begun, with Artemis II scheduled for 2025,** while China plans to establish a lunar research station with completion targeted between **2028 and 2035**.
    - Private companies like Intuitive Machines and Astrobotic are pioneering **commercial lunar payload services.**
- **Mars Exploration Advancement: India's Mangalyaan, UAE's Hope probe, NASA's Perseverance rover,** and **China's Tianwen-1/Zhurong missions** are key major advancements.
    - The **Rosalind Franklin rover** is **slated for a launch to Mars in 2028**.
    - This mission aims to explore the Martian surface in search of signs of past life and to gather crucial data about the planet's geology and environment.
- **Defense Space Capabilities:** The U.S. Space Force received a **$30 billion budget for FY2024**, focusing on space domain awareness and resilient satellite networks.
    - India established the **Defence Space Agency** and demonstrated **ASAT capabilities through Mission Shakti**.
        - Also, India is planning to launch its own space station by 2030,
    - China's continued development of counter space capabilities**, including the SJ-21 satellite** with potential robotic arm technology, has prompted increased global focus on space security.
- **Deep Space Exploration:** NASA's **OSIRIS-REx** successfully returned asteroid samples from **Bennu** in 2023.
    - ESA's **JUICE mission launched to study Jupiter's moons**. China announced its **Tianwen-4 mission to study Neptune,** marking the first dedicated mission to the ice giant.
    - The **James Webb Space Telescope** continues to revolutionize our understanding of distant galaxies and exoplanets.

What are the Key Issues Arising Out of Advancement in the Space Sector?

- **Space Debris Crisis:** Millions of pieces of orbital debris exist in **Low Earth Orbit (LEO)** at least **26,000** the size of a **softball** or larger that could destroy a satellite on impact
    - **Russia's 2021 ASAT test** created over 1,500 trackable debris pieces.
    - The February 2022 **near collision risk between Starlink and China's space station** highlighted the urgent need for international traffic management.
    - Cleanup costs are estimated at **billions** with current technology limited to removing only a few objects annually.
    - The United Nations treaties, including the Convention on **International Liability for Damage Caused by Space Objects (1972)** and the **Convention on Registration of Objects Launched into Outer Space (1976**), aim to regulate space debris.
        - However, these frameworks remain largely ineffective in enforcement.
- **Weaponization of Space:** The **U.S. The Space Force's 2024** budget increased by $30 billion, focusing on space warfare capabilities.
    - Recent satellite jamming incidents **during conflicts (notably in Ukraine)** show increasing **space-based electronic warfare.**
    - Over **80 countries** own satellites and many of these countries consider access to space systems and services as important contributors to their national security, raising concerns about **potential space militarization.**
        - Also**,** Developing nations face a **"space divide**" with limited access to crucial satellite services, affecting disaster management and communications.
- **Environmental Impact of Launches:** Studies show **rocket launches contribute to ozone depletion,** with aluminum oxide particles from solid rocket motors particularly concerning.
    - SpaceX's increased launch frequency releases significant upper atmosphere pollutants, with each **Falcon 9** launch producing approximately **336 tons of CO_2.**

    - Satellite **re-entries are releasing increasing amounts of aluminum** in the upper atmosphere. Environmental impact assessments lag behind the rapid increase in launch frequency.
- **Legal and Regulatory Gaps:** The **1967 Outer Space Treaty** remains inadequate for current commercial space activities.
    - Property rights in space remain undefined, **creating uncertainty for lunar and asteroid mining plans**.
    - Space tourism operates in a **regulatory grey area**, with the regulatory bodies struggling to define safety standards after **Virgin Galactic's flight path deviation incident.**
- **Space Spectrum Allocation Conflicts:** There is a dramatic **increase in satellite constellation applications since 2019**, straining available radio frequencies.
    - Second-gen Starlink satellites leak **30 times more radio interference**, threatening astronomical observations.
    - Developing countries struggle to **protect their orbital slots** and spectrum rights against larger operators.
- **Space Supply Chain Vulnerabilities:** Critical materials for spacecraft remain concentrated in a few countries (**China controls 90% of rare earth processing**).
    - The space industry's dependence on specific regions (like **Taiwan for chips**) creates strategic vulnerabilities.
    - India's import costs in the space technology sector are **12 times higher than the earnings from exports**

What are the Key Recent Developments in the Indian Space Sector?

- **Status:**
    - In 2021, the Indian space industry contributed **2% to global share in the space sector**. This is expected to rise to 8% by 2030 and further to **15% by the year 2047.**
        - **Also, India allows 100% FDI in the space sector**
- **Policy Frameworks and Government Support:**
    - **Indian Space Policy 2023:** This policy defines the role of private sector players and streamlines authorization processes for both government and private space activities.
        - **IN-SPACe**: The Indian National Space Promotion and Authorization Centre serves as a single-window agency, promoting private sector collaboration and supporting industry clusters, manufacturing hubs, and incubation centers.
        - **New Space India Limited (NSIL**): As ISRO’s commercial arm, NSIL drives high-tech collaborations, creating demand for private sector involvement through technology transfers and aggregating resources.
- **Recent Achievements**
    - **Chandrayaan-3 Lunar Landing:** The historic lunar south pole landing led to August 23 being celebrated as "**National Space Day.**"
        - It highlights India’s technological prowess and symbolizes the "Make in India" vision in space exploration.
    - **X-ray Polarimeter Satellite (XPoSat):** Launched in January 2024, it is advancing India's capabilities in space-based astronomy.
    - **Aditya-L1 Mission**: Launched to study the Sun's atmosphere, this mission represents India’s expanding interest in solar research.

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- **Startups and Private Sector Growth:**
  - **Rising Startups:** The sector boasts **101 space-related startups,** with total funding of **USD 108.5 million**.
    - **Skyroot Aerospace** launched India's first privately developed rocket, **Vikram-S;**
    - **Agnikula Cosmos** established a private launch pad
    - **Bellatrix Aerospace** specializes in propulsion technologies.

What Measures can be Adopted for More Balanced Development of the Space Sector?

- **International Space Traffic Management Framework:** Establish a **UN-led Space Traffic Management authority** with binding regulatory powers, similar to the **International Civil Aviation Organization for aviation**.
  - Implement mandatory space debris mitigation guidelines with penalties for non-compliance.

    - Create a global space object registration system with **real-time tracking capabilities.**
    - Require **collision avoidance systems** for all new satellites, following **OneWeb's LeoLabs Collision Avoidance**.
    - Develop international standards for **satellite end-of-life disposal.**
- **Space Sustainability Fund and Incentives:** Create a global fund for debris removal and sustainability projects.
    - Offer **tax incentives for companies developing green propulsion systems**
    - Implement a **"polluter pays" principle with orbital usage fees** based on satellite lifetime and debris risk.
    - Support development of reusable technology, noting SpaceX's achievement of reducing launch costs.
- **Democratizing Space Access:** Develop **regional space ports** through public-private partnerships.
    - Create technology transfer programs between **established and emerging space nations,** similar to **ESA's successful cooperation with African space agencies.**
    - Establish international satellite data sharing protocols, following **ISRO's disaster monitoring data sharing model**.
    - Support small satellite development in developing nations through technical assistance and launch quotas.
- **Enhanced Space Education and Workforce Development:** Launch global space education initiatives.
    - Establish international space universities in developing regions. Create apprenticeship programs linking traditional space agencies with the private sector, like **NASA's successful Commercial Crew program model**.
    - Support STEM education focusing on space technology in developing nations through scholarship programs.
- **Environmental Protection Measures:** Mandate environmental impact assessments for all launches, measuring upper atmosphere effects.
    - Require use of **green propulsion systems**. Establish space environment monitoring network tracking launch impacts on atmosphere.
    - Create **recycling requirements for space hardware**. Implement carbon offset requirements for space activities.
- **Legal and Regulatory Framework Modernization:** Update **Outer Space Treaty through additional protocols** addressing commercial space activities.
    - Establish a **clear property rights framework for space resources** while protecting scientific interests.
    - Develop standardized safety regulations for space tourism, learning from **Virgin Galactic incidents.** Implement cybersecurity standards for space infrastructure protection.

Conclusion:

The **exponential advancements in space technology** have broadened humanity's capabilities but also pose significant challenges, from space debris to regulatory gaps. For a sustainable and balanced global space ecosystem, collaborative frameworks, democratized access, and robust regulatory measures are essential. **India, leveraging both ISRO and private partnerships,** has the potential to emerge as a **major global player in space exploration.**

Drishti Mains Question:

The weaponization of space presents significant challenges to global security and stability.” Analyze the factors driving space weaponization and suggest measures to ensure the peaceful use of outer space.

UPSC Civil Services Examination, Previous Year Question (PYQ)

Q.1 What is India’s plan to have its own space station and how will it benefit our space programme? **(2019)**

Q.2 Discuss India’s achievements in the field of Space Science and Technology. How the application of this technology helped India in its socio-economic development? **(2016)**

Q.3 What is the main task of India’s third mood mission which could not be achieved in its earlier mission? List the countries that have achieved this task. Introduce the subsystems in the spacecraft launched and explain the role of the ‘Virtual Launch Control Centre’ at the Vikram Sarabhai Space Centre which contributed to the successful launch from Sriharikota. **(2023)**
