

Environmental impact of space launches

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Abstract

Space launches had been instrumental in medical improvements and satellite deployment. However, amid their significance, the environmental effect of these launches remains a vital problem. This summary explores the complicated interplay between rocket propulsion, atmospheric pollution, and ecological outcomes resulting from area launches.

The evaluation spans the phases of a space launch, from ignition to ascent, highlighting emissions like carbon dioxide, soot, and water vapor launched into the ecosystem. These emissions result in localized disturbances and worldwide-scale influences, affecting atmospheric balance and potentially contributing to ozone layer depletion.

The environmental results increase to terrestrial and marine ecosystems, with rocket launches posing dangers of ground and water contamination. Wildlife habitats close to release web sites face disruption, elevating concerns for biodiversity and ecosystem fitness.

Mitigation techniques and technological advancements intention to reduce the environmental effect. Innovations in inexperienced propulsion technology and advanced launch web page designs align with environmental control practices to reduce the ecological footprint.

Regulatory frameworks and collaborative efforts among stakeholders are crucial in addressing these environmental demanding situations. Emphasizing international cooperation, these frameworks play a pivotal role in balancing space exploration goals with environmental upkeep.

Looking beforehand, sustainability in space launches is predicated on advancements in era, coverage interventions, and a concerted global dedication. This summary advocates for a future wherein space exploration coexists harmoniously with the vital of maintaining our planet's ecosystems.

Keywords: rocket propulsion, biodiversity, ecosystem fitness, terrestrial and marine ecosystems.

Introduction

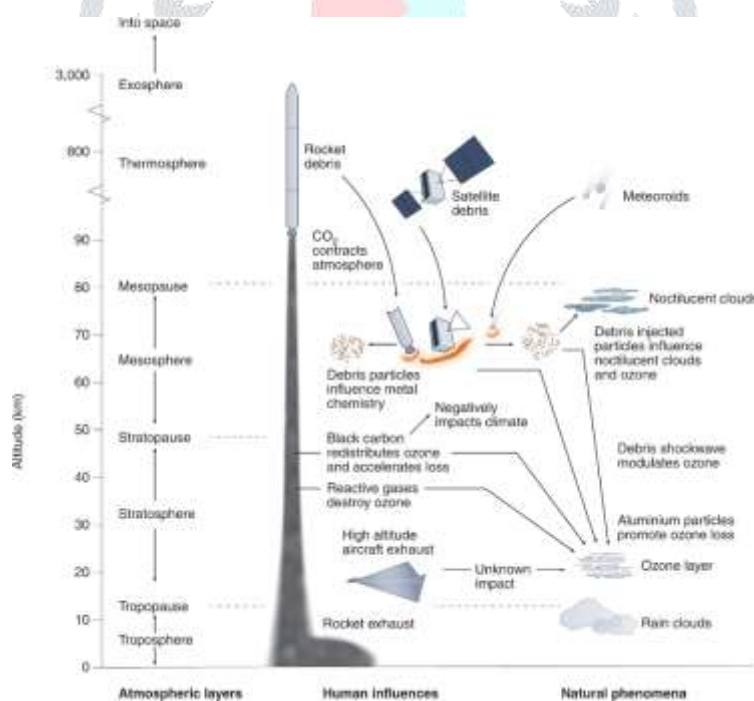
The environmental impact of space launches is an more and more crucial concern inside the realm of space exploration and technological advancement. Each release, pivotal for scientific studies, satellite tv for pc deployment, and space exploration, comes with a complex array of environmental implications that traverse atmospheric disturbances, atmosphere disruptions, and potential global-scale consequences. Understanding and addressing these impacts are vital for making sure sustainable spacefaring activities as humanity continues to push the bounds of exploration past Earth.

Rocket propulsion, the fundamental mechanism riding space launches, releases various emissions and pollutants into the environment. These emissions, including carbon dioxide, soot, water vapor, and other compounds, make contributions to atmospheric pollutants. The ignition and ascent phases of a launch generate big warmth, sonic booms, and chemical exhaust, altering atmospheric conditions and potentially impacting local air first-rate.

Furthermore, the trajectory of a rocket release and its next stages can result in the dispersion of pollution throughout exclusive atmospheric layers, potentially contributing to ozone layer depletion or altering atmospheric chemistry. These atmospheric disturbances would possibly have implications for climate styles, atmospheric stability, and the worldwide weather device, although the exact quantity and importance of those impacts are topics of ongoing studies and difficulty. Beyond the atmospheric consequences, space launches can also pose dangers to terrestrial and marine ecosystems. Launch sites, frequently located near herbal habitats, face the capability for ground and water infection. Toxic chemical substances from rocket propellants and residues can infiltrate soil and water our bodies, affecting local plant life and fauna. Wildlife habitats close to launch websites may experience disruptions, potentially threatening biodiversity and environment fitness.

Recognizing and mitigating those environmental influences require revolutionary approaches and improvements in generation. Efforts are underway to expand and put into effect more sustainable propulsion systems, inclusive of green propulsion technology and cleanser fuel alternatives. Additionally, upgrades in release site layout and operational practices aim to limit the ecological footprint of space launches.

The regulatory landscape surrounding area launches and environmental conservation is likewise a critical thing. International cooperation, regulatory frameworks, and collaboration amongst space corporations, non-public entities, and environmental organizations are essential for establishing suggestions, standards, and



great practices that balance the imperatives of space exploration with environmental stewardship.

Fig(i) Atmospheric Impacts of Rocket Launches

In conclusion, the environmental impact of area launches spans atmospheric perturbations, capability ozone layer results, and risks to terrestrial and marine ecosystems. Addressing those concerns requires a multi-faceted approach, integrating technological innovation, regulatory oversight, and international collaboration to make sure that the pursuit of space exploration aligns with the imperative of maintaining our planet's ecosystems for cutting-edge and future generations.

Rocket engine technologies

Rocket engine systems represent the foundational era using space exploration, satellite tv for pc deployment, and numerous aerospace endeavors. These systems embody quite a number propulsion technology, each with wonderful mechanisms, characteristics, and environmental implications.

1. Liquid Fuel Engines:

Overview: Liquid gas engines utilize liquid propellants, typically a aggregate of liquid oxygen (LOX) and liquid hydrogen (LH2) or liquid kerosene (RP-1), saved one at a time in tanks onboard the rocket. These propellants are combined and ignited within the combustion chamber to provide thrust.

Operation: The managed combustion of liquid propellants generates excessive-pressure gases expelled via a nozzle, generating thrust that propels the rocket. Liquid gasoline engines provide extra manage over thrust modulation and may be shut down or restarted throughout flight.

Environmental Footprint: Liquid gas engines usually produce purifier exhaust as compared to strong rocket boosters. However, they nevertheless emit pollutants like carbon dioxide, water vapor, and hint quantities of different chemical substances, contributing to atmospheric pollutants.

2. Solid Rocket Boosters:

Overview: Solid rocket boosters use strong propellant, usually a mixture of powdered metals and oxidizers bound collectively in a stable form. Once ignited, these boosters burn continuously till their gasoline is depleted.

Operation: The combustion of stable propellants generates thrust, and these boosters can't be throttled or shut down as soon as ignited. Solid rocket boosters are frequently used as strap-on boosters or as a part of the initial degree of a rocket's ascent.

Environmental Footprint: Solid rocket boosters produce greater severe and dense exhaust plumes containing particulate count number, metal oxides, and chlorine compounds. These emissions can make a contribution to atmospheric pollution and feature extra instant environmental affects as compared to liquid gas engines.

Environmental Footprints of Rocket Engine Systems:

Carbon Dioxide Emissions: Both liquid gas engines and stable rocket boosters release carbon dioxide, contributing to greenhouse gas emissions.

Soot and Particulate Matter: Solid rocket boosters, due to their composition, produce more particulate be counted and soot of their exhaust compared to liquid fuel engines. These emissions will have instant local environmental impacts.

Water Vapor and Trace Chemicals: Both propulsion structures launch water vapor, that may make a contribution to cloud formation in the higher ecosystem. Additionally, they emit trace amounts of chemical compounds that would have atmospheric implications.

In essence, whilst both liquid gas engines and stable rocket boosters are vital for area launches, they've various environmental footprints. Liquid gasoline engines commonly offer extra manipulate and convey cleanser exhaust compared to stable rocket boosters, which emit greater particulate be counted and dense plumes. As the aerospace enterprise progresses, improvements in propulsion technology intention to reduce environmental influences by means of exploring greener propulsion alternatives and cleanser gas compositions.

Atmospheric effects:

Types of Pollutants Released:

Carbon Dioxide (CO₂): Rocket engines emit large amounts of carbon dioxide throughout launches. While CO₂ is naturally going on within the ecosystem, the additional release from rocket emissions contributes to elevated atmospheric concentrations.

Soot and Particulate Matter: Incomplete combustion of rocket propellants can generate soot and particulate matter. These debris, while launched into the surroundings, can have an effect on air exceptional and doubtlessly effect climate methods.

Water Vapor: Rocket engines expel giant portions of water vapor as a byproduct of burning liquid hydrogen or other hydrogen-based totally fuels. Water vapor is a powerful greenhouse fuel that could have an effect on atmospheric temperature and humidity.

Hydrochloric Acid and Alumina Particles: Solid rocket boosters regularly contain perchlorates that, when combusted, release hydrochloric acid. Additionally, stable rocket exhaust may additionally incorporate alumina debris, that may affect atmospheric chemistry.

Atmospheric Perturbations:

Local Atmospheric Disturbances: Rocket launches create intense acoustic shockwaves and heat, leading to nearby disturbances within the environment. The fast ascent of a rocket can generate full-size noise tiers and thermal stress on the surrounding air.

Stratospheric Effects: Rocket emissions injected into the stratosphere can influence atmospheric chemistry and dynamics. These emissions might also result in localized temperature adjustments and changes in stratospheric winds, impacting atmospheric circulation styles.

Ozone Layer Depletion:

Chemical Reactions: The exhaust gases from positive rocket engines include chlorine-primarily based compounds. When these gases reach the stratosphere, they can provoke chemical reactions that destroy down ozone molecules. Chlorine is specially regarding as it can catalytically break ozone, contributing to ozone layer depletion.

Stratospheric Ozone Layer: Ozone (O₃) inside the stratosphere performs a important position in absorbing harmful ultraviolet (UV) radiation from the Sun. Depletion of the ozone layer increases the influx of UV radiation to the Earth's surface, posing dangers to human health and ecosystems.

Impact on UV Radiation: Ozone layer depletion due to rocket emissions may accentuate UV radiation exposure in affected areas, doubtlessly main to elevated dangers of pores and skin most cancers, cataracts, and damage to marine and terrestrial ecosystems.

Mitigating these atmospheric results requires a complete knowledge of the pollutants emitted, their interactions within the surroundings, and the improvement of cleanser propulsion technologies. Sustainable spacefaring practices, together with using greener propellants and propulsion systems, together with stepped forward launch web page designs and operational protocols, aim to lessen the environmental footprint of space launches and minimize their effect on atmospheric composition and balance. Additionally, continued research and monitoring are vital to assess and deal with the lengthy-term implications of space launch emissions on Earth's environment.

Impact on Terrestrial and Marine Ecosystem

1. Ground and Water Contamination:

Space launches, specifically at release sites, can introduce diverse pollutants and contaminants into the surrounding surroundings.

Soil Contamination: The ignition and ascent of rockets release residues and unburned propellants that may infiltrate the soil. Toxic chemicals found in rocket propellants, which include hydrazine and different compounds, can potentially seep into the floor, affecting soil pleasant and composition. Contamination may additionally persist after launches, posing risks to plant life and groundwater.

Water Body Contamination: Launch sports, together with fueling operations and capability mishaps, pose dangers of water infection. Spillage of propellant fuels or runoff from release sites can introduce pollutants into nearby water bodies, potentially impacting aquatic ecosystems and the exceptional of drinking water

resources. This infection could have an effect on aquatic plants and fauna, leading to ecological imbalances and health dangers for organisms dependent on these water structures.

2. Wildlife and Habitats:

The locations of many launch web sites coincide with herbal habitats and natural world areas, leading to capacity disruptions for diverse species and ecosystems.

Habitat Disruption: The noise, vibrations, and physical disturbances associated with launches can disrupt close by natural world habitats. Sudden loud noises from rocket launches might also disturb or displace sensitive species, affecting their breeding, nesting, or feeding behaviors. Habitats adjacent to launch websites might also revel in alterations in their herbal techniques due to those disruptions.

Biodiversity Impact: Launch activities may additionally pose risks to biodiversity, particularly for species dwelling close to launch web sites. The presence of toxic materials within the surroundings following a release can effect the health and viability of local plants and fauna, potentially main to population declines or changes in species composition.

Addressing those ecosystem influences necessitates enforcing mitigation measures and environmental management practices. Strategies including improved gasoline containment systems, runoff control, and publish-launch web page remediation efforts purpose to reduce ground and water contamination. Wildlife tracking, habitat conservation measures, and buffer zones round launch web sites are looking for to mitigate disturbances to natural habitats and reduce ability impacts on neighborhood biodiversity.

Understanding and coping with the environmental footprint of area launches are critical steps in ensuring that those sports coexist harmoniously with terrestrial and marine ecosystems. Efforts to mitigate and minimize these impacts are essential for maintaining biodiversity, defensive natural habitats, and maintaining the ecological balance in areas surrounding release sites.

Mitigation strategies and technological advancements

1. Green Propulsion Technologies:

Electrified Propulsion: Electric propulsion structures, along with ion thrusters, provide promising alternatives to conventional chemical propulsion. They use strength to boost up charged debris, decreasing the reliance on chemical propellants and emitting fewer harmful byproducts.

Biodegradable or Non-Toxic Propellants: Research focuses on developing propellants that reduce environmental effect with the aid of being biodegradable or non-poisonous. These propellants intention to reduce the discharge of harmful chemical compounds into the ecosystem and ecosystems.

2. Hydrogen and Methane-Based Propulsion:

Hydrogen Fuel: Hydrogen-powered engines produce water vapor as their primary exhaust, minimizing the emission of pollution harmful to the environment. Research explores hydrogen as a smooth, efficient gasoline for area propulsion.

Methane Propulsion: Methane-based totally engines showcase promise because of their cleanser combustion homes compared to traditional fuels, emitting fewer pollutants all through space launches.

Three. Aerospike Engines and Advanced Propulsion Systems:

Aerospike Engines: These engines provide higher performance and purifier combustion, probably reducing the environmental impact of rocket launches through optimizing thrust and lowering gas consumption.

Advanced Propulsion Concepts: Concepts like solar sails, nuclear propulsion, and beamed electricity propulsion are beneath exploration for their capability to minimize the environmental footprint of space launches.

Four. Launch Site Design and Environmental Management:

Site Selection and Preparation: Careful choice and preparation of launch websites can limit the impact on close by ecosystems and habitats. Remote and environmentally sensitive areas may be prevented to reduce disruption.

Water Reclamation and Waste Management: Implementing water reclamation systems and green waste control practices at launch web sites can mitigate floor and water contamination dangers.

5. Reducing Particulate and Chemical Emissions:

Improved Combustion Technologies: Advancements in combustion chamber designs intention to optimize gas burn performance, lowering the production of soot and dangerous emissions at some point of the ignition and ascent stages.

Filtering Systems and Exhaust Capture: Deploying filtering systems and exhaust seize mechanisms can assist reduce the release of particulates and pollution into the atmosphere at some point of launches.

Regulatory framework and best practices

1. Regulatory Frameworks Governing Space Launches:

National and International Regulations: Space launches are problem to guidelines imposed by way of country wide area corporations and global our bodies. National guidelines govern release sports within a rustic's jurisdiction, even as worldwide agreements and treaties, consisting of the Outer Space Treaty and the Liability Convention, provide overarching recommendations for accountable space activities.

Licensing and Compliance: Space release operators normally require licenses and allows to conduct launches. Regulatory our bodies, like the FAA inside the United States, examine and oversee compliance with protection standards, environmental protocols, and operational tips.

2. Environmental Impact Assessment (EIA) and Mitigation Measures:

EIA Requirements: Space launch sports regularly necessitate environmental effect checks to assess capacity risks and affects on ecosystems, air satisfactory, water our bodies, and local groups. These checks resource in identifying potential environmental dangers and developing mitigation techniques.

Mitigation Strategies: Best practices involve imposing mitigation measures recognized thru EIAs, including minimizing floor contamination, keeping wildlife habitats, and coping with chemical residues to prevent water pollution.

3. Green Propulsion Technologies and Sustainable Practices:

Development of Sustainable Propulsion Systems: Regulatory our bodies inspire the development and adoption of eco-friendly propulsion systems, like electric propulsion or biofuels, to minimize the environmental footprint of rocket launches.

Emission Reduction Measures: Best practices contain the implementation of emission discount technologies and practices all through release operations, aiming to lessen pollutants released into the ecosystem.

4. Launch Site Design and Environmental Management:

Site Selection and Design: Best practices in launch site selection remember minimizing environmental effect by means of choosing sites with decrease ecological sensitivity. Launch web site design contains features to mitigate noise, save you soil infection, and guard close by ecosystems.

Waste Management and Cleanup: Implementation of waste management protocols and publish-launch cleanup sports are critical in preventing residual infection and restoring release websites to their herbal nation.

5. Stakeholder Collaboration and Public Engagement:

Collaborative Approach: Regulatory bodies foster collaboration among space groups, personal entities, environmental companies, and local groups. This collaboration ensures transparency, understanding sharing, and adherence to environmental safety desires.

Public Engagement: Engaging local groups and stakeholders within the selection-making process fosters cognizance, guarantees network involvement, and addresses concerns regarding the environmental influences of area launches.

6. Continuous Improvement and Adaptive Regulations:

Adaptive Regulations: Best practices recommend for dynamic and adaptive regulatory frameworks that evolve with technological advancements and rising environmental demanding situations.

Periodic Reviews and Updates: Regular critiques and updates of policies ensure their alignment with contemporary medical understanding, technological advancements, and changing environmental requirements.

The improvement and adherence to sturdy regulatory frameworks and fine practices are pivotal in safeguarding the environment and ensuring the sustainability of area launch activities. This technique requires a collaborative and proactive stance, encompassing stringent regulations, innovative technology, and ongoing efforts to stability the imperatives of space exploration with environmental conservation.

Future trends and best practices

1. Advancements in Green Propulsion Technologies:

Innovative Propulsion Systems: Envisioning the improvement and adoption of superior propulsion structures that limit dangerous emissions. Electric propulsion, ion engines, and opportunity gasoline resources, including methane-based fuels, maintain promise for reducing pollutants launched all through area launches.

Reusable Rockets: Anticipating a shift closer to reusable rocket generation, in which spacecraft are designed for more than one launches, significantly lowering the environmental impact in step with launch and decreasing typical emissions.

2. Sustainable Launch Site Design and Operations:

Environmental Impact Assessments: Envisioning comprehensive environmental effect exams performed prior to selecting launch web sites, ensuring minimum disruption to surrounding ecosystems and natural world habitats.

Infrastructure and Waste Management: Planning for advanced waste management structures at release websites, enforcing recycling, and sustainable infrastructure designs to mitigate the effect of space release sports on nearby environments.

3. Advancements in Monitoring and Assessment:

Remote Sensing Technologies: Anticipating improvements in far off sensing technology to monitor and check the environmental effect of space launches more as it should be. Satellite-primarily based monitoring systems can song pollutants, examine modifications in air and water quality, and gauge ecosystem health.

Data Transparency and Analysis: Emphasizing the want for obvious sharing of environmental impact information from area launches, facilitating collaborative analysis and fostering a better understanding of lengthy-term effects.

4. Regulatory Framework Enhancements:

Adaptive Regulatory Approaches: Envisioning adaptable regulatory frameworks that evolve along technological improvements. These frameworks could set stringent but bendy requirements to accommodate innovations while ensuring environmental protection.

International Collaboration: Strengthening international cooperation amongst space organizations, governments, and environmental bodies to set up and put into effect policies that harmonize across borders and sell worldwide sustainability standards.

5. Research and Innovation Funding:

Investment in Environmental Research: Advocating for extended investment and support for research tasks targeted on knowledge and mitigating the environmental impact of area launches. This consists of studies on pollutants, their long-time period outcomes, and sustainable alternatives.

Incentivizing Green Practices: Encouraging public and personal entities to spend money on environmentally pleasant practices thru monetary incentives, grants, and rewards for sustainable improvements.

6. Public Engagement and Education:

Awareness and Education Campaigns: Fostering public awareness and training applications about the environmental effect of space launches. Engaging the public in knowledge the importance of mitigating these results for international sustainability.

7. Continuous Evaluation and Adaptation:

Iterative Approaches: Stressing the want for non-stop evaluation, remarks, and variation of strategies. Regular reassessment of environmental impacts, improvements in generation, and shifts in regulatory frameworks make sure dynamic and effective measures.

The destiny of mitigating the environmental consequences of area launches hinges on a holistic technique that amalgamates technological innovation, stringent yet adaptable regulations, sturdy tracking structures, and collaborative efforts among stakeholders. By embracing sustainability as a center guiding principle of space exploration, humanity can stride forward in its quest for the stars even as safeguarding the ecological balance on Earth.

Conclusion

Space launches, critical to humanity's pursuit of medical discovery and technological progress, bring a significant environmental footprint that needs interest, comprehension, and proactive mitigation strategies. This studies paper has traversed the multifaceted landscape of the environmental results engendered by way of space launches, illuminating the complicated interplay among rocket propulsion, atmospheric adjustments, and ecological impacts.

Throughout the stages of a space release, from ignition to ascent and beyond, emissions like carbon dioxide, soot, water vapor, and different compounds permeate the atmosphere, changing its composition and dynamics. These emissions make a contribution to localized disturbances and pose ability worldwide-scale implications, inclusive of atmospheric perturbations and the prospect of ozone layer depletion.

Moreover, the repercussions increase to terrestrial and marine ecosystems, in which launch sports close to habitats pose risks of ground and water infection. Wildlife habitats face disruption, hinting at potential threats to biodiversity and ecosystem fitness.

Envisioning the destiny necessitates a proactive stance towards sustainable practices and improvements. Advancements in inexperienced propulsion technologies, coupled with reusable rocket structures, hold promise in lowering emissions and minimizing the ecological effect in step with launch. Sustainable launch site designs, complete environmental impact tests, and improved waste management structures similarly make contributions to mitigating the environmental footprint of area launches.

The pursuit of effective mitigation strategies and advancements in tracking technology, together with remote sensing structures, enables complete assessments of environmental impacts. Transparent information sharing and collaboration foster a international knowledge of long-time period results, paving the manner for knowledgeable decision-making and adaptive regulatory frameworks.

Regulatory upgrades, global collaboration, and accelerated investment in studies initiatives underscore the urgency of balancing space exploration targets with environmental stewardship. Public engagement and training play pivotal roles in fostering recognition and advocacy for sustainable practices, ensuring broader societal participation in addressing these essential environmental concerns.

In end, the pursuit of space exploration should harmonize with the vital of safeguarding Earth's ecosystems. Embracing a holistic approach, amalgamating technological innovation, stringent rules, collaborative efforts, and public engagement, promises a destiny where humanity keeps its celestial journey even as maintaining the delicate balance of our domestic planet. The quest for the celebs can indeed coexist harmoniously with the imperative of environmental sustainability, making sure a destiny in which area exploration enriches human knowledge with out compromising the fitness of our planet.

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