SpaceTech Industry Landscape Overview

Q3 2021

September 2021

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SpaceTech Analytics

Table of Contents

SpaceTech Industry Landscape Overview 2021 Q3 summarizes key observations in the SpaceTech ecosystem, a rapidly evolving and exponentially growing industry. In it, we have assembled information about **key industry trends** and created an **unprecedented database** of more than **12,000** SpaceTech-related companies, **5,000** leading investors, **200** R&D Hubs and Associations, and **140** government organizations.

By offering insights into a number of **public and private companies** engaged in various subsectors of the space economy, the **Space Industry Database and SpaceTech Landscape** provide a comprehensive analysis. We also provide a primer on topical issues facing the industry at this important inflection point, as we increasingly transition from an historical period of **high-cost low-activity government space programs** to burgeoning **commercial space activities** driven by plunging costs through private innovation.

The study pays special attention to space-related companies relying on **AI, DeepTech, and Longevity**. By using them, they can further stimulate space activities. SpaceTech has a **huge economic potential**, and has already resulted in the emergence of goods and services that have become an integral part of our lives.

Approach of the Report

Database

Identification of relevant:

- Companies
- Investors
- Hubs
- Universities & Research Centers
- Government Ministries, Departments & Agencies
- Space Associations

Applied Research & Analytics Methods

- Descriptive Analysis
- Mixed Data Research
- Exploratory Data Analysis
- Comparative Analysis
- Qualitative Data Collection
- Data Filtering

Data Sources*

- Media Overview (Articles, Press Releases)
- Industry-Specialized Databases
- Publicly Available Sources (Websites)
- Industry Reports and Reviews
- Interviews with Industry Leaders

Relying on various research methods and analytics techniques, this report provides a comprehensive overview of the space industry. This approach has certain limitations, especially when it comes to the leveraging of publicly available data sources and secondary research. SpaceTech Analytics is not responsible for the quality of the secondary data presented herein; however, we do our best to eliminate said risks by using different analytics techniques and cross-checking data. Please note that we did not deliberately exclude certain companies from our analysis. In fact, the main reason for their non-inclusion was incomplete or missing information in the available sources. With respect to the investors in the main database, we include only institutional investors who have invested into SpaceTech or SpaceTech-related companies. The companies included in the database are those that belong completely to the SpaceTech industry; that partially belong to it through working with clients from the SpaceTech industry; or that have separate departments in a SpaceTech company that works in this sector or cooperates with clients from this sector.

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Contributors to this SpaceTech Analytics

KLEOS
Melanie Delannoy

IM
Rand Simberg

FOR ALL MOONKIND
Michelle Hanlon

SPACEBORN UNITED
Egbert Edelbroek

AGING ANALYTICS AGENCY
Aging Analytics Agency

FemTech Analytics
FemTech Analytics

TRANS ASTRA
Joel Sercel

Interplanetary Enterprises
Chris Lewicki

Cislunar Space Development Company
Dallas Bienhoff

SPACE ECONOMY RISING
Kevin O'Connell

CONFERS
Ian Christensen

Space Tourism Society
John Spencer

MANKINS SPACE TECHNOLOGY
John Mankins

ORBITFAB
Daniel Faber

the Armor Group, LLC
Jim Armor

COLORADO SCHOOL OF MINES EARTH • ENERGY • ENVIRONMENT
George Sowers

Daniel Sax

CISLUNAR INDUSTRIES
Gary Calnan

Executive Summary

After over six decades of government spaceflight and slow progress on the high frontier, we are at the cusp of a new exciting era of **commercial space activities** that will soon dwarf those of the government. A huge **reduction in the cost of access** driven by purpose-driven commercial efforts is going to drive down the costs of all other space activities, and in many cases, create now ones that have been long dreamt of, but **were unaffordable**.

These will include:

- Private orbital spaceflight
- The utilization of extraterrestrial resources
- Space servicing
- Hotels for tourists
- Commercial labs for research
- Increasingly larger space habitats, perhaps rotating for artificial gravity
- Huge space telescopes at all wavelengths to learn more about our universe
- The collection of abundant energy in space for clean use on Earth
- Factories and warehouses for space manufacturing
- In-space assembly
- Human settlements on other worlds, bringing once-Earthly life out into the solar system

Many of these things are already happening, and others are just **on the horizon**. Money is flowing into the commercial-space sector by the billions, with **explosive economic growth** expected in this decade and those decades coming. As always, though, challenges remain. The legal issues of **resource utilization**, and **off-planet property rights** and governance remain in their infancy and will have to evolve with the growth of current activities and the appearance of new ones. In addition, the growing population of **satellites and space junk** in near-Earth orbit is a threat to our very ability to get into space if it gets out of control, and **space-traffic management** and debris removal have legal hurdles as well as technical and economic ones. The economic future in a time of government **deficits, potential war, and financial bubbles** is (also as always) uncertain, and many in society will oppose the development and settlement of space for various philosophical reasons. Nonetheless, as this report will show, the future of space, after the aspirations of decades of dreams, **has never been brighter**.

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Report Description

This project includes a **first-of-its-kind methodology** developed by the SpaceTech Analytics team **to identify the relatedness of the companies that are actively contributing to the fast-growing SpaceTech industry.** The methodology includes the sorting of space companies into three main categories:

Core companies

Verge companies

Space-Applied Businesses

The SpaceTech Industry Q3 Report is based on a comprehensive business and scientific overview of the global SpaceTech economy, which is constantly growing; was valued at **$4.671T in 2021; and is expected by many to grow to $10T by 2030**. According to the most conservative estimates, **it accounts for 5% of global GDP.**

SpaceTech Analytics (STA) is a leading strategic and analytical agency focused on the emerging markets in Satellite Technology, Advanced Startups, Space Law, and Economics. It concentrates its efforts on actively gaining expertise in Space Medicine sphere and other industries related to SpaceTech.

STA produces **regular analytical reports** on major areas of high potential in the space industry; maintains ratings of companies and governments based on their innovation potential and business activity in the SpaceTech sphere; and provides **strategic consulting and investment intelligence services** to top-tier clients, including major investment funds and banks, family offices, insurance companies, government organizations, large companies, and other organizations.

Report Description

This analytical report provides a market and technological overview of the SpaceTech industry at a comprehensive level. It highlights both **business insights** and **state-of-the-art techniques** that are being developed to address the key challenges of deep-space exploration, *in-situ* resource utilization, space-traffic management, and space transportation infrastructure, in addition to many other space sectors that will allow humanity to become a multi-planetary species.

In addition to providing company descriptions, this project is designed to **issue key strategic recommendations and guidance regarding space-related technologies** and techniques within the reach of companies, other entities, and nations, in order to help them optimize their action plans and strategies, providing specialized guidelines for business, and investment core decisions.

Thus, this work includes financial analysis, industry trends and investment overview, and top private-sector and publicly traded companies in the SpaceTech Industry which, along with government activities, provides a **comprehensive overview** of market activity in the industry.

Novel SpaceTech Analytics Methodology	**SpaceTech Government Activity**	**Space Health and Private Space Flights Overview**
Industry Trends & Investment Overview	**Space Law Overview**	**Off-Planet Construction**
SpaceTech Industry in Figures	**Economics of Space Overview**	**Satellite Servicing Overview**
100 Leading Companies in SpaceTech Sector	**Space Transportation Infrastructure Overview**	**In-Situ Resource Utilization Overview**
Top Publicly Traded Companies in SpaceTech Industry	**Space Traffic Management**	**Space Solar Power, Space Settlement Overview**

SpaceTech Analytics Methodology

The analysis includes more than 12,000 SpaceTech companies that were chosen according to original methodology. All the entities that were analyzed for the SpaceTech Industry Landscape Overview were divided into three main categories: Core Companies, Verge Companies, and Space-Applied Businesses based on the following criteria:

CORE COMPANY

1. Has a subsidiary and/or an acquisition company involved in the SpaceTech Industry.
2. The company's activity description includes a clear affiliation with the SpaceTech Industry.
3. Has at least one self-sufficient division or direction of activity that is involved in the SpaceTech industry; and this is totally clear from the company's website or other resources.
4. Space technology is at the core of the company operations/production; the company develops SpaceTech-focused products/services/projects.

SpaceTech Analytics Methodology

All the analyzed companies were selected by means of manual and automated search from open web sources. The further sorting of the database was executed both manually and with the use of algorithms. The methodology may contain a slight inaccuracy due to the partially manual construction of the database.

VERGE COMPANY

1

The company didn’t specify clearly the industries and customers, but its products and services could potentially be applied in the SpaceTech Industry. In addition, the the company operates in the general categories of Aerospace, Telecommunication, Defense, Navigation, and/or some other related categories. Some combination of these factors allows us to assume that the company is space-related.

2

Has space technologies, but not as a core technology or a core department.

3

One of the company’s products is used in aerospace; it has products related to satellite communication.

4

SpaceTech is mentioned but not defined as a distinct sector; there is no specific space department.

5

Related through the application of Satellite Communication or other space technologies in their core solutions.

6

The company operates in the aerospace industry and has SpaceTech-related partners or buyers/users/suppliers.

7

The company operates in the aerospace industry and has SpaceTech-related partners or buyers/users/suppliers.

8

The connection to space technology is mentioned in external resources describing the company's activity.

SpaceTech Analytics Methodology

The largest share of the database consists of space-related companies. All of the companies included are developing technologies that will form the backbone of the rapidly growing space industry. Their technologies are at different stages of development, from prototype to first experiments, to being placed into orbit or on another planet.

SPACE-APPLIED BUSINESS

Drones

Drones as a transportation solution may be used for spacewalk mission, space mining, space assembly, exploration, transportation, etc.

Nano-technologies

NanoTech, and molecular manufacturing in particular, will be crucial for all advanced activities within the space industry.

Smart Materials

Smart materials may significantly improve human viability in space and space settlement capabilities.

Cybersecurity

With the growing amount of data transferred through space, the need for cybersecurity is becoming ever-more salient.

Robotics

Robotics will form the main workforce on Earth, and will be even more an integral part of any space activity.

Expert systems (AI)

AI is especially important due to its connectivity to all of the other discussed technologies and due to the increasing levels of data involved.

Additive Manufacturing (3D)

Additive Manufacturing is crucial for providing construction or assembly in a quick, efficient, reliable, and inexpensive manner (on Earth or beyond it).

SpaceTech Analytics Industry Classification

SpaceTech Core Companies / SpaceTech Verge Companies

Space Services
- Education and Training
- Service and Consulting
- Science and Engineering
- Security & Defense

Space Observation
- Space Imagery
- Remote Sensing
- Navigation and Mapping

Space Technologies
- Robotics and UAV
- Software and Hardware
- Space Medicine

Space Development
- Space Travel & Exploration
- Spacecraft Development
- Natural Resources

Data from Space
- 5G Communication
- AI Solutions
- Data Solutions

Space Manufacturing
- Manufacturing
- Material and Product Supply

Space-Applied Businesses
- Drones
- Nanotechnologies
- Smart Materials
- Cyber Security
- Robotics
- Expert systems (AI)
- Additive Manufacturing (3D)

SpaceTech Landscape Framework

SpaceTech Analytics

Science and R&D

- Astronomy & Astrophysics
- Earth Science
- Astronautics
- Space Medicine
- Space Architecture
- Astrobiology

Frontier Technologies

- Engineering
- Robotics
- Software
- BIoTech
- Artificial Intelligence
- Machine Learning

Spacefaring

- Spaceports
- Logistics and Transportation
- Space Tourism and Private Spaceflight
- Launch Infrastructure

Satellites & Space Imagery

- Satellite Communication
- Satellite Manufacture
- Space Imagery
- Navigation
- Data Gathering
- Weather Forecasting

Spacecraft Construction

- Assembly
- Repair
- Materials & Part Production
- Orbital Infrastructure

Supporting Industries

- Training
- Consulting
- Research & Education
- HR

Necessary Advanced Space Technologies

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Propulsion

- Nuclear (Thermal and Electric)
- Light Sails
- Solar/Beamed Power Thermal
- Orbital Propellant Storage

Life Support

- Food Production
- Recycling and Waste Management
- Thermal Control
- Space Health

Orbital Assembly and Servicing

- Robotics
- Rendezvous and Proximity Operations
- Warehousing
- Docking/Mating

In-Situ Resource Utilization

- Regolith Processing
- Dust Management
- Regolith Beneficiation
- Millstock Production

Satellite Industry Terrestrial Products and Services

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Satellite Ground Equipment

- Network Equipment
- Satellite Dishes
- Mobile Phones And Automobile GNSS
- Mobile Satellite Terminals

GNSS Chipsets

- Agricultural
- Avionics
- Maritime
- Rail

Services

- Television
- Navigation
- Broadband Internet
- VSAT Webs

Sensing

- Surveying
- Weather and Climate Monitoring
- Remote Fire and Smoke Analysis

The SpaceTech Industry in Figures

September 2021

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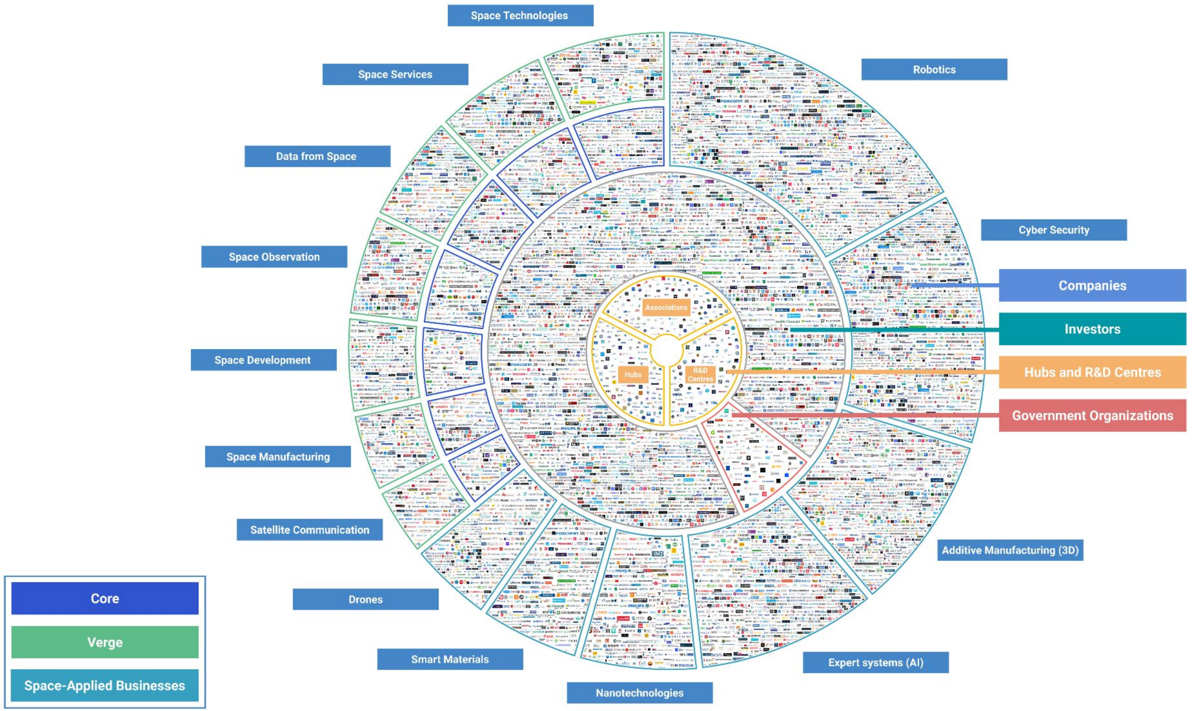
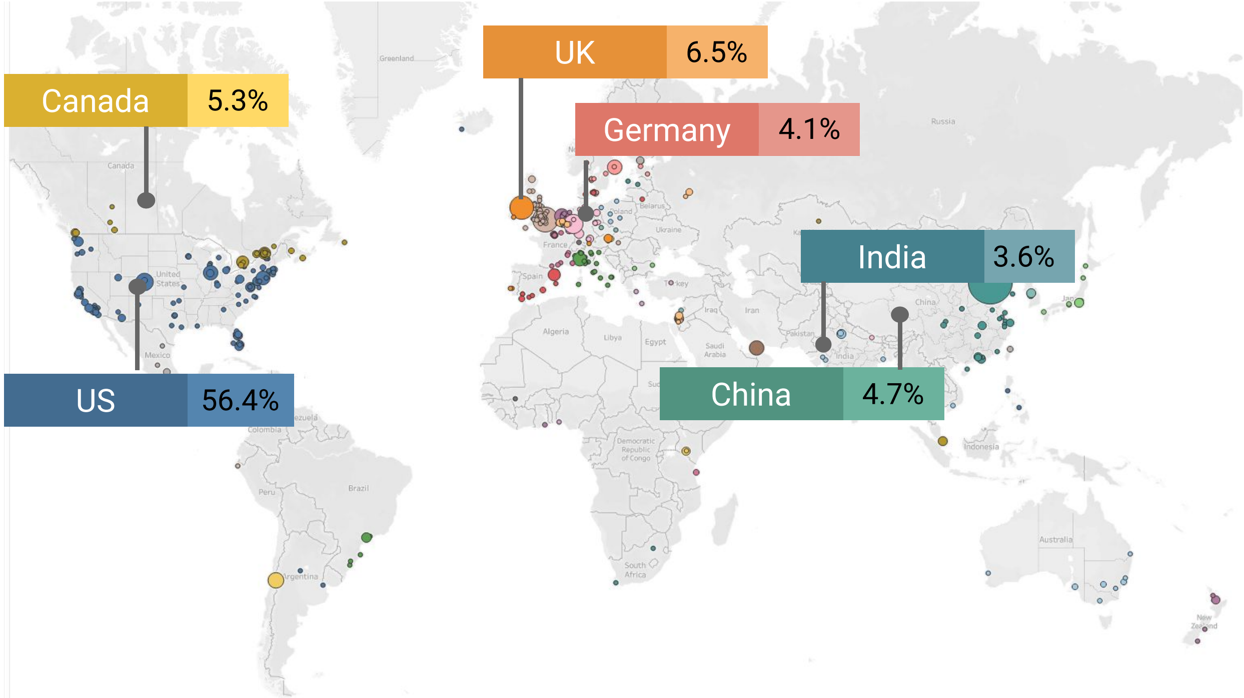
Global SpaceTech Ecosystem 2021

12,000 Companies	5,000 Investors	200 R&D Hubs and Associations	140 Government Organizations



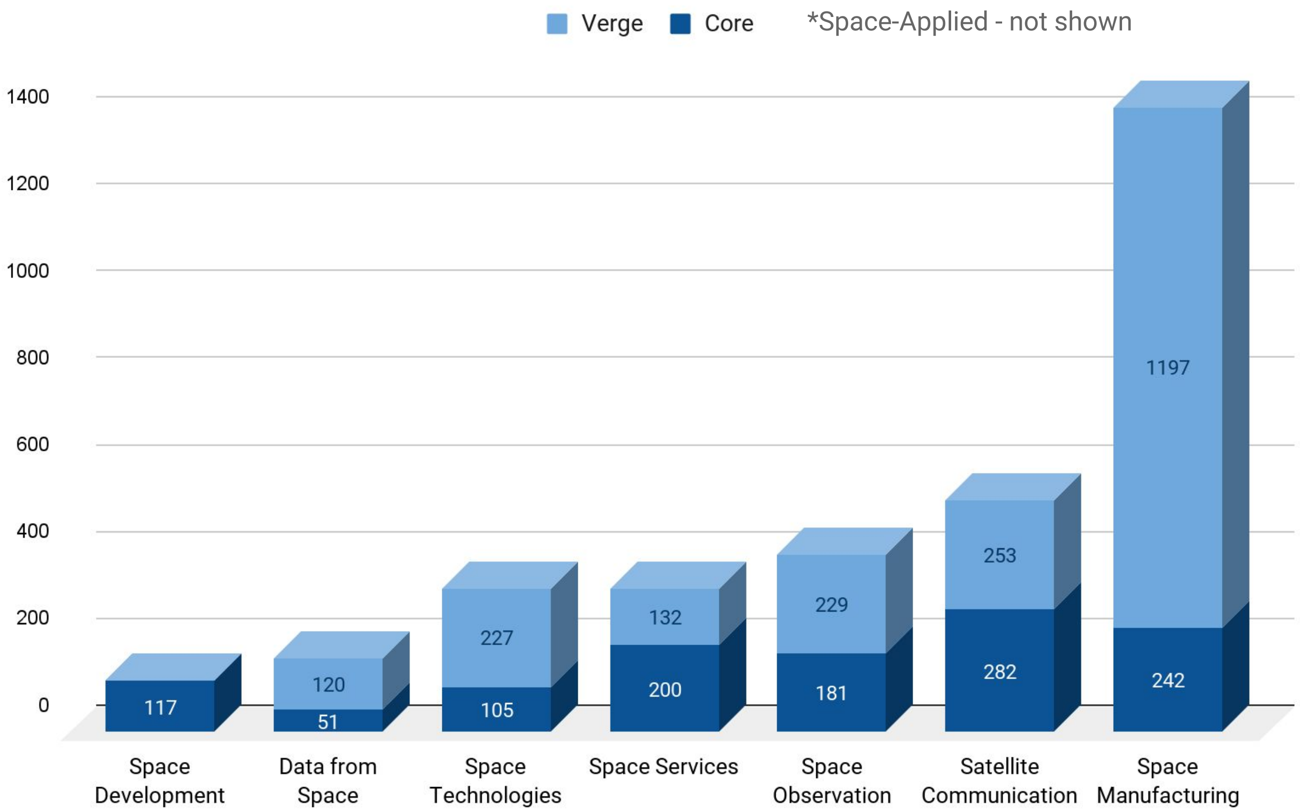
USA	Canada
UK	Germany
China	France
India	Israel
Spain	Japan
Australia	Eastern Europe
Singapore	France
Southern America	Ireland
Gulf Region	EU
Africa	Sweden

Regional Distribution of SpaceTech Companies in 2021



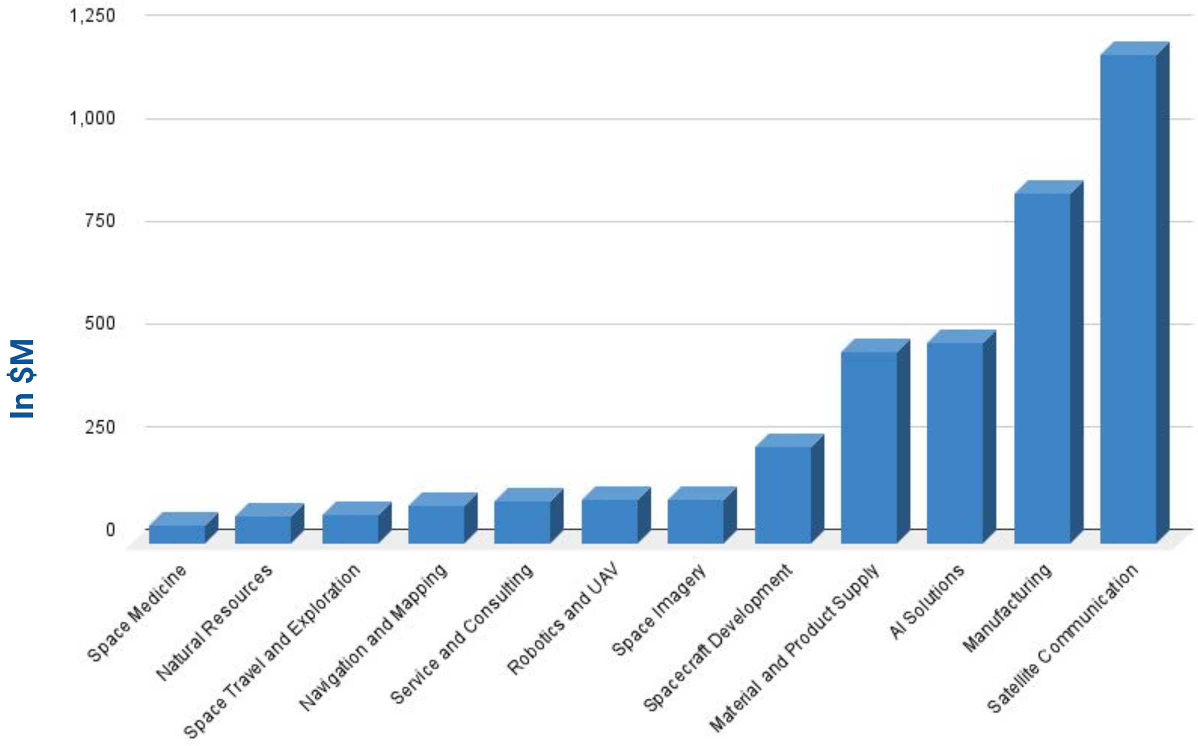
The US is firmly in the lead, representing 56.4% of the world's SpaceTech companies. The UK ranks second (6.5%), followed by Canada, China, Germany, and India at 5.3%, 4.7%, 4.1% and 3.6% respectively.

SpaceTech Core and Verge Sectors by Number of Companies in 2021



More than 3,000 core and verge SpaceTech companies have been classified into 14 categories. Space Manufacturing and Satellite Communication appear to be the two largest sectors. The Space Observation subsector is also significant in its size. There are a large number of different subsectors fueling the space industry.

Total Funding by Category in 2021

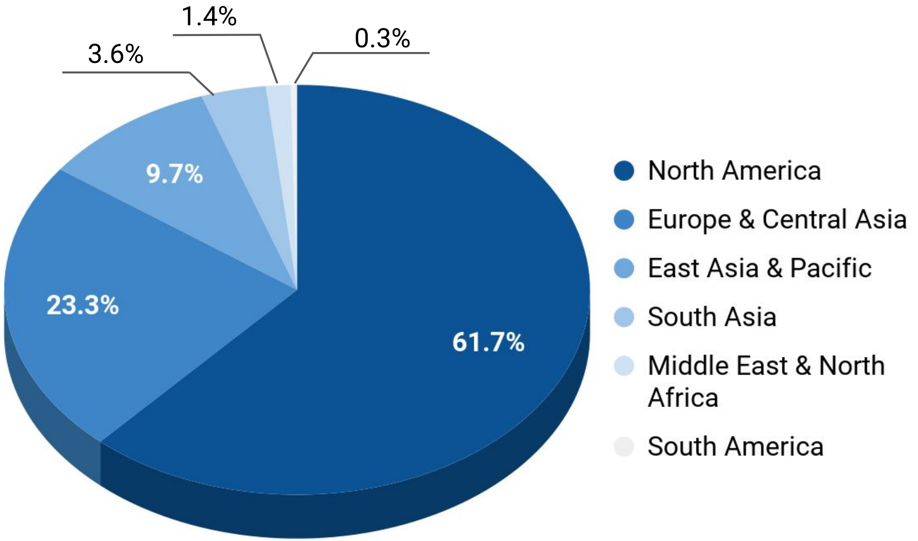


Companies in the SpaceTech Industry are currently receiving high rates of investment. This chart shows the total amounts of investment received in different categories of the SpaceTech Industry in 2021. The Satellite Communication sector holds the top position, but the graph also shows that companies in the Manufacturing, AI Solutions, and Material and Product Supply sectors are receiving high levels of investment.

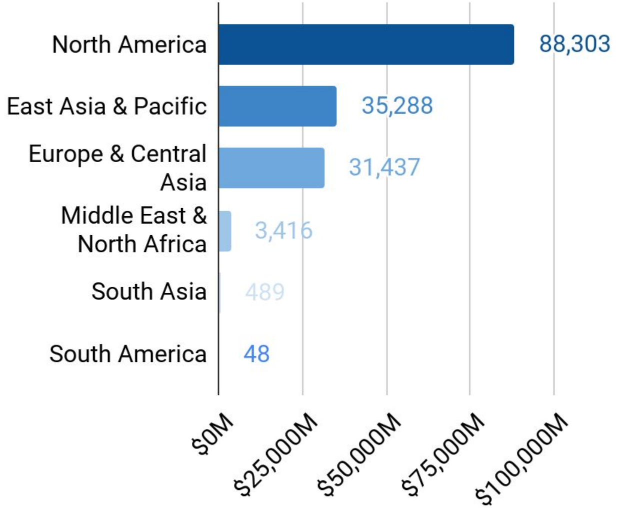
Investment Levels by Region

The US and Canada are the world leaders by the number of SpaceTech companies and levels of investment received so far in 2021. East Asia and Europe have received similar levels of funding, but Europe has a higher number of companies. Despite a small share of companies (only 1.4% of the total), the Middle East and North Africa region has received more than $3.4B in investment so far, putting it in fourth place by that measure.

Number of companies by region, %

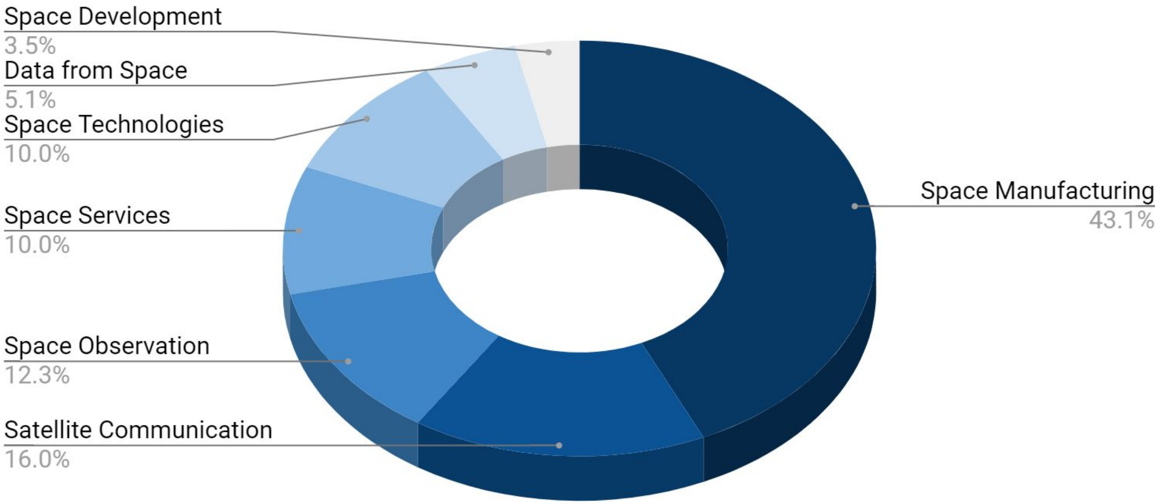


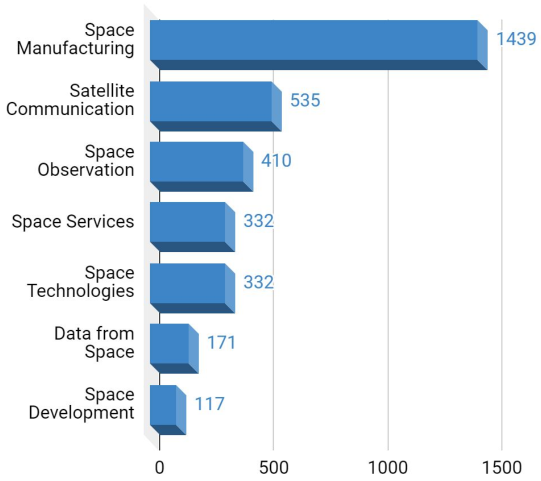
Investment levels in 2021 by region, M$



Areas of SpaceTech Usage (Core Companies by SpaceTech Subsector)

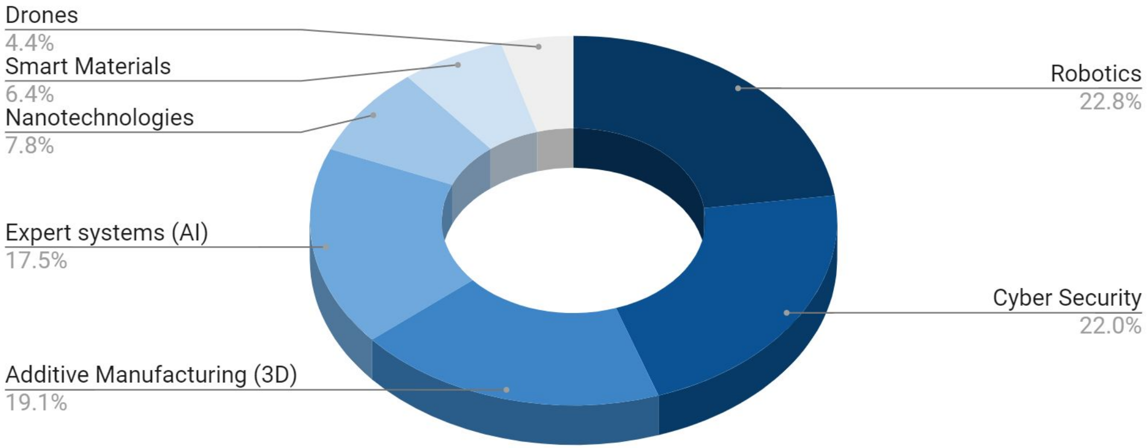
Over the past few decades, the space industry has attracted a large number of participants, with new space and non-space companies entering various industry-development chains. Most companies are involved in Space Manufacturing (over 1,400 companies, or 43.1% of all core companies). This sector is followed by the Space Communication and Space Observation sectors with 535 (16.0%) and 410 (12.3% of total) companies respectively.

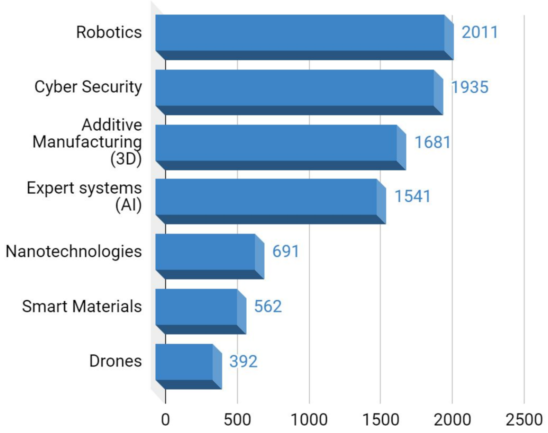




Areas of SpaceTech Usage (Verge Companies by SpaceTech Sectors)

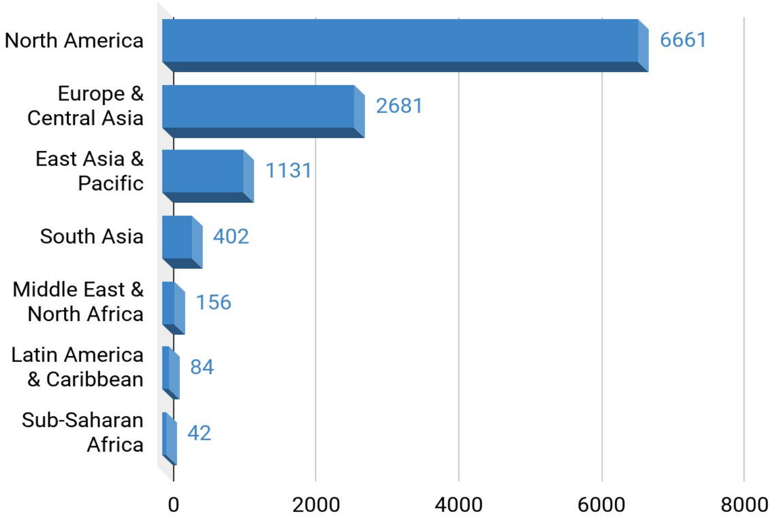
Division by sectors are almost even among verge companies. Robotics and Cyber Security engage 22.8% (2011 companies) and 22.0% (1935 companies) respectively. Additive Manufacturing and Expert systems sectors account for another 37% of all related companies (19.1% and 17.5% respectively). The rest of the sectors — Nanotechnologies, Smart Materials and Drones — In addition to other activities, are engaged in improving existing and finding new technologies to explore and develop space.



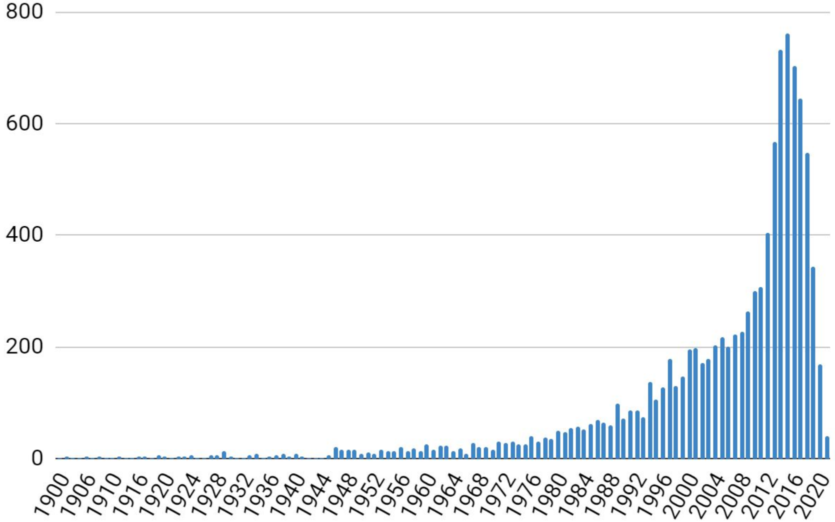


Company Regional and Year of Founding Distribution (by Number of Companies)

Number of companies by regions, 2021



Number of companies by founding year

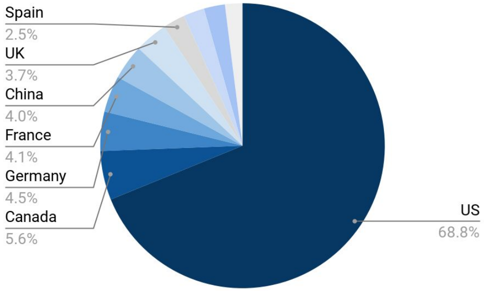


North America is the leading region by the number of SpaceTech companies, with more than 6600 companies in the sector. It is followed by Europe and Central Asia with 2681 companies and East Asia & Pacific with 1131 companies.

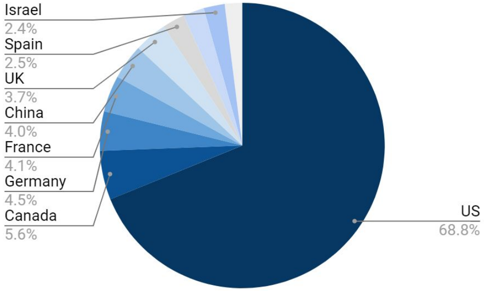
Starting in the 1990s, the number of SpaceTech companies has been growing exponentially. There was a boom of companies being founded from early 2009 through the third quarter of 2019. With the pandemic outbreak, the number of new companies dropped, but it should not change the trend of the recent decade.

Company Regional Distribution in 2021 (by Categories and Number of Companies)

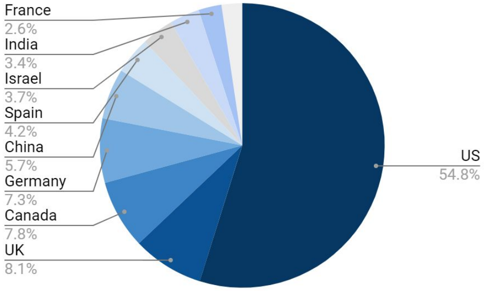
Space Manufacturing

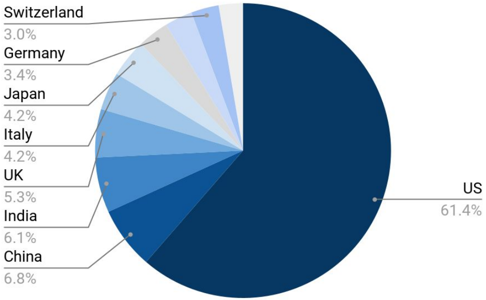


Satellite Communication

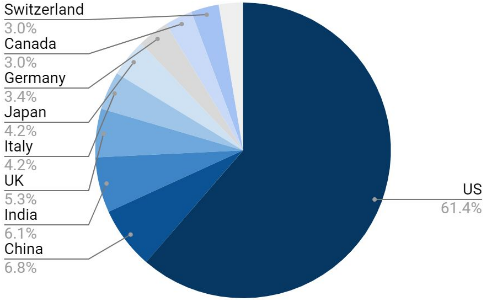


Space Observation

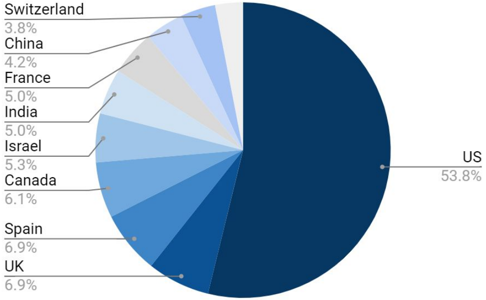




Space Services



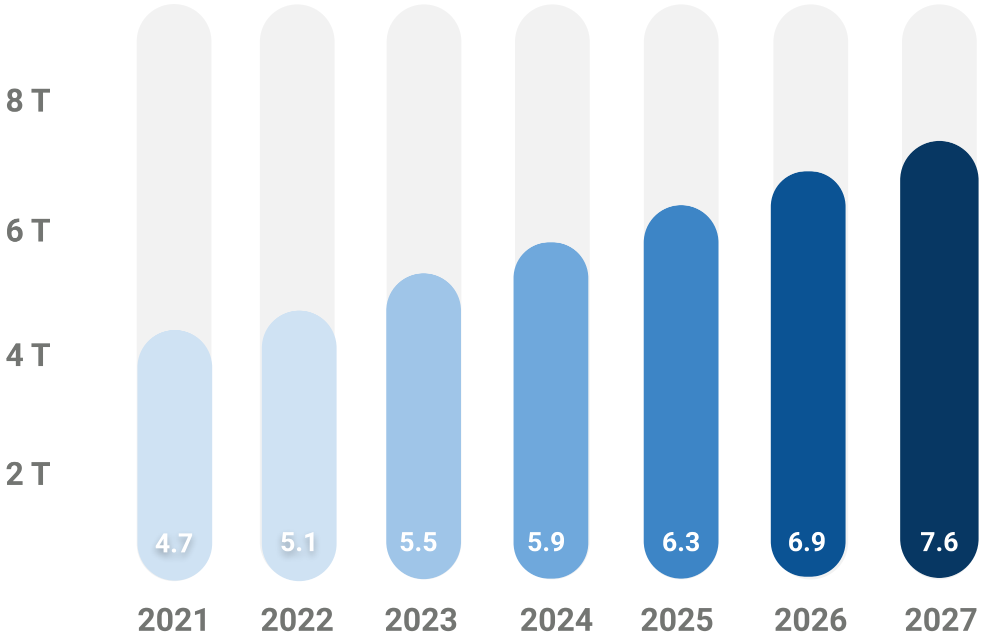
Data from Space



Space Development

The Global SpaceTech Economy

World SpaceTech Industry Capitalisation Projections, $T



Showing stable growth, the global SpaceTech capitalisation was estimated at **$4.671T** in the Q3 2021 and is expected to grow to **$10T** by 2030.

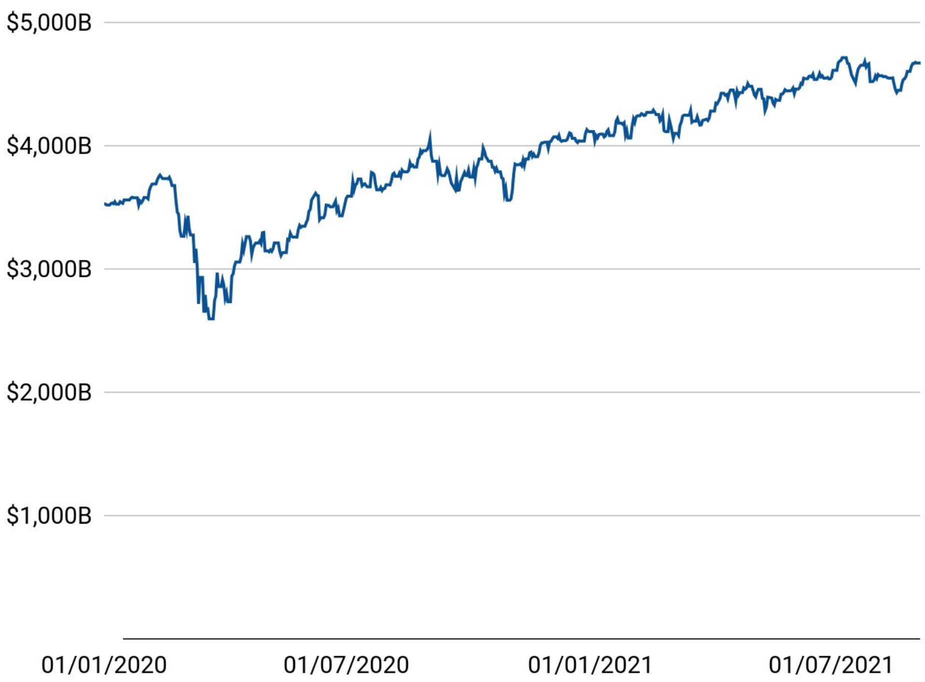
According to the most conservative estimates, it accounts for 5% of the global GDP.

This will have a dramatic impact on the annual growth in the global SpaceTech market, primarily because of the growth of the development of Satellite Technologies, the **Space Exploration** sector and advances in **IT**, **FinTech**, and other digital technologies.

Public-Sector interest in the SpaceTech industry is expected to grow. Then in May of 2020, NASA launched a crewed flight to the International Space Station (ISS) on a commercially developed U.S. rocket. The launch represented the first time that the U.S. had flown a crewed mission to the ISS since 2011.

SpaceTech Publicly Traded Companies

Cumulative Capitalisation Dynamics in $B



Despite the crisis and dramatic fall in companies' capitalisation in February 2020, the capitalization of **177 publicly traded companies** grew from **$3,526T** at the beginning of 2020 to **$4,671T** at the Q3 2021. The total capitalisation increase is 32.6%.

The largest core companies by market capitalization are Korea Aerospace Industries, IHI Corporation. AT&T Inc., and Honeywell International Inc.

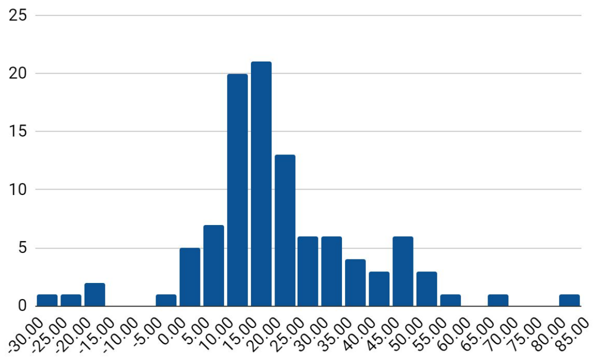
SpaceTech companies are similar to other companies in the sector (i.e. the ones that reached series B or C funding rounds), which means that the **growth** in their market capitalization can be an approximation of the dynamics in the entire sector. Anticipated growth in the industry is expected to **affect** favorable market capitalisation of SpaceTech corporations.

SpaceTech Stock Market

Our SpaceTech stock index includes more than **170** corporations operating entirely or partially in the space and IT sectors in 2021. Their market capitalisation demonstrates significant growth, exceeding that of the entire market (represented as the **S&P 500 index**), as well as the general **SpaceTech industry** indices (ROKT and ITA). The SpaceTech stock market segment is, therefore, less volatile compared to them (as measured by the standard deviation).
The negative skewness of average daily returns means that the median and mode are greater than average, therefore distribution gravitates towards greater positive returns. High kurtosis of the return distribution implies that the investor will experience occasional extreme returns (either positive or negative), and more extreme than predicted by the normal distribution of returns.

Index	Correlation with longevity market	Average daily return in 2020	Average daily volatility in 2020	Skewness	Kurtosis
SpaceTech Index	-	0.08	1.50	-0.77	11.7
ROKT	0.97	0.07	2.53	0.01	-0.96
S&P500	0.71	0.08	2.08	-0.41	-0.4
ITA	0.74	0.02	2.91	0.68	0.6

SpaceTech Stock YTD Returns Histogram



SpaceTech Projects of Non-Space Companies

SpaceTech industry is experiencing rapid growth and gaining momentum even among entities that were not space-related initially. Based on our top 20 verge Space-Tech companies we picked those of them who have recently started to contribute to the industry or just challenge themself to take a place in booming industry.

AMAZON

Project Kuiper is an initiative by Amazon to launch a constellation of Low Earth Orbit satellites that will provide low-latency, high-speed broadband connectivity to unserved and underserved communities around the world.

JACOBS

Space Exploration Challenges that the Jacobs Engineering Group is addressing:

Space radiation protection
Robotics and autonomous systems
Science and planetary destinations

INTEL

Intel officially became one of the first AI technology enablers to supply its VPU in a “satellite-as-a-service” space mission. Intel's most advanced **AI-based chip** has made it to space with the launch of **PhiSat-1**.

GARMIN

Garmin is engaged in the provision of **navigation, communications** and information devices, most of which are enabled by Global Positioning System (**GPS**) technology, which conclude a major part of the worldwide **satellite business**.

Top SpaceTech Breakthroughs

2010	2011	2014	2014	2014	2015
Hayabusa	**Messenger**	**Rosetta**	**Philae**	**ISS**	**New Horizons**
First spacecraft to return to Earth with samples from an asteroid. It was a Japanese spacecraft that explored the asteroid Itokawa. It was a long mission for Japan; the spacecraft was launched in 2003.	**First spacecraft to orbit Mercury.** Messenger was a U.S. spacecraft that studied Mercury's surface and environment. The spacecraft crashed on the planet's surface after running out of propellant on April 29, 2015.	**First spacecraft to orbit a comet.** Rosetta - European Space Agency spacecraft that carried Philae. The expectation was that the craft would help to decode the history of the solar system.	**First spacecraft to land on a comet.** Philae took seven hours to descend to the comet's surface. The lander was to fire two harpoons and use three ice screws in its legs to anchor itself to the surface of the comet.	**First 3D print in outer space.** The 3D-printer developed by Made in Space successfully produced some parts aboard the ISS. The analysis of those parts revealed that microgravity didn't affect them significantly	**First spacecraft to fly by Pluto.** New Horizons observed a large, young, heart-shaped region of ice on Pluto and found mountains made of water ice that may float on top of nitrogen ice.

Top SpaceTech Breakthroughs

2015	2015	2018	2019	2019	2021
Falcon 9	**Dawn**	**Cold Atom Lab**	**New Horizons**	**Chang'e 4**	**Perseverance**
First rocket stage to return to its launch site. SpaceX did its first relaunch of a previously flown Falcon 9 first stage on March 30, 2017. The first Falcon Heavy test flight occurred on February 6, 2018.	**First spacecraft to orbit a dwarf planet (Ceres).** Dawn was launched September 27, 2007 by the U.S, and flew past Mars on February 17, 2009, to help reshape its trajectory toward the asteroid belt.	**The first facility to produce the fifth state of matter.** A Bose-Einstein condensate was produced, in Earth's orbit by lowering atoms to ultracold temperatures in vacuum and weightlessness.	**Farthest object (2014 MU69) explored by a spacecraft.** The Kuiper Belt object MU69 has been officially named “Arrokoth”, a Native American term meaning “sky” in the Powhatan language.	**First landing on the Moon's far side.** Eight chinese devices measured radiation emitted by naturally decaying heavy elements. These spectral data helped quantify the amounts of minerals on the lunar surface.	**First aircraft to attempt controlled flight on another planet.** The rover has an onboard helicopter Ingenuity that will help in land surveying and probable landing areas.

Investment Overview

September 2021

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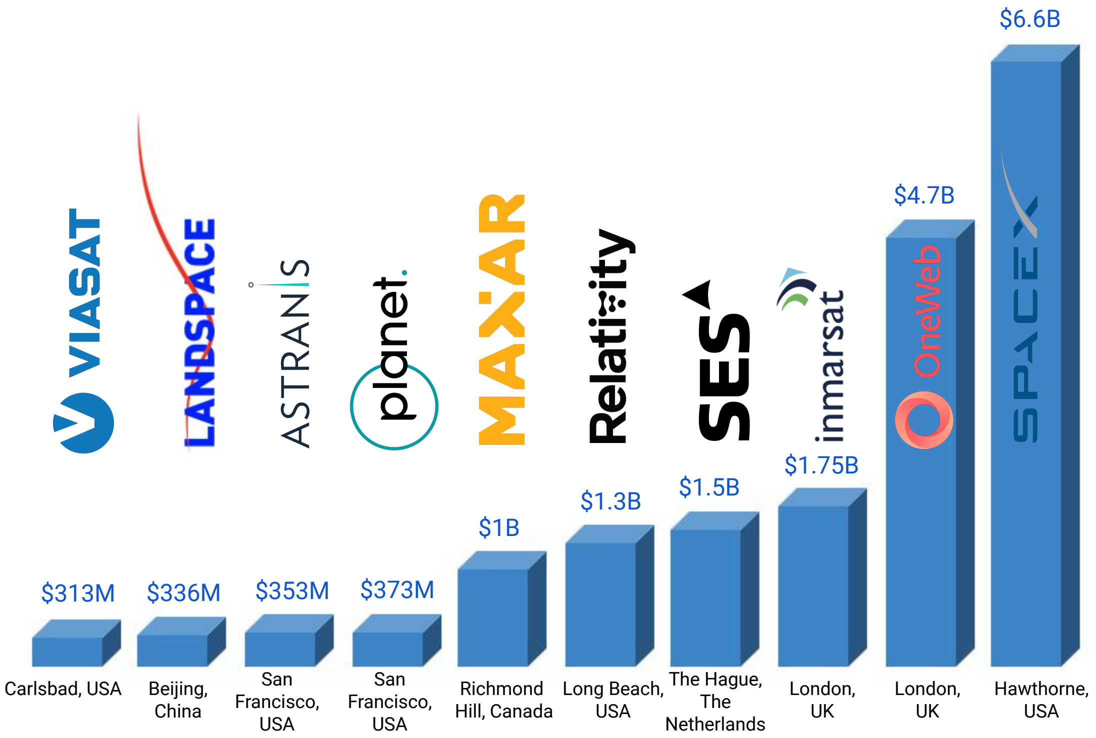
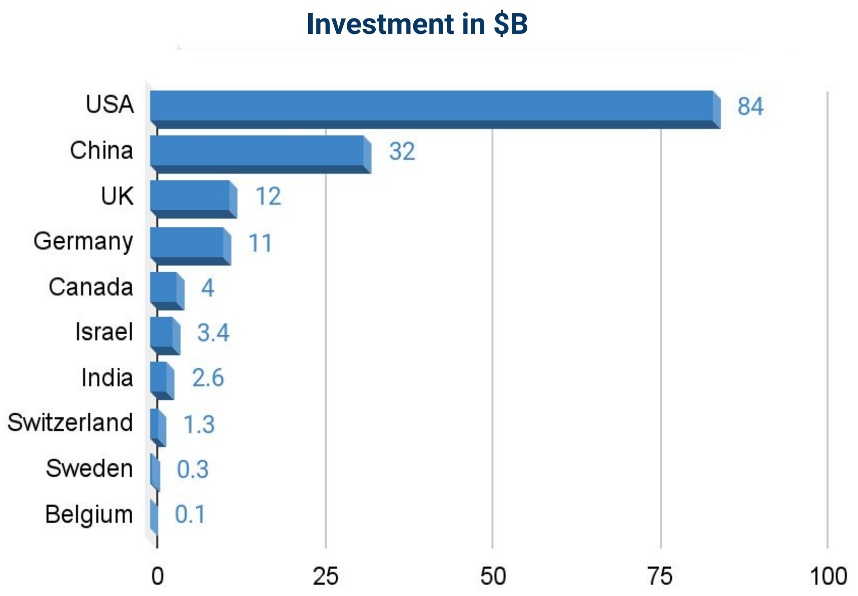
Two Thirds of Total Investment are in Only Two Companies

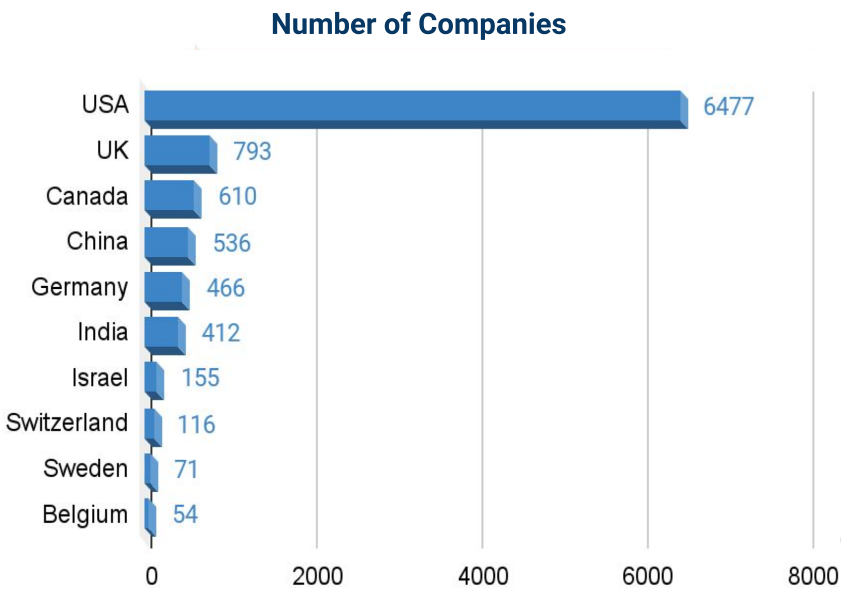
During the last couple of years, a lot of companies have gone through major improvements and changes. The more companies become Space-focused, the more investment appear in the industry, and therefore, new players and decision-makers emerge on the global SpaceTech market. We have analyzed the investment that were made into the top space-focused companies. SpaceX has the leading position with a $6.6B raised. British OneWeb follows right after Elon Musk's company with $4.7B investment. The smallest amount of investment in our list received ViaSat - $313M.

Investment in SpaceTech-Focused Companies Totalled $132.2B Globally in 2020



Top 10 Countries in SpaceTech Sector in 2021





With a total of **$84B** invested in **6,477 companies, the US** is an undisputed leader in terms of SpaceTech investment. This is approximately six times the amount invested in SpaceTech companies in **China** - the second largest country in terms of spacetech investment (**$32B** invested in **332 companies)**. China is closely followed by the **United Kingdom** where funding is mostly raised from public sources and IPOs, and not by way of private funding.

Top Manufacturing Companies

Estimated Revenue	
$500M to $10B+	DASSAULT AVIATION; NEC; LOCKHEED MARTIN; AIRBUS
$50M to $500M	SEAKR Engineering, Inc.; JP DONOVAN; LATÉCOÈRE; TURKISH AEROSPACE; EAGLEPICHER TECHNOLOGIES; Swissto12; MAXAR; Dynetics A Leidos Company
$1M to $50M	ECHODYNE; ROCKET LAB; SPACE MICRO; VORAGO TECHNOLOGIES; ACCION SYSTEMS; GILMOUR SPACE; SPECTROLAB A Boeing Company; AAC CLYDE SPACE

The top manufacturing companies in space have a range of estimated revenues, but even the small ones can be important. However, companies with the highest revenues have a wider range of products beyond those space related.

Top Satellite Companies

Total Funding	Companies
$200M-$2B	MAXAR, Astroscale, ST Engineering, AST SpaceMobile, ASTRA, AMOS by Spacecom, SPACEFLIGHT
$30M-$200M	AVANTI, SATELLOGIC, SATMEX REACHING HIGHER, bigblu broadband investor relations, TERRAN ORBITAL
$60K-$30M	gsi global surface intelligence, BELLATRIX AEROSPACE Propelling Dreams, PIXXEL, AAC CLYDE SPACE, Satelles, planetek hellas

The overall funding level of satellite manufacturing companies has greatly increased during the past six months.

SpaceTech Companies with Disruptive Technologies

The graphic represents those companies of the SpaceTech industry, that use or create technologies that can disrupt the market or create a large shift in paradigm. These companies are the first many think of after SpaceX when mentioning SpaceTech Industry. Their solutions include 3D printing rockets and space tugs, converting upper stages to space facilities, utilizing 3D printers on the International Space Station, and even constructing rotating habitats. Some of them engage in situational intelligence, cleaning up space, upgrading satellites, private lunar activities, monitoring methane leaks from space, locating space junk, or bringing space-based transparency to the industrial supply chain.

SPVs Becoming More Important Financial Instruments in the Industry

Reasons for creating special-purpose entities	
Securitization	Risk sharing
Finance	Asset transfer
Maintaining the secrecy of intellectual property	Financial engineering
Circumvent regulatory restrictions	Property investing

A special-purpose entity (special-purpose vehicle/SPV) is a special purpose company, or "project company", formed to carry out a specific project or for a specific purpose. An SPV allows more effective management of individual business processes, financial flows or even raising funds.

Some of SpaceTech SPV initiators

SPACE CAPITAL®	Space Capital SPV Fund
VOYAGER SPACE HOLDINGS	Space Fund Voyager Space SPV, LLC
SpaceFund™	Type One SpaceFund Co-Invt SPV a series of Helios Holdings Master LLC
AXIOM SPACE	Axiom Space PML SPV 1 LP
ispace	IF SPV 1st Investment Partnership

100 Leading Companies in SpaceTech Sector

September 2021

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SpaceTech Analytics

Introduction

The Spacetech industry is comprised of a large variety of spheres: from companies that study **propulsion and manufacture engines** to companies that develop **medicine for astronauts;** from those that only produce specific materials to those that design both software and hardware for launch systems. Since SpaceTech is an extremely broad industry tag, there are many companies that touch upon **space-related and applied technologies**, but don't quite reach the scale of space activities, e.g., **satellite services users**. However, there is still a very large number of companies that are on the front lines of the space frontier and have formidable market **capitalisation and investment**.

There are companies that manufacture launch systems, that manufacture satellites for all purposes, and there are companies that support these companies, or utilize their services. Other companies are lower tier, which manufacture **crucial parts of the this space hardware** (e.g. thrusters for space station modules). Others develop new technologies, that can be capitalized on in the near future. Investment is pouring into all of these companies. This section on space finance will describe them.

100 Leading Companies in SpaceTech Sector*

0.5-1K

Virgin Orbit
eutelsat
NEC
Integral Systems
Advantech Wireless
BlueHalo
ENSCO
Turbocam International
EaglePicher Technologies

1-5K

USA United Space Alliance
LinQuest Corporation
SES
Thaicom
ViaSat
Nexteam Group
OHB
SEM AFO
ULA
EchoStar
Magellan Aerospace
ASRC Federal
SSL
Kratos Defense & Security Solutions
sonaca aircraft
TESAT Spacecom
航天宏图 Piesat
Gilat
Radiall
Astronics Corporation
CASC 中国航天
Cytec
Aerojet Rocketdyne Holdings, Inc.
Aerospace
SPS Technologies
exede Internet
Comtech Xicom Technology
Scitor Corporation
Avibras
HEICO Component Repair Group
AKKA
DRS Defense Solutions
SNC Sierra Nevada Corporation
SENER
Isdefe
Vicor
lisi
Weinschel Associates & Broadband RF & Microwave Solutions
CASIL
Maxar Technologies
Latécoère
KAI Korea Aerospace Industries, Ltd.
Ball
inmarsat

5-10K

Dassault Aviation
QinetiQ
SpaceX
Yuzhnoye design office
Teledyne Technologies Everywhereyoulook
Carlisle Interconnect Technologies
Dynetics Technical Solutions
AirBorn
OSI Systems
TCS TeleCommunication Systems
Turkish Aerospace
Space Systems Loral
Curtiss-Wright
elecnor
EnerSys
Leica Geosystems
DigitalGlobe
Türksat
Orbital
arqiva
IRZ
Microsemi

>10K

United Technologies
Pall Corporation
Mitsubishi Heavy Industries
BSNL Connecting India Faster
Safran Aerospace · Defence · Security
BAE Systems
Northrop Grumman
華潤創業有限公司 China Resources Enterprise, Limited
Boeing
Keysight Technologies
IHI
Spirit Aerosystems
Lockheed Martin
UTC Aerospace Systems
NavCom A John Deere Company
L3
Orbital ATK
Amgen
Collins Aerospace A United Technologies Company
Microchip
ST Electronics

* (According to the Number of Employees)

100 Leading Core Companies in SpaceTech Sector (by Number of Employees)

1	Advantech Wireless	12	BAE Systems	23	Curtiss-Wright
2	Aerojet Rocketdyne Holdings	13	Ball Aerospace	24	Cytec Industries
3	AirBorn	14	Bharat Sanchar Nigam	25	Dassault Aviation
4	Airbus	15	BlueHalo	26	DigitalGlobe
5	Akka Belgium	16	Boeing	27	DRS Defense Solutions
6	Amgen	17	Carlisle Interconnect Technologies	28	Dynetics
7	Anaren	18	CASIL	29	EaglePicher Technologies
8	Arqiva	19	China Resources	30	EchoStar
9	ASRC Federal	20	China Spacesat Technology	31	ELECNOR
10	Astronics	21	Collins Aerospace	32	EnerSys
11	Avibras	22	Comtech Xicom Technology	33	ENSCO

100 Leading Core Companies in SpaceTech Sector (by Number of Employees)

34	Eutelsat
35	Exede Satellite Internet
36	Gilat Satellite Networks
37	Heico
38	IHI Group
39	Inmarsat Plc
40	IRZ
41	Isdefe
42	Keysight Technologies
43	Korea Aerospace Industries
44	Kratos Defense
45	L-3 Communications
46	Latecoere
47	Leica Geosystems
48	LinQuest
49	LISI AEROSPACE
50	Lockheed Martin
51	Loral
52	Magellan Aerospace
53	Maxar Technologies
54	Microchip Technology
55	Microsemi
56	Mitsubishi Heavy Industries
57	NavCom Technologies
58	NEC Aerospace Systems
59	Nexteam Group
60	Northrop Grumman
61	OHB System
62	Orbital ATK
63	Orbital Sciences Corporation
64	Osi Systems
65	Pall
66	PIESAT

100 Leading Core Companies in SpaceTech Sector (by Number of Employees)

67	QinetiQ
68	Radiall Corp
69	Safran
70	Scitor Corporation
71	Semafo
72	Sener
73	SES Networks
74	Sierra Nevada Corporation
75	Singapore Technologies Electronics
76	Sonaca
77	Space Shuttle Hi-Tech
78	SpaceX
79	Spirit Aerosystems
80	SPS Technologies
81	SSL
82	TeleCommunication Systems
83	Teledyne Technologies
84	Tesat
85	Thaicom Public Company
86	The Aerospace Corporation
87	TriQuint Semiconductor
88	Turbocam International
89	Turkish Aircraft Industries
90	Turksat A.S.
91	United Launch Alliance
92	United Space Alliance
93	United Technologies
94	UTC Aerospace Systems
95	ViaSat
96	Vicor Corporation
97	Virgin Orbit
98	Yuzhnoye State Design Office
99	Weinschel
100	Wesco Aircraft

100 Leading Investors in SpaceTech Sector

September 2021

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100 Leading Investors in SpaceTech Sector (by Number of Investment)

1	Y Combinator	12	IDG Capital	23	Index Ventures
2	EASME	13	Kleiner Perkins	24	Khosla Ventures
3	Techstars	14	Venture Kick	25	General Catalyst
4	MassChallenge	15	Plug and Play Tech Center	26	Start-Up Chile
5	500 Startups	16	Right Side Capital Management	27	GV
6	SOSV	17	Wayra	28	Threshold
7	New Enterprise Associates	18	Bessemer Venture Partners	29	Goldman Sachs
8	Accel	19	SV Angel	30	Alumni Ventures Group
9	Sequoia Capital	20	Andreessen Horowitz	31	First Round Capital
10	Intel Capital	21	NYSERDA	32	Norwest Venture Partners
11	Crowdcube	22	Lightspeed Venture Partners	33	Battery Ventures

100 Leading Investors in SpaceTech Sector (by Number of Investment)

34	Venrock
35	Greylock
36	Creative Destruction Lab
37	GGV Capital
38	Sequoia Capital China
39	ZhenFund
40	Silicon Valley Bank
41	Bpifrance
42	High-Tech Grunderfonds
43	Canaan Partners
44	Insight Partners
45	Founders Fund
46	Ocado Group
47	Tiger Global Management
48	Menlo Ventures
49	Redpoint
50	Greycroft
51	Enterprise Ireland
52	Polaris Partners
53	Benchmark
54	Foundation Capital
55	Tencent
56	Mayfield Fund
57	Mastercard
58	Matrix Partners China
59	Kima Ventures
60	Brand Capital
61	Matrix Partners
62	CRV
63	True Ventures
64	Salesforce Ventures
65	Tech Coast Angels
66	Global Founders Capital

100 Leading Investors in SpaceTech Sector (by Number of Investment

67	RRE Ventures	78	OrbiMed	89	Carbon Trust
68	Pario Ventures	79	BDC Venture Capital	90	NortonLifeLock
69	Atlas Venture	80	BoxGroup	91	National Science Foundation
70	Neotribe Ventures	81	Five Arrows Principal Investments	92	Spark Capital
71	Alchemist Accelerator	82	Highland Capital Partners	93	Wavemaker Partners
72	Startupbootcamp	83	Innovate UK	94	Blue Cloud Ventures
73	Felicis Ventures	84	Slow Ventures	95	Qualcomm Ventures
74	National Institutes of Health	85	HAX	96	Partech
75	AngelList	86	Berkeley SkyDeck	97	Founder Collective
76	Innovation Works	87	FundersClub	98	Shenzhen Capital Group
77	Bain Capital Ventures	88	3i Group	99	Spero Ventures
				100	Social Starts

30 SpaceTech Core Investors

1	Copernic Space	11	IoT Tribe Space	21	Space Ventures Investors
2	CosmiCapital	12	NewSpace Capital	22	Spaced Ventures
3	Delta-V	13	NewSpace NYC	23	SpaceFund
4	Earth Space Robotics	14	Noosphere Venture Partners	24	SpaceStarters
5	EBAN Space	15	Orbital Ventures	25	SpaceTec Capital
6	Explorer 1 Fund	16	Promus Ventures	26	SPARX Space Frontier Fund
7	Future Space Accelerator	17	Seraphim Capital	27	Starbridge Venture Capital
8	GEN Space	18	Silicon Valley Space Center	28	Starburst Ventures
9	Hemisphere Ventures	19	Space Angels	29	Type One Ventures
10	Interplanetary Fund Management Group	20	Space Capital	30	Voyager Space Holdings

Thirty SpaceTech Core Investors

Here are represented thirty investment funds that invest only into the space technology and exploration industry. Some of them have already gained much revenue and status, while others are only at the beginning of their way.

Top Publicly Traded Companies in SpaceTech Industry

September 2021

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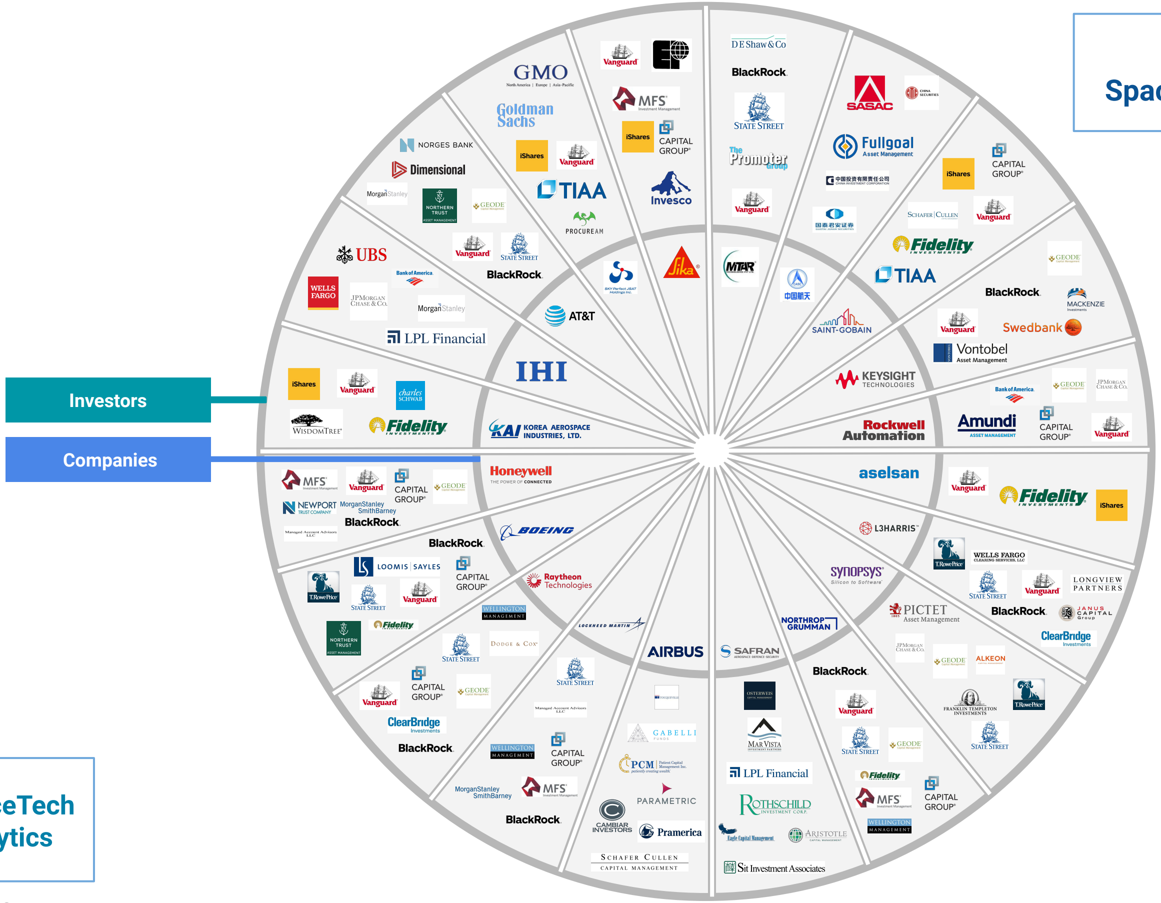
Top 20 Core Publicly Traded Companies by Capitalization in 2021

1	Korea Aerospace Industries	$3.2T
2	IHI Corporation	$368.4B
3	AT&T Inc.	$194.4B
4	Honeywell International Inc.	$157.7B
5	The Boeing Company	$127.9B
6	Raytheon Technologies Corporation	$126.1B
7	SKY Perfect JSAT Holdings Inc.	$125.5B
8	Airbus SE	$106.2B
9	Lockheed Martin Corporation	$100.7B
10	Northrop Grumman Corporation	$58.6B
11	Safran SA	$53.5B
12	Sika AG	$51.5B
13	Synopsys, Inc.	$51.0B
14	L3Harris Technologies, Inc	$46.7B
15	MTAR Technologies Limited	$39.5B
16	Compagnie de Saint-Gobain S.A	$38.6B
17	Rockwell Automation, Inc.	$37.7B
18	ASELS	$36.1B
19	Keysight Technologies, Inc.	$33.0B
20	China Spacesat	$33.0B

Top 20 Verge Publicly Traded Companies by Capitalization in 2021

1	Amazon.com, Inc	$1.8T
2	Hindustan Aeronautics	$456.5B
3	Comcast Corporation	$274.3B
4	Intel Corporation	$218.1B
5	Cyient Limited	$113.1B
6	Analog Devices, Inc.	$61.6B
7	TE Connectivity Ltd.	$50.6B
8	Kuang-Chi Technologies Co.	$50.3B
9	Microchip Technology Incorporated	$43.3B
10	Mitsui & Co.	$36.7B
11	Garmin Ltd.	$34.3B
12	TransDigm Group Incorporated	$33.2B
13	China Aerospace Times Electronics CO.	$21.6B
14	ON Semiconductor Corporation	$19.5B
15	Jacobs Engineering Group Inc.	$17.6B
16	Shanghai Huace Navigation Technology	$15.7B
17	Beijing Xinleineng Technology	$14.3B
18	Sumitomo Precision Products	$12.8B
19	Alicon Castalloy Limited	$11.1B
20	Dassault Aviation SA	$8.7B

Top 20 Core Publicly Traded Companies by Capitalization in 2021



The Largest Shareholders of Top SpaceTech Publicly Traded Companies

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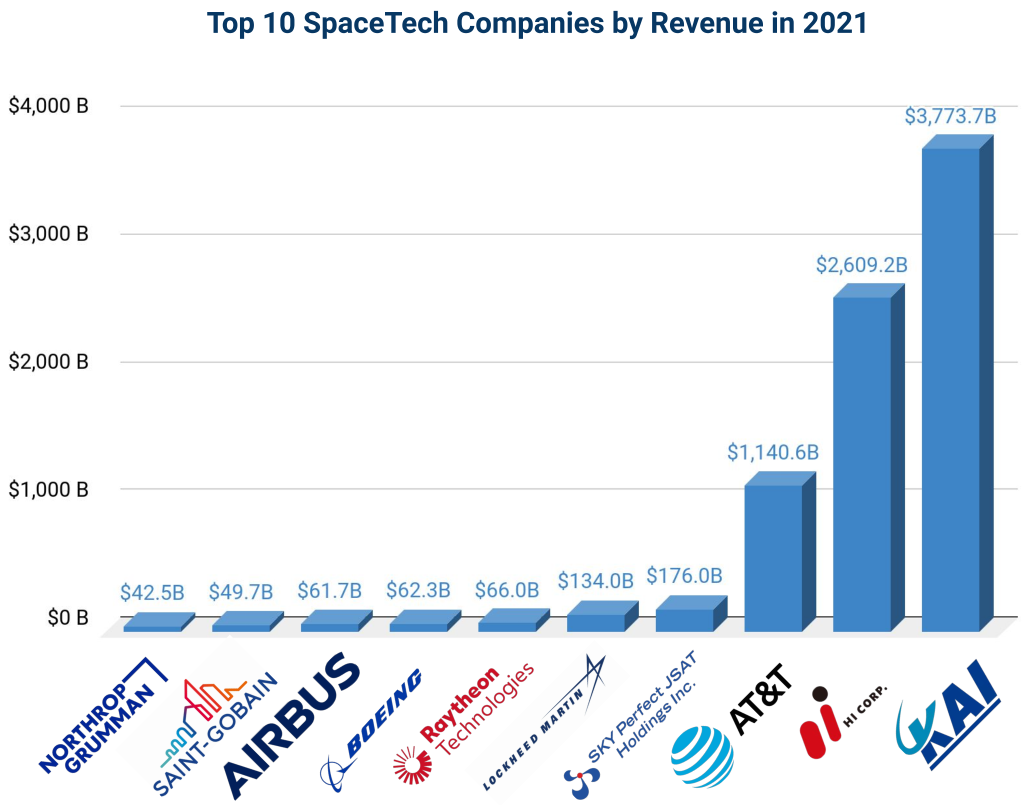
Latest and Upcoming IPOs

Company	IPO Date	Description
Mtar Technologies	15.03.2021	MTAR Technologies is a nuclear and space-equipment manufacturing company.
MDA	07.04.2021	MDA is an international space-mission partner, and a robotics, satellite systems, and geointelligence pioneer.
Astra Space	30.06.2021	Astra is a rocket-launch startup that provides satellite delivery and launch services.
Momentus	13.08.2021	Momentus offers orbital infrastructure services necessary to enable enterprise and commercial activities to flourish in space.
Spire Global	17.08.2021	Spire Global Inc. is a space-to-cloud data analytics company utilizing satellites to provide maritime, aviation, and weather tracking.
Virgin Orbit	23.08.2021	Virgin Orbit operates LauncherOne, a flexible air-launched launch service for commercial and government-built small satellites.
Rocket Lab	25.08.2021	Rocket Lab delivers a range of complete rocket systems and technologies for fast and low-cost payload deployment into orbit, and plans a lunar mission.
Redwire	08.09.2021	With its space-assembly technology, Redwire is uniquely positioned to assist its customers in solving the complex challenges of future space activities.
BlackSky	10.09.2021	BlackSky Global is a satellite-imaging-as-a-service startup based in Seattle.
Accion Systems	upcoming	Accion Systems provides in-space propulsion systems for satellites based on proprietary technology developed at MIT.

Top Ten Companies by Revenue

- In 2021, Korea Aerospace Industries (KAI) reported the largest total revenue at **$3,773.6B.**
- The second largest company, which reported **$2,609.2B,** was HI Corporation.
- Valued at **$1,140.6B,** the third largest SpaceTech company in 2021 was AT&T Inc.
- With the revenue **$176.0B** SKY Perfect JSAT Holdings Inc. was the fourth largest company in the industry.
- The fifth largest company**,** with **$134.0B,** was the US company Lockheed Martin.
- Raytheon Technologies and the Boeing corporation with revenue **of $66.0B and $62.3B** were the sixth and seventh largest companies respectively.
- **With revenue of $61.7B,** Airbus SE is considered to be the eighth largest company by revenue in the industry.
- With revenues of **$49.7B** and **$42.5B,** Saint-Gobain and Northrop Grumman are the ninth and tenth largest in the industry.



Space Focused ETFs: ARK Space Exploration and Innovation ETF

ARK INVEST

The ARK Space Exploration & Innovation ETF has an objective to grow its capital through investing at least 80% of its assets in domestic and foreign equity securities of companies that are engaged in the Fund's investment theme of Space Exploration and innovation. The fund is actively managed and they state, that they are investing in those companies that are "benefitting from technologically enabled products"

ETF Ticker	ARKX
Inception Date	March 3, 2021
Exchange	Cboe BZX Exchange
Expense Ratio	0.75%
Net Assets	$627M
# of Holdings	47
Portfolio Manager	Catherine D. Wood

Top 5 Holdings			
Weight	**Company**	**Ticker**	**Shares Held**
9.88%	TRIMBLE INC	TRMB	621,811
7.57%	THE 3D PRINTING ETF	PRNT	1,127,419
6.06%	IRIDIUM COMMUNICATIONS INC	IRDM	782,475
5.75%	KRATOS DEFENSE & SECURITY	KTOS	1,472,435
5.63%	L3HARRIS TECHNOLOGIES INC	LHX	142,352

Source: ARK Invest

Space Focused ETFs: Procure Space ETF

PROCUREAM

The Procure Space ETF seeks investment results that correspond generally to the performance, before the Fund's fees and expenses, of an equity index called the "S-Network Space Index." The Fund invests 80% of its total assets in companies that receive at least 50% of their revenue or profits from one or more segments of the space industry. This policy is "non-fundamental," however, which means that it may be changed without the majority of the Fund's outstanding shares.

ETF Ticker	UFO
Inception Date	November 4, 2019
Exchange	Nasdaq
Expense Ratio	0.75%
Net Assets	$120M
# of Holdings	36
Portfolio Manager	Lewellyn Tong Desai

Top 5 Holdings			
Weight	**Company**	**Ticker**	**Shares Held**
5.89%	GARMIN LTD	GRMN	41,948
5.74%	TRIMBLE INC	TRMB	75,945
5.71%	IRIDIUM COMMUNICATIONS INC	IRDM	152,042
5.50%	GLOBALSTAR INC	GSAT	3,790,531
5.22%	SES SA	SESG FP	731,792

Source: PROCUREAM

Space Focused ETFs: SPDR S&P Kensho Final Frontiers

STATE STREET GLOBAL ADVISORS SPDR®

The S&P Kensho Final Frontiers Index is designed to invest in companies whose products and services are driving innovation in the exploration of deep space and the deep ocean. The Index also comprises the deep-sea exploration components of the S&P Kensho Drones Index. It tracks companies that produce products and services that enable space travel, exploration, and ultimately settlement, or are a necessary component of the supply chain for such products and services.

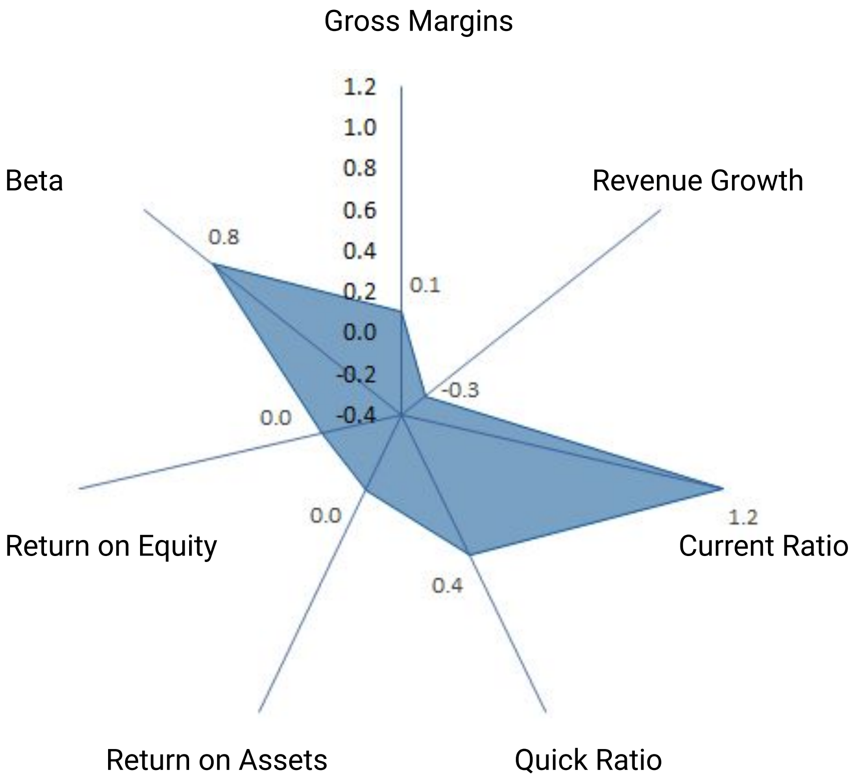
ETF Ticker	ROKT
Inception Date	October 22, 2018
Exchange	NYSE ARCA EXCHANGE
Expense Ratio	0.45%
Net Assets	$22.5M
# of Holdings	34
Portfolio Manager	SSGA Funds Management, Inc.

Top 5 Holdings			
Weight	**Company**	**Ticker**	**Shares Held**
5.02%	IRIDIUM COMMUNICATIONS INC	IRDM	23,396
4.45%	L3HARRIS TECHNOLOGIES INC	LHX	4,139
4.39%	TELEDYNE TECHNOLOGIES INC	TDY	2,150
4.12%	HONEYWELL INTERNATIONAL	HON	3,952
4.02%	NORTHROP GRUMMAN	NOC	2,416

Source: SPDR

Korea Aerospace Industries

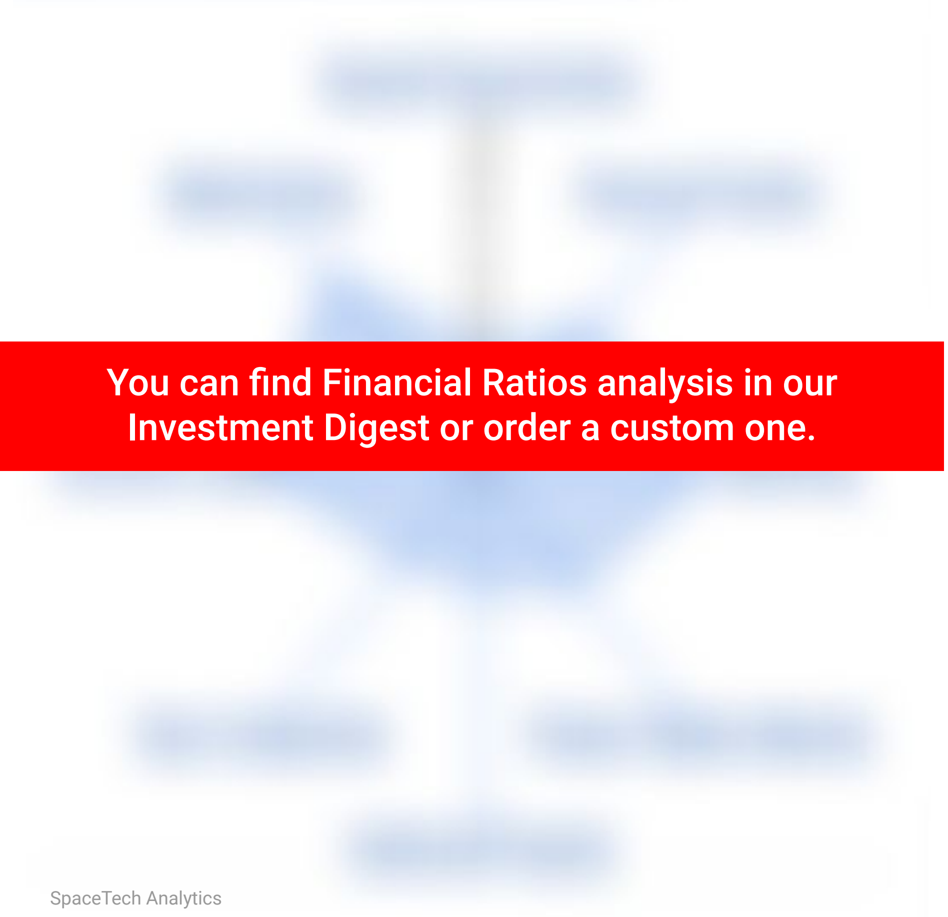
KOREA AEROSPACE INDUSTRIES, LTD.



Korea Aerospace Industries manufactures multi-purpose satellites, and space-launch vehicles. It also sells aircrafts and airframe components in South Korea, as well as aircraft maintenance, and aircraft training systems; repair, and overhaul services.

Ticker	Mean Daily Return	Volatility of Daily Returns	Growth After IPO	EBITDA (B$)
047810.KS	-0.01%	2.73%	38.68%	222.5

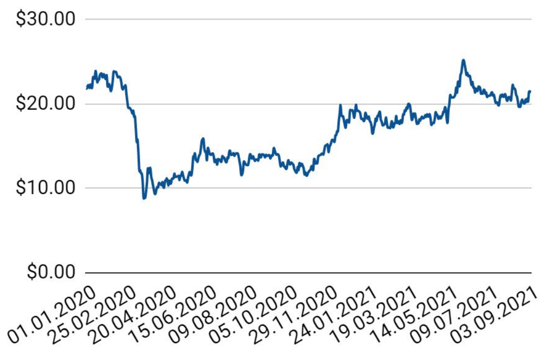
IHI Corporation



You can find Financial Ratios analysis in our Investment Digest or order a custom one.

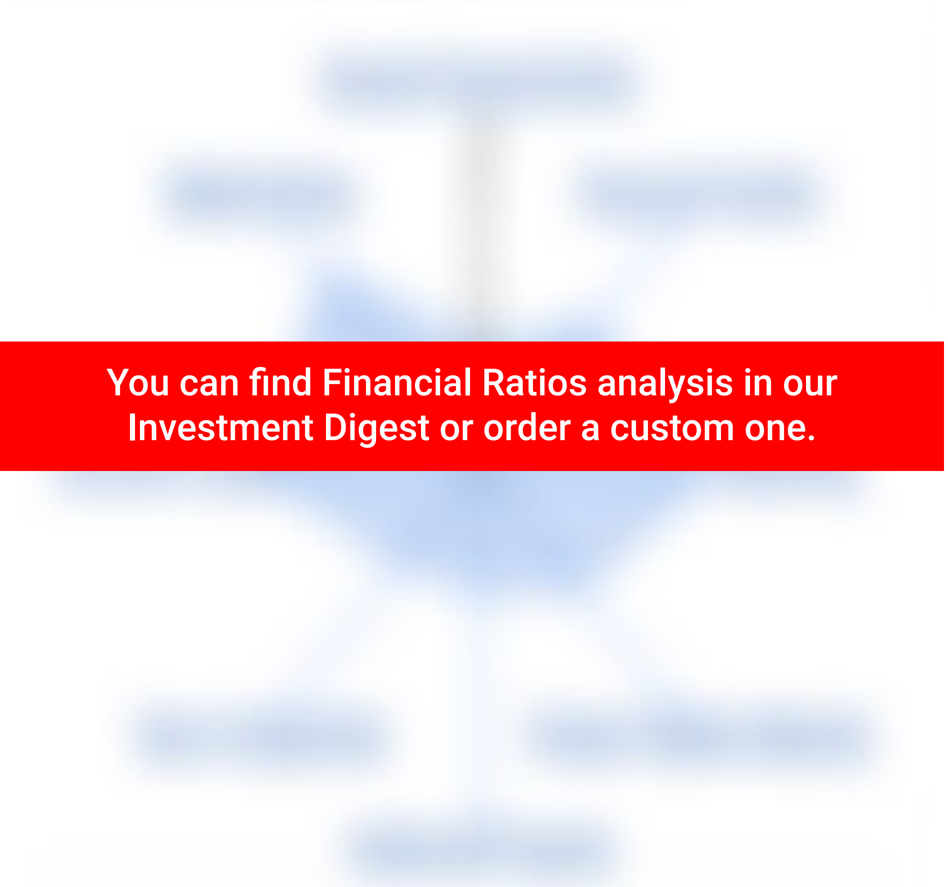
IHI Corporation operates in aero engine, space, and defense, and other business areas. It offers rocket systems, and aero engines and air traffic control systems; as well as engages in the space exploration business. It operates in Japan, China, Asia, North America, Central and South America, Europe, and internationally.

Stock price (in $)



Ticker	Mean Daily Return	Volatility of Daily Returns	Growth After IPO	EBITDA (B$)
7013.T	0.00%	3.15%	114.47%	110.5

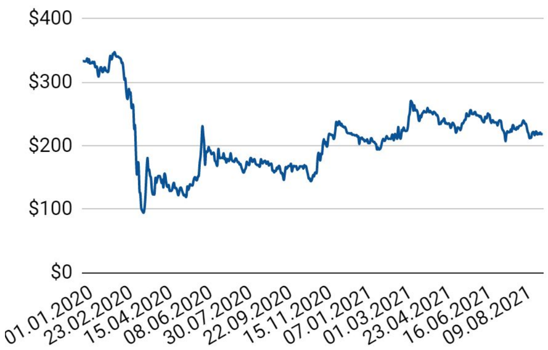
AT&T Inc.



You can find Financial Ratios analysis in our Investment Digest or order a custom one.

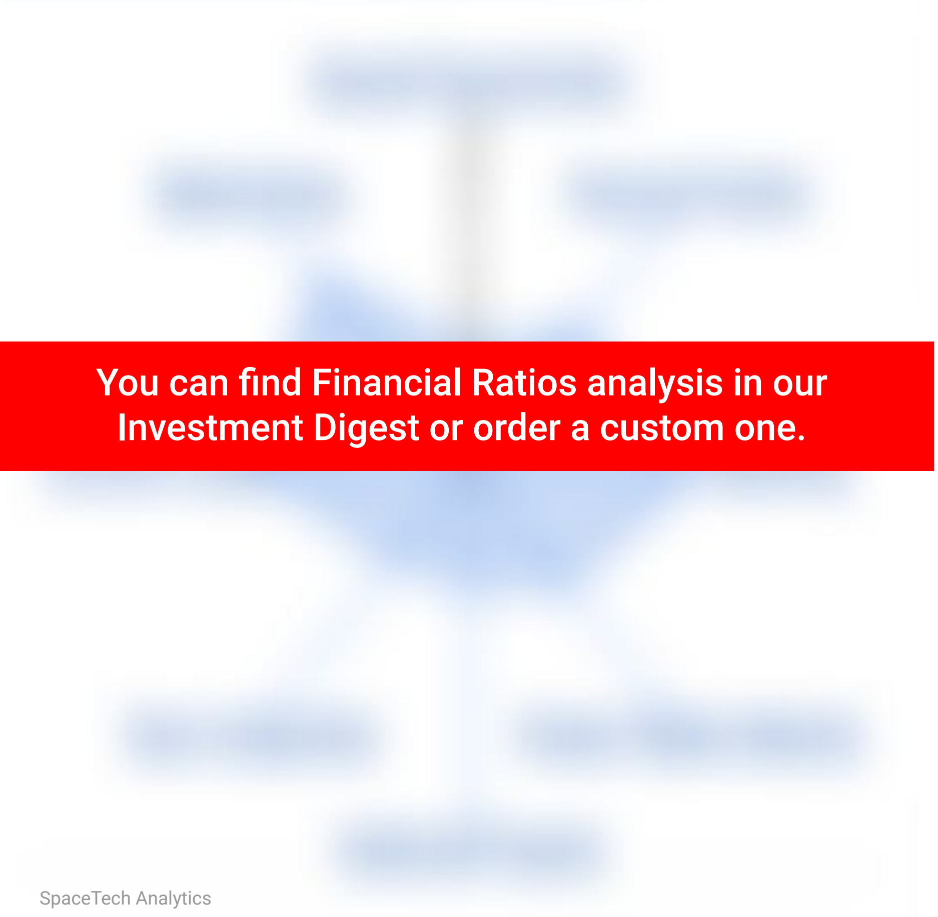
AT&T Inc. provides telecommunication, media, and technology services worldwide. AT&T is helping NASA improve communications across its Deep Space Network (DSN). AT&T is also providing a high-speed VPN to connect DSN's giant radio antennas around the world.

Stock price (in $)



Ticker	Mean Daily Return	Volatility of Daily Returns	Growth After IPO	EBITDA (B$)
T	-0.07%	1.71%	455.85%	52.8

Honeywell International Inc.



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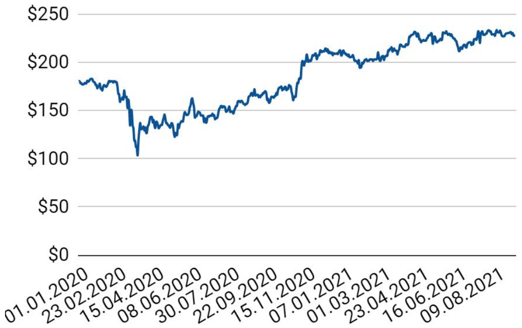
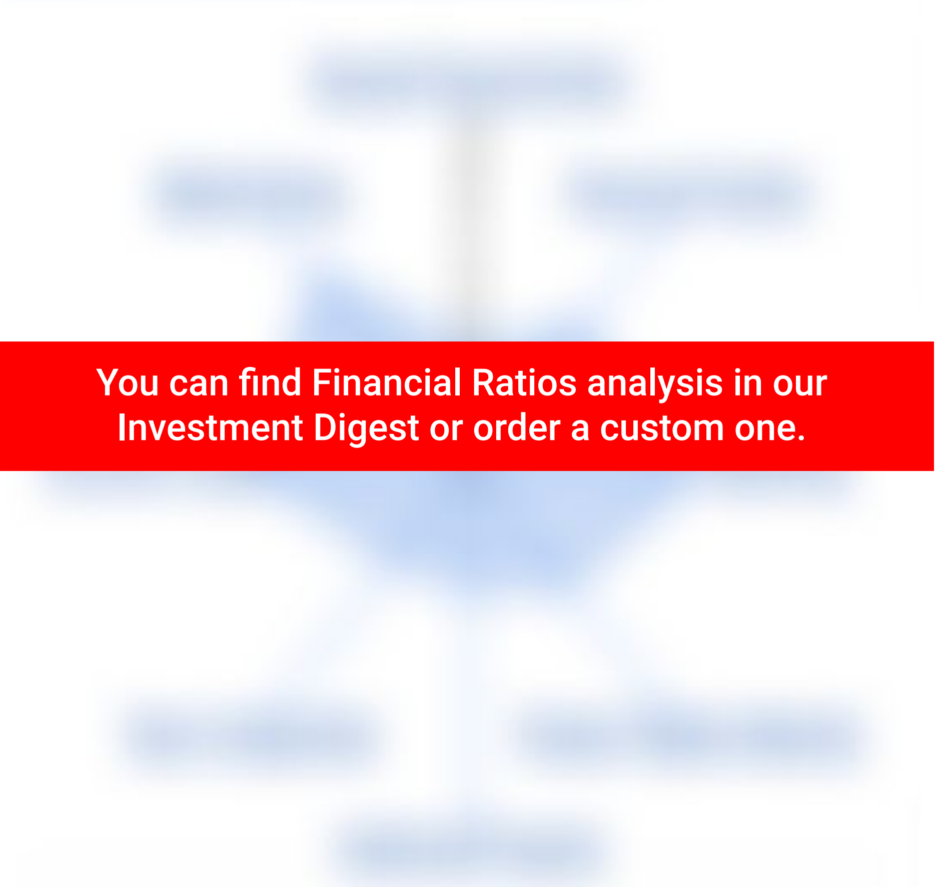
Honeywell International Inc. operates as a diversified technology and manufacturing company worldwide. Its Aerospace segment offers full range of power units, integrated avionics, satellite and space components, and and propulsion, as well aircraft wheels and brakes; spare parts, engine controls, flight safety, communications and navigation systems, and repair, overhaul, and maintenance services.

Stock price (in $)



Ticker	Mean Daily Return	Volatility of Daily Returns	Growth After IPO	EBITDA (B$)
HON	0.05%	2.11%	2 561.34%	8.3

The Boeing Company



You can find Financial Ratios analysis in our Investment Digest or order a custom one.

The Boeing Company, together with its subsidiaries, designs, develops, manufactures, sales, services, and supports jetliners, military aircraft, satellites, missile defense, human space flight and launch systems. The company operates through four segments: Commercial Airplanes; Defense, Space & Security; Global Services; and Boeing Capital.

Ticker	Mean Daily Return	Volatility of Daily Returns	Growth After IPO	EBITDA (B$)
BA	-0.08%	4.06%	11 355.61%	-1.8

SpaceTech Government Activity

September 2021

www.spacetech.global

SpaceTech Analytics

Officials on Government Cooperation with Private Space Companies

Cooperation between governments and private companies is becoming ever-more important in the SpaceTech industry. Companies are increasingly looking to space as a place of business, and government space agencies all over the world have been changing in multiple ways, particularly by partnering with corporations to rapidly develop needed new technologies.

Jean-Jacques Dordain

Chancellor of the International Space University

“Alphasat is the fruit of a public private partnership between ESA and Inmarsat, an excellent example of how ESA is boosting Europe’s competitiveness and growth.”

Kathy Lueders

Associate Administrator of the Human Exploration and Operations Mission Directorate

“It’s difficult to put into words how proud I am of the people who got us here today. I am simply amazed at what the NASA and SpaceX teams have accomplished together.”

Charles F. Bolden

Former Head of NASA

"Turning over low-Earth orbit transportation to private industry will also allow NASA to focus on an even more ambitious mission: sending humans to Mars."

Jeffrey DeWit

CFO of NASA

“How you drive that is based on what we’re doing now, which is trying to now prove the concepts and get the commercial sector involved. The only outcome for this is a positive, not only for NASA but for the space economy for private companies.”

How the Governments Cooperate with Private Companies: NASA & Small Businesses

Boost and Support

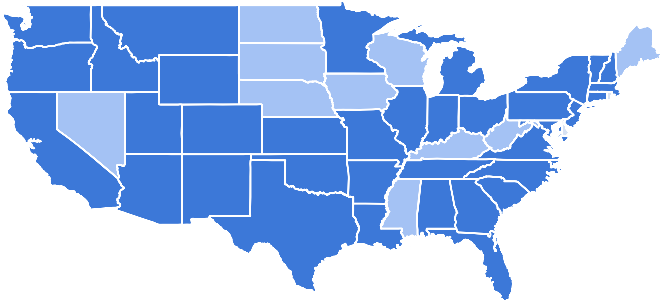
Small businesses are vital to NASA's mission, helping expand humanity's presence in space and improve life on Earth. NASA has selected **365 U.S. small business** proposals for initial funding from the agency's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program, a total investment of **more than $45M**.

19% of the research institutions partnering with small business for STTR are classified as Minority Serving Institutions (MSIs)

Through the program, NASA works with U.S. small businesses and research institutions to advance cutting-edge technologies. The agency provides up to **$125K** for companies to establish the merit and feasibility of their innovations. Phase I SBIR contracts are awarded to small businesses and last for six months, while Phase I STTR contracts are awarded to small businesses in partnership with a research institution and last for **13 months**. Based on their progress during Phase I, companies may submit proposals to subsequent SBIR/STTR opportunities and receive additional funding.

Source: NASA

NASA Provides 45 Million Boost to U.S Small Businesses



289 small businesses and **47** research institutions across **38** states, D.C., and Puerto Rico selected to receive funding that supports technology development for NASA missions

91 companies selected for their first SBIR/STTR award

198 companies with previous awards selected

How the Governments Cooperate with Private Companies: NASA & SpaceX

NASA

NASA is getting ready to send astronauts to explore more of the Moon as part of the Artemis program, and the agency has selected SpaceX to continue development of the first commercial human lander that will safely carry the next two American astronauts to the lunar surface. At least one of those astronauts will make history as the first woman on the Moon. Another goal of the Artemis program includes landing the first person of color on the lunar surface.

"With this award, NASA and our partners will complete the first crewed demonstration mission to the surface of the Moon in the 21st century as the agency takes a step forward for women's equality and long-term deep space exploration,"

said Kathy Lueders, NASA's associate administrator for Human Explorations and Operations Mission Directorate. "This critical step puts humanity on a path to sustainable lunar exploration and keeps our eyes on missions farther into the solar system, including Mars."

Source: NASA

The firm-fixed price, milestone-based contract total award value is

$2.89B

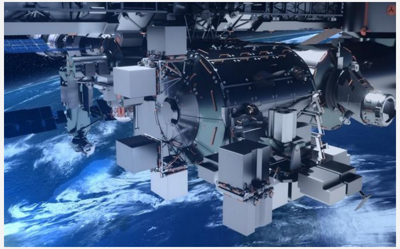
Illustration of SpaceX Starship human lander design that will carry the first NASA astronauts to the surface of the Moon under the Artemis program.

How the Governments Cooperate with Private Companies: ESA's Initiatives

With the aim to commercialise the **KUBIK Incubator facility on ISS Columbus, ESA and Kayser Italia** signed the Bioreactor Express **commercial partnership in July 2019**. The KUBIK facility is suitable for a range of experiments in biology, biotech, human research, fluid physics, and materials science. It is equipped with a centrifuge and thermal control capability. The use of existing hardware such as experiment containers enable a competitive pricing for commercial customers.

ESA and the County of Cornwall in the UK have partnered up to redevelop part of Goonhilly Earth Station, an existing commercial station in Cornwall, UK, to enable it to provide Europe's first deep-space tracking services on a commercial basis.

The Goonhilly project will be initially funded through a **€9.5M investment** from the UK's Cornwall & Isles of Scilly Local Enterprise Partnership.



Airbus Defence and Space partnered with ESA on **7 February 2018** to start developing a new commercial service for the International Space Station called Bartolomeo.

From early 2021, the versatile Bartolomeo 'All-in-one Mission Service' will provide end-to-end access for external payloads on the Station for many mission types at competitive prices.

The ICE Cubes service is the first European commercial opportunity to conduct research in space. This pioneering agreement signed between ESA and Space Applications Services NV/SA, Belgium, offers room to run experiments and conduct research in weightlessness inside ESA's Columbus laboratory on the International Space Station.

Launched in May 2018, the service provides rapid and simplified access to the station on a commercial basis.

Source: ESA

ISRO Space Policy is Opening up to Private Activities

ISRO tests satellites developed by private sector for the first time

Only recently has the Indian Space Research Organisation (ISRO) started to allow private space activity in India. Two satellites by Indian startups—**SpaceKidz India** and **Pixxel (incorporated as Sygyzy)**—were tested at the ISRO's UR Rao Satellite Centre of the in Bengaluru. This is a first for the space agency, which so far has only taken help in manufacturing and fabrication of various parts of satellites and rockets from the Indian industry. ISRO helped these two companies fix problems with the solar panels on their respective satellites.

Confirming the development, ISRO spokesperson **Vivek Singh** told HT that the two firms have finished the testing already. In the coming months, these two firms will also test their engines at Sriharikota spaceport and the Thiruvananthapuram rocket center.

"There have been several firms that have worked with ISRO in the past, but these firms are into manufacturing satellites. They are almost through with their development. In our next PSLV launch, they could be our co-passengers," he said.

Source: Hindustan Times

A satellite designed by students from **SpaceKidz** India had been launched by ISRO as an experiment in **January 2019** using the fourth stage of the PSLV—which usually goes to waste—as the platform for the KalamSat.

Another startup, **Skyroot** is working toward developing a launch vehicle that is likely to be launched by the end of the year. ISRO will share their spaceports—the existing one at Sriharikota and the upcoming one in Thoothukudi—with industries for such missions.

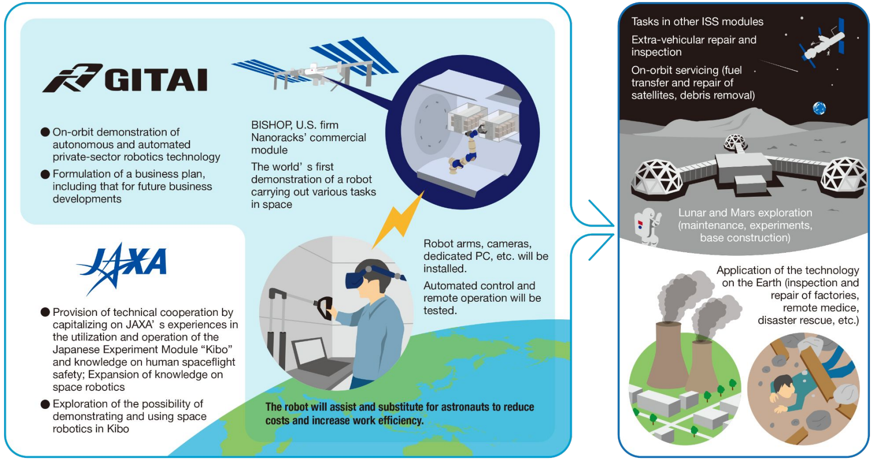
JAXA is Partnering on Space Robotics

GITAI and JAXA to Embark on the Co-creation of World's First Space Robot Business

GITAI Japan and the Japan Aerospace Exploration Agency (JAXA) will co-create a new business concept for the robotization of work in space as a project of the JAXA Space Innovation through Partnership and Co-creation (J-SPARC) initiative*2. Under this project, the organizations aim to identify tasks in space that require robotization, develop robotics technologies that will carry out the tasks, and provide services using robots.

Technology demonstration of GITAI's robot in the ISS BISHOP Airlock Module (mock-up) built at GITAI Tokyo office.

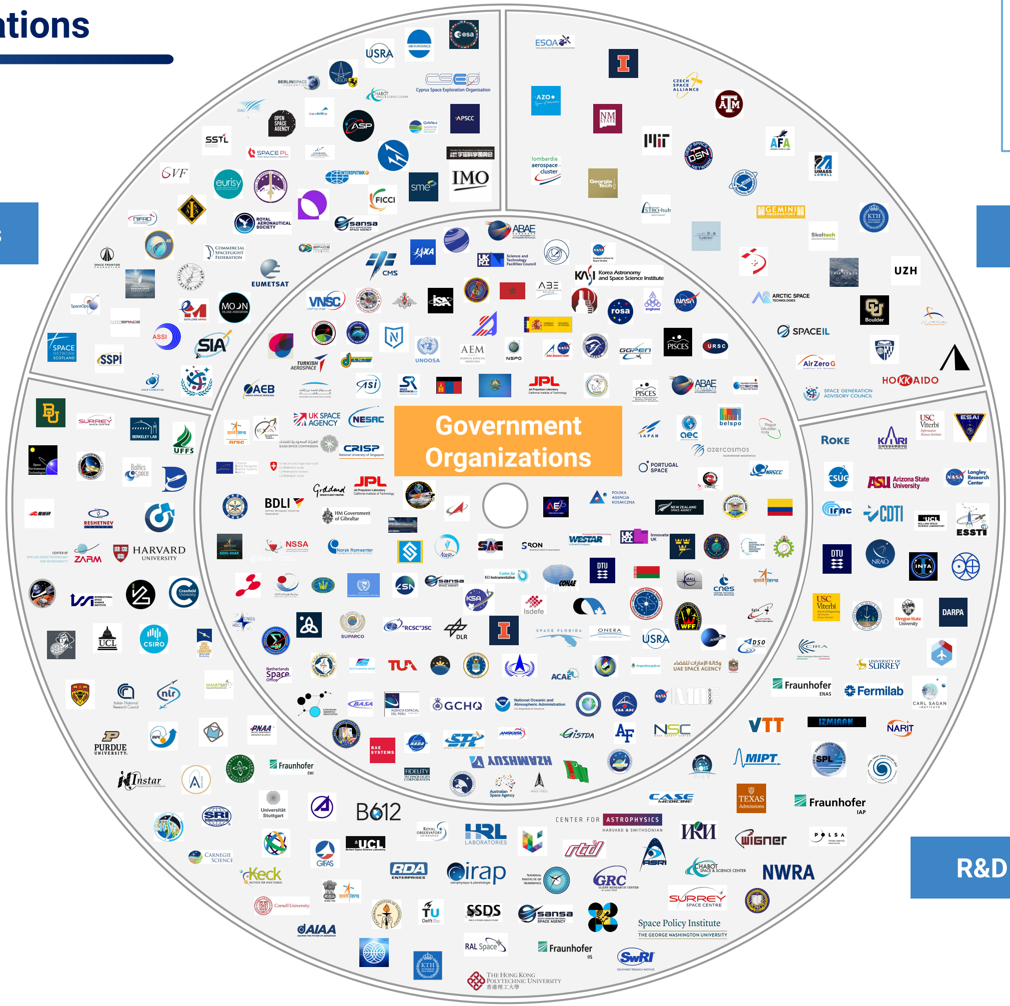
Source: JAXA



GITAI will, for the first time as a private-sector company in the world, perform a technology demonstration of its robots designed for the autonomous control and automation of the processing of specific tasks. JAXA will support GITAI's activities through technical cooperation while also aiming to expand its knowledge on space robotics through this project. GITAI and JAXA will also explore new services based on space robotics that can be provided for the International Space Station (ISS) and other future missions.

R&D Hubs, Associations and Government Organizations

Government Organizations - 136
R&D Centres - 132
Associations - 53
Hubs - 19



Associations

Hubs

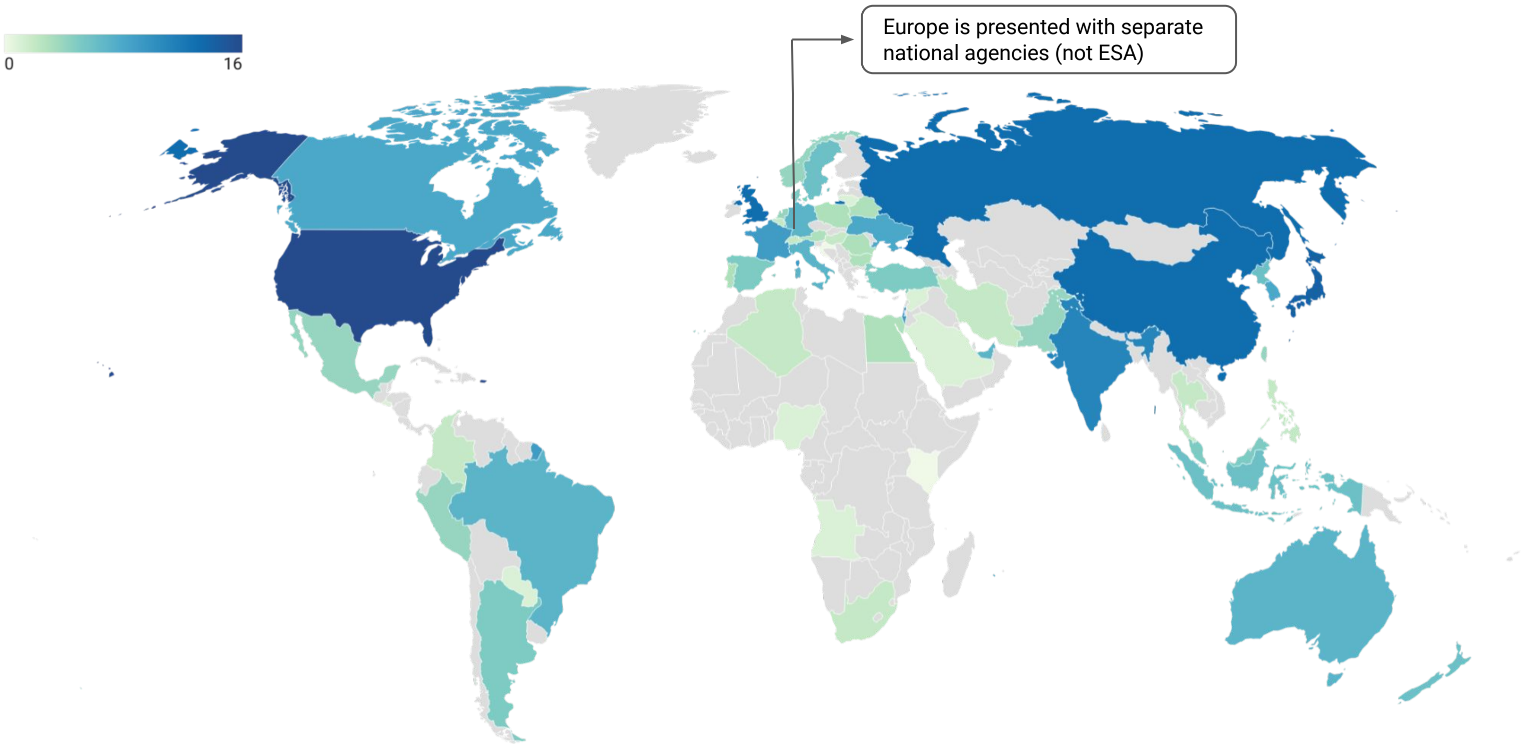
R&D Centres

SpaceTech Analytics

Comparative Matrix Methodology

Methodology	Content	Some findings
The analysis includes the fifty largest national space agencies selected by budget size. They were compared by sixteen indicators of space activity. All the indicators are equally weighted at 1 point each, so the general score ranges from 0 to 16. Generally, the indicators belong to 2 groups: capabilities and goals.	The general analysis begins with defining sixteen core indicators of each country's space activity. Based on that analysis, a "heat" map of countries differing by space activity was created. The next slides represent the matrices of the space activities, including detailed information per country. The first five matrices include information about the country's goals and commitments, with the following five about the capabilities.	The US is clearly the most active on the map (with all sixteen points). However, the spread of space activity on the African continent is less expected. The activity of the countries of Oceania is also noticeable. The trend is justified, as space technology can bring many benefits to the economy or nature of countries. However, more and more countries growing clearly interested in engaging in more ambitious areas like space mining or Mars settlement.

Space Activity by Country



The countries were rated by the number of the sixteen Space Activity Indicators described on the next page. In recent years, with reducing costs, space activity among African countries has been growing significantly.

Indicators of Space Activity

1	Astronauts	Has trained astronauts able to participate in space missions
2	Satellites	Operates own satellites at the orbit
3	Sounding rockets	Can build and use sounding rockets
4	Outer Space Treaty	Acceded to the Treaty
5	Moon Agreement	Acceded to the Treaty
6	Artemis Accords	Acceded to the Artemis Accords (Moon exploration program)
7	National legislation on space-resource utilization	Passed the legislation
8	Spaceport(s)	Has spaceport(s) with launch capabilities
9	Orbital payload	Can deliver payload to orbit
10	Liquid rocket engines	Has the ability to develop and deploy engines
11	Space probes	Has the ability to operate probes
12	Human spaceflight	Has the ability and corresponding technologies to send people to space and keep them alive
13	Space mining	Have established a goal to develop space mining technologies and perform research on it
14	Mars Program	Have established the goal of Mars exploration or settlement, and sent or plan to send missions to Mars
15	Moon Program	Have established the goal of Moon exploration or settlement, and sent or plan to send missions to Moon
16	Space Medicine	Researches and develops Space Medicine techniques

Plunge of the Cost of Space Activities will Make Smaller Nations More Ambitious

Country	Acceded to/Ratified Outer Space Treaty	Acceded to/Ratified Moon Agreement	Acceded to/Ratified Artemis Accords	Passed National Legislation on Space-Resource Utilization	Space Mining Activity	Mars Program	Moon Program
USA	+	-	+	+	+	+	+
China	+	-	-	+	+	+	+
UAE	+	-	+	+	+	+	+
Germany	+	-	-	-	+	-	-
France	+	-	-	-	-	-	-
Russia	+	-	-	+	+	+	+
India	+	-	-	-	-	+	+
Japan	+	-	+	+	+	+	+
Saudi Arabia	+	-	-	-	-	-	-

Plunge of the Cost of Space Activities Will Make Smaller Nations More Ambitious

Country	Acceded to/Ratified Outer Space Treaty	Acceded to/Ratified Moon Agreement	Acceded to/Ratified Artemis Accords	Passed National Legislation on Space-Resource Utilization	Space Mining Activity	Mars Program	Moon Program
Italy	+	-	+	-	-	-	+
South Korea	+	-	+	-	-	-	+
UK	+	-	+	+	+	+	+
Algeria	-	-	-	-	-	-	-
Canada	+	-	+	+	-	-	+
Belgium	+	-	-	-	-	-	-
Spain	+	-	-	-	-	-	-
Switzerland	+	-	-	+	-	-	-
Luxembourg	+	-	+	+	+	-	+
Netherlands	+	+	-	-	-	-	-

Plunge of the Cost of Space Activities will Make Smaller Nations More Ambitious

Country	Acceded to/Ratified Outer Space Treaty	Acceded to/Ratified Moon Agreement	Acceded to/Ratified Artemis Accords	Passed National Legislation on Space-Resource Utilization	Space Mining Activity	Mars Program	Moon Program
Sweden	+	-	-	-	-	-	-
Norway	+	-	-	-	-	-	-
Taiwan	-	-	-	-	-	-	-
Ukraine	+	-	+	-	-	-	+
Austria	+	+	-	-	-	-	-
Poland	+	-	-	-	-	-	-
South Africa	+	-	-	+	-	-	-
Indonesia	+	-	-	-	-	-	-
Brazil	+	-	+	-	-	-	-
Argentina	+	-	-	-	-	-	-

Plunge of the Cost of Space Activities will Make Smaller Nations More Ambitious

Country	Acceded to/Ratified Outer Space Treaty	Acceded to/Ratified Moon Agreement	Acceded to/Ratified Artemis Accords	Passed National Legislation on Space-Resource Utilization	Space Mining Activity	Mars Program	Moon Program
Pakistan	+	-	-	-	-	-	-
Egypt	+	-	-	-	-	-	-
Angola	-	-	-	-	-	-	-
Croatia	-	-	-	-	-	-	-
Israel	-	-	-		-	-	-
Australia	+	-	-	-	+	-	+
Portugal	+	-	+	-	+	+	+
Nigeria	-	-	-	-	+	-	-
Mexico	-	-	-	-	-	-	-
Iran	+	-	-	-	-	-	-

Plunge of the Cost of Space Activities will Make Smaller Nations More Ambitious

Country	Acceded to/Ratified Outer Space Treaty	Acceded to/Ratified Moon Agreement	Acceded to/Ratified Artemis Accords	Passed National Legislation on Space-Resource Utilization	Space Mining Activity	Mars Program	Moon Program
Romania	-	-	-	-	-	-	-
Philippines	+	-	-	-	-	-	-
Turkey	-	+	-		-	-	-
New Zealand	+	-	+	-	-	-	+
Kenya	-	-	-	-	+	-	-
Bulgaria	+	-	-	-	-	-	-
Colombia	-	-	-	-	-	-	-
Denmark	+	-	-	-	-	-	-
El Salvador	+	-	-	-	-	-	-
Hungary	+	-	-	-	-	-	-

Current Capabilities of Government Agencies are Small, but will Grow Rapidly

Country	Astronauts	Operates Satellites	Have Spaceport(s)	Sounding Rocket Capability	Orbital Payload Capability	Ability to Develop and Deploy Liquid Rocket Engines	Ability to Operate Space Probes	Human Spaceflight Capability
USA	+	+	+	+	+	+	+	+
China	+	+	+	+	+	+	+	+
UAE	+	+	-	-	-	-	+	-
Germany	+	+	-	+	-	+	-	-
France	+	+	+	+	+	+	+	-
Russia	+	+	+	+	+	+	+	+
India	+	+	+	+	+	+	+	-
Japan	+	+	+	+	+	+	+	-
Saudi Arabia	-	+	-	-	-	-	-	-

Current Capabilities of Government Agencies are Small, but will Grow Rapidly

Country	Astronauts	Operates Satellites	Have Spaceport(s)	Sounding Rocket Capability	Orbital Payload Capability	Ability to Develop and Deploy Liquid Rocket Engines	Ability to Operate Space Probes	Human Spaceflight Capability
Italy	+	-	+	+	-	+	-	-
South Korea	+	+	+	+	+	+	-	-
UK	+	+	+	+	+	+	-	-
Algeria	-	+	-	+	-	-	-	-
Canada	+	+	-	+	-	-	-	-
Belgium	+	-	-	-	-	-	-	-
Spain	+	+	+	+	-	+	-	-
Switzerland	-	-	-	+	-	-	-	-
Luxembourg	-	-	-	-	-	-	-	-
Netherlands	+	+	-	+	-	-	-	-

Current Capabilities of Government Agencies are Small, but will Grow Rapidly

Country	Astronauts	Operates Satellites	Have Spaceport(s)	Sounding Rocket Capability	Orbital Payload Capability	Ability to Develop and Deploy Liquid Rocket Engines	Ability to Operate Space Probes	Human Spaceflight Capability
Sweden	+	+	+	+	-	+	-	-
Norway	-	+	+	+	-	-	-	-
Taiwan	-	+	+	+	+	-	-	-
Ukraine	+	+	-	+	+	+	-	-
Austria	+	-	-	-	-	-	-	-
Poland	+	+	-	+	-	-	-	-
South Africa	-	-	-	-	-	-	-	-
Indonesia	+	+	+	+	-	-	-	-
Brazil	+	+	+	+	-	+	-	-
Argentina	-	+	+	+	-	-	-	-

Current Capabilities of Government Agencies are Small, but will Grow Rapidly

Country	Astronauts	Operates Satellites	Have Spaceport(s)	Sounding Rocket Capability	Orbital Payload Capability	Ability to Develop and Deploy Liquid Rocket Engines	Ability to Operate Space Probes	Human Spaceflight Capability
Pakistan	-	+	+	+	-	-	-	-
Egypt	-	+	+	+	-	-	-	-
Angola	-	+	-	-	-	-	-	-
Croatia	-	-	-	-	-	-	-	-
Israel	+	+	+	+	+	-	-	-
Australia	-	-	+	+	-	-	-	-
Portugal	-	-	+	-	-	-	-	-
Nigeria	-	+	-	-	-	-	-	-
Mexico	+	+	-	+	-	-	-	-
Iran	-	-	+	+	+	-	-	-

Current Capabilities of Government Agencies are Small, but will Grow Rapidly

Country	Astronauts	Operates Satellites	Have Spaceport(s)	Sounding Rocket Capability	Orbital Payload Capability	Ability to Develop and Deploy Liquid Rocket Engines	Ability to Operate Space Probes	Human Spaceflight Capability
Pakistan	-	+	+	+	-	-	-	-
Egypt	-	+	+	+	-	-	-	-
Angola	-	+	-	-	-	-	-	-
Croatia	-	-	-	-	-	-	-	-
Israel	+	+	+	+	+	-	-	-
Australia	-	-	+	+	-	-	-	-
Portugal	-	-	+	-	-	-	-	-
Nigeria	-	+	-	-	-	-	-	-
Mexico	+	+	-	+	-	-	-	-
Iran	-	-	+	+	+	-	-	-

Current Capabilities of Government Agencies are Small, but will Grow Rapidly

Country	Astronauts	Operates Satellites	Have Spaceport(s)	Sounding Rocket Capability	Orbital Payload Capability	Ability to Develop and Deploy Liquid Rocket Engines	Ability to Operate Space Probes	Human Spaceflight Capability
Romania	+	+	-	-	-	-	-	-
Philippines	-	+	-	-	-	-	-	-
Turkey	-	+	-	+	-	+	-	-
New Zealand	-	+	+	+	+	-	-	-
Kenya	-	+	-	-	-	-	-	-
Bulgaria	+	+	-	-	-	-	-	-
Colombia	-	+	-	-	-	-	-	-
Denmark	-	+	+	-	-	+	-	-
El Salvador	+	+	-	-	-	-	-	-
Hungary	-	+	-	-	-	-	-	-

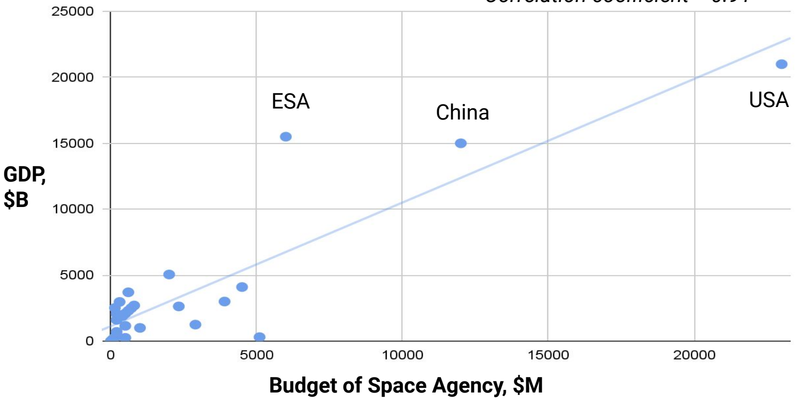
GDP and Government Space Spending Show Positive Correlation

The linear model demonstrates a strong pattern of correlation. The trend is apparent: the higher the GDP, the larger the space agency budget. However, Japan and the UAE are outliers of pattern violation.

The major space players set the trend. **China** seems to challenge the **USA**, while **ESA** seems to be less enthusiastic about the race. However, the scale of these three players somewhat distorts the overall picture, as the other players look relatively small.

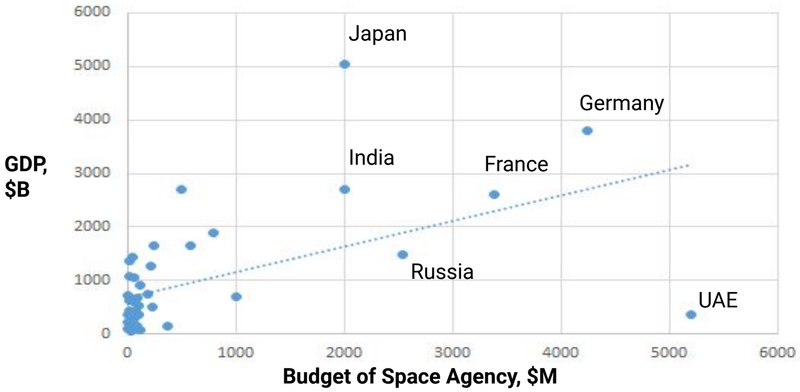
** EU is represented by the European Space Agency*

Correlation coefficient = 0.91



This graph includes forty-three countries and the outliers were excluded (**USA**, **ESA**, **China**). The positive trend is still observable, though the scatter of values looks larger. This means that the policies and priorities of states play an important role. **The UAE** spends a notably disproportionate amount on space. **Russia** also outspends with regard to its GDP. Conversely, despite a large GDP, **Japan** spends relatively less money on space than the others.

Correlation coefficient = 0.53



Companies and R&D Centers Subordinated to National Space Agencies

US

- NASA
- Ames Research Center
- Goddard Space Flight Center
- Kennedy Space Center
- JPL — Jet Propulsion Laboratory, California Institute of Technology
- Goddard Institute for Space Studies
- WFF
- NSSC — NASA Shared Services Center
- Space Center Houston
- Space Flight Awareness — NASA Marshall Space Flight Center
- NSC — NASA Safety Center

Luxembourg

- LSN
- Luxembourg Institute of Science and Technology (LIST)
- esric
- SnT

UAE

- UAE Space Agency
- UAEU — United Arab Emirates University
- Mohammed Bin Rashid Space Centre
- SnT
- Khalifa University
- United Arab Emirates Space Reconnaissance Center

Argentina

- CONAE
- ARSAT
- Instituto Argentino de Radioastronomía
- Centro Tecnológico Aeroespacial
- CONICET
- ITEFA
- CNEA

New Zealand

- New Zealand Space Agency
- The University of Auckland, New Zealand
- XERRA
- Institute for Radio Astronomy & Space Research

India

- ISRO
- LPSC
- NRSC — National Remote Sensing Centre
- URSC
- Semiconductor Laboratory, Department of Space
- NESAC
- IPRC
- Physical Research Laboratory
- NARL — National Atmospheric Research Laboratory
- SAC

Australia

- Australian Space Agency
- CSIRO
- University of South Australia
- Australian Government, Bureau of Meteorology
- Space Industry Association of Australia
- ACSER — Australian Centre for Space Engineering Research
- Australian Government, Geoscience Australia

South Korea

- KARI — Korea Aerospace Research Institute
- Korea Aerospace University
- 국방과학연구소 — Agency for Defense Development
- KAIST
- KASI — Korea Astronomy and Space Science Institute
- KIGAM
- ETRI — Electronics and Telecommunications Research Institute

United Kingdom

- UK Space Agency
- dstl
- Reaction Engines
- OneWeb
- Launch UK
- diamond
- Shetland Space Centre
- esero
- Space Hub Sutherland
- UK Research and Innovation / Innovate UK
- Science & Technology Facilities Council

Russia

- РОСКОСМОС
- Khrunichev State Research and Production Space Center
- Reshetnev Company
- Арсенал
- NPO Energomash
- Glavkosmos
- ЦНИИМАШ / TSNIIMASH
- Fakel
- НПЦАП
- РКЦ Прогресс

Government Agencies (According to Number of Employees*)

1-100

CRISP National University of Singapore

Norsk Romsenter Norwegian Space Agency

IAES

aec Agencia Espacial de Colombia

Polska Agencja Kosmiczna

ISA Israel Space Agency Ministry of Science, Technology & Space

Netherlands Space Office

KSA Kenya Space Agency

الهيئة السعودية للفضاء Saudi Space Commission

rosa

Portugal Space

وكالة الإمارات للفضاء UAE Space Agency

Australian Space Agency

Rymdstyrelsen Swedish National Space Agency

100-1000

CSA ASC

HSO Hungarian Space Office

KARI 한국항공우주연구원 Korea Aerospace Research Institute

Algerian Space Agency

LSA Luxembourg Space Agency

AEXA Agencia Espacial Mexicana

سازمان فضایی ایران Iranian Space Agency

Державне космічне агентство України

Philippine Space Agency

sansa South African National Space Agency

asi agenzia spaziale italiana

UK Space Agency

FFG Forschung wirkt.

European Global Navigation Satellite Systems Agency

EgSA وكالة الفضاء المصرية Egyptian Space Agency

Danish Aerospace Company

>1000

CONAE

РОСКОСМОС

INTA

LAPAN

इसरो isro

JAXA

NASA

esa

CNSA

NASRDA

DLR

cnes Centre National d'Études Spatiales

* Those agencies for which the numbers of employees could not be readily determined are not represented here.

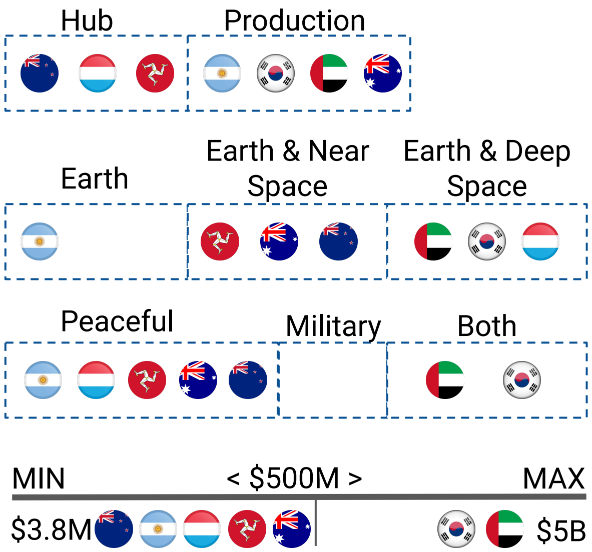
The Space Industry is Gaining Momentum

With it becoming a hot topic, as well as a necessity, dozens of countries worldwide are beginning to develop national space industries. Some countries stand out among others in this trend. They are called New Space Nations and the following slides include an analysis of seven such nations: Australia, New Zealand, Argentina, South Korea, Luxembourg, the Isle of Man and the United Arab Emirates.

Each country differs by these main four parameters

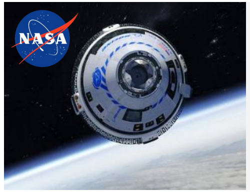
Model	**Hub:** A country attracts space organizations, providing favorable business environment, accessible investment funds, simplified regulation, lower taxation, etc. **Production:** A country founds state companies, develops manufacturing and R&D capacities; state organizations play a crucial role in space industry
Ambitions	Regarding space exploration, some countries are aimed solely at researching practical things to improve the country's socio-economic performance. Others are ready to invest in deep-space activities with unknown and and potentially illusory achievements in the distant future (e.g. Mars settlement).
Applications	In search of economic benefit, prestige, or technology maturation, countries develop their space industries. For the most part, this is for the peaceful use of technology, but in some cases military applications are important as well.
Budget	The budget of each country differs according to the wealth of the nation and the three parameters above. The UAE is an example of a country with great ambitions and considerable wealth ($5B space budget).

Comparison tables



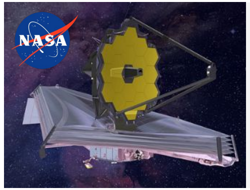
Plans for the Future

Launches and Landings Scheduled by NASA and Other Countries in 2021-2022



Date: No Earlier Than 2022
Mission: Boeing Crew Flight Test
Description: NASA astronauts Mike Fincke, Nicole Mann, and Barry "Butch" Wilmore are slated to launch aboard Boeing's CST-100 Starliner atop a United Launch Alliance Atlas V rocket.

Date: Late 2021
Mission: Lucy Mission
Description: Launching from Kennedy Space Center in Florida, Lucy will be the first space mission to study the Trojan asteroids associated with the planet Jupiter.



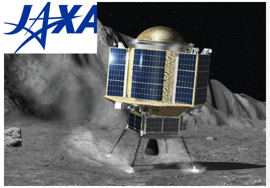
Date: No Earlier Than December 18, 2021
Mission: James Webb Space Telescope
Description: The James Webb Space Telescope will find the first galaxies that formed in the early universe and peer through dusty clouds to see stars forming planetary systems.

Date: No earlier than 4 November 2021
Mission: Part of Artemis 1
Description: The SLS is planned to launch the Orion spacecraft and use the ground operations and launch facilities at NASA's iconic Kennedy Space Center in Florida.

Date: 2021-2022
Mission: CNSA, Tiangong Space Station
Description: In April 2021 China launched the core module of its stationary space station to Earth orbit. The carrier rocket then went to an uncontrolled fall. Other modules will be launched in the following year.

Date: No Earlier Than December 2021
Mission: ISRO, Gaganyaan
Description: Gaganyaan is a first Indian vehicle capable of containing three crew members. ISRO will launch Vyomitra, humanoid robot inside in order to conduct some tests.

Date: No Earlier Than 2022
Mission: ESA, European Robotic Arm
Description: The Robotic Arm is going to be launched to the ISS and attached to the Russian Segment. The purpose of it is assembly work and maintenance



Date: No Earlier Than January 2022
Mission: JAXA, SLIM Lunar Lander
Description: Smart Lander for Investigating Moon is designed to demonstrate innovative landing techniques, that will highly improve the accuracy of landing.

Source: NASA

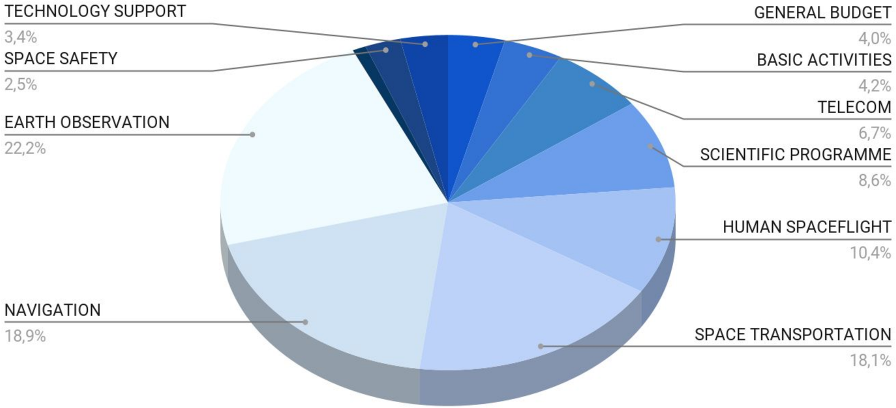
ESA and Countries Budget Distribution

ESA's activities fall into two categories – "mandatory" and "optional." Programs carried out under the General Budget and the Space Science program budget are "mandatory"; they include the agency's basic activities (studies on future projects, technology research, shared technical investment, information systems and training programmes).

All Member States contribute to these programs on a scale based on their Gross National Product (GNP). The other programmes, known as "optional," are only of interest to some Member States, who are free to decide on their level of involvement.

Optional programs cover areas such as Earth observation, telecommunications, satellite navigation and space transportation. Similarly, the International Space Station and microgravity research are financed by optional contributions.

ESA Budget by Domain for 2021: 6.49 €B*



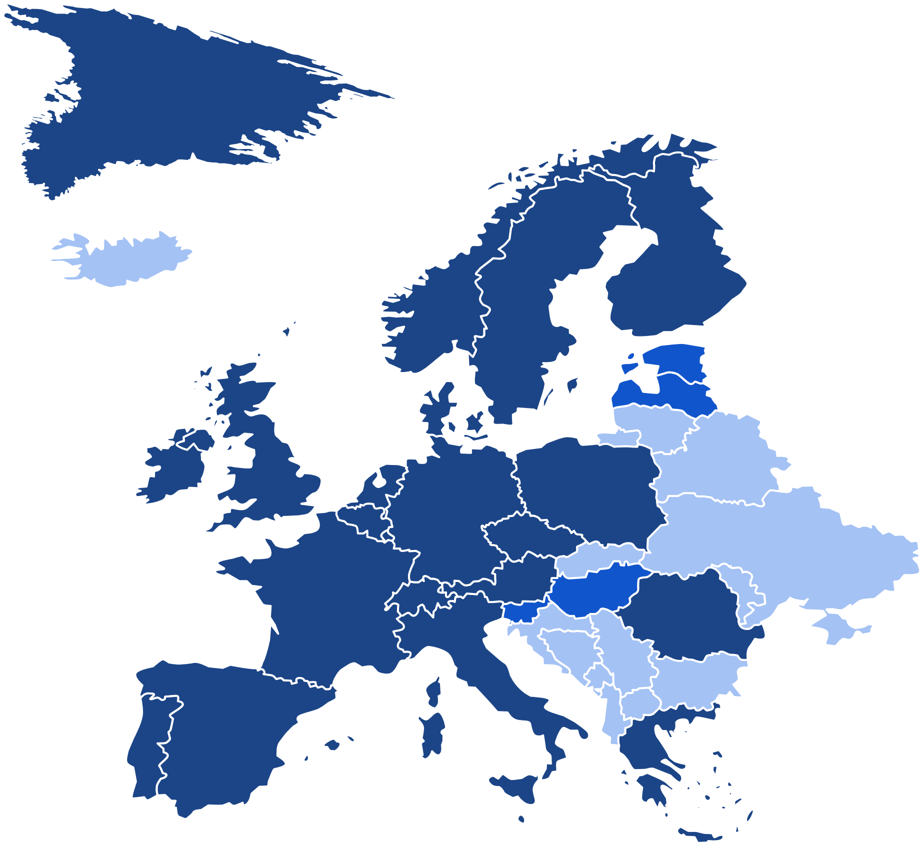
*Includes activities implemented for other institutional partners

Source: ESA

ESA's and Countries' Contributions

ESA's activities are funded by contributions from member countries based on gross national income. About **45%** of the amount is contributed by **Germany** and **France**. In terms of funding, the top priority is Earth observation applications. The second place is occupied by the cost of the launch vehicle. Every three to four years, ESA members agree on a budget plan for several years at a conference of ESA members. Although the plan is subject to change, it defines the main direction of action.

As a rule, countries have their own space programs, which interact in different ways with ESA financially and organizationally. For example, the French space agency CNES has a budget that exceeds the funds allocated by ESA twice. The Agency coordinates work with such national programs. There are also joint projects between ESA and the national space agencies. Since 1975, more than **30 such programs** have been implemented.



Source: ESA

Conclusions

1. The key space players--the USA, China, and Russia--still dominate the industry and own most satellites.
2. The United States continues to have the highest level of space activity, led by NASA and the military. In particular, it dominates all other countries in terms of space budgets and the number of people flying into space.
3. Space is becoming relatively more accessible and affordable, allowing smaller countries to launch satellites with less effort and resources. As a result, many countries in Africa, Latin America, and Asia have begun developing space technologies. For example, Kenya and Bahrain have joined the list of countries operating satellites. New Zealand hosts Rocket Lab, a potential rival to SpaceX. However, in most countries, the space industry is still underdeveloped.
4. Those countries that entered the space race in the 20th century have a significant advantage over newcomers. For example, Argentina and Ukraine are still ahead of the UAE in some ways, although they spend much less money on the space sector, while the latter has to play catch up.
5. Some of the new nations have introduced new approaches to industry development such as space hubs, while some others are following the traditional paved path. The space-hub model allows nations to develop their space industries even with limited funds. It works through the creation of a favorable business environment to provide an incubator for private SpaceTech companies.
6. Economic prosperity, concomitant technological development, security issues, and prestige are among the main motives for the development of autonomous capabilities in space.
7. International cooperation and coordination are becoming particularly important. Thus, national space agencies become more critical in their ability to represent and connect multiple actors. This is reflected by the fact that their number has increased significantly in recent decades.
8. ESA is the most prominent example of cooperation in the space industry. Its most-recent budget is $7.71B. 22.2% of the funds are allocated for Earth observation, 18.9% for navigation, and 18.1% for space transportation.

September 2021

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FOR ALL MOONKIND™

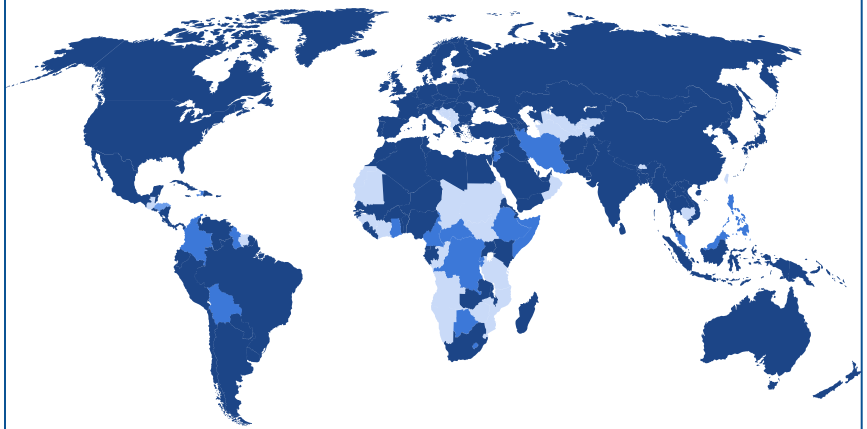
Michelle Hanlon

Introduction

The Outer Space Treaty, formally **Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies**, is a treaty that forms the basis of international space law. There are currently 111 States Parties to it.

Signed	27 January 1967
Location	London, Moscow and Washington, D.C.
Effective	10 October 1967
Condition	5 ratifications, including the depositary Governments
Depositary	Governments of the United Kingdom of Great Britain and Northern Ireland, the Union of Soviet Socialist Republics and the United States of America

Outer Space Treaty



Countries that have signed and ratified the treaty

Countries that have just signed the treaty

Countries that have not signed the treaty

1967 Outer Space Treaty is the Foundation of International Space Law

After the launch of the first satellite in 1957 UN Member States established the Committee on the Peaceful Uses of Outer Space (COPUOS), the forum where all space treaties were negotiated. Ten years later, it resulted in a UN treaty that laid out the principles for space activities.

The basic framework on international space law was:

- The exploration and use of space is the province of all mankind.
- Outer space shall be free for exploration and use by all States.
- Outer space is not subject to national appropriation by claim of sovereignty.
- States shall not place weapons of mass destruction in orbit or on celestial bodies.
- The Moon and other celestial bodies shall be used exclusively for peaceful purposes;
- States shall be responsible for national space activities and be liable for damage caused by their space objects.
- States shall avoid harmful contamination of space and celestial bodies.

There are Ancillary Agreements to the OST

Astronaut Rescue Agreement

This agreement was formed in 1968 in order to protect the astronauts and help them survive the unplanned landing or other emergencies. States are told they "shall immediately take all possible steps to rescue them and render them all necessary assistance."

Liability Convention

This convention, formed in 1972, follows and expands one point of the previous Outer Space Treaty about the damage caused by space operations. Its first article says: *"A launching state shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the earth or to aircraft flight."*

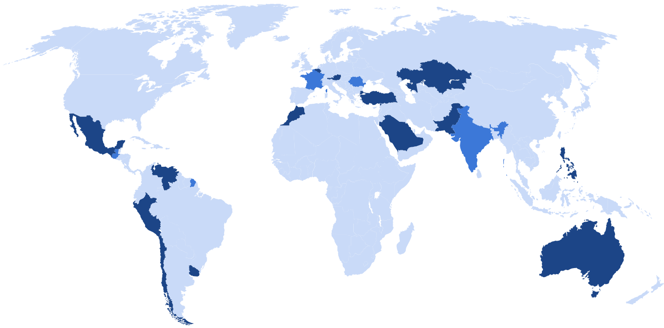
Registration Convention

It was agreed on 1975 that countries shall keep track of every vehicle on the orbit in order to avoid collisions. *“When a space object is launched into earth orbit or beyond, the launching State shall register the space object by means of an entry in an appropriate registry which it shall maintain.”*

The 1979 Moon Agreement is in Conflict with the OST

The Moon Agreement states that **space itself** is “the common heritage of mankind” while OST declares that the **exploration and use** of space shall be “the province of all mankind.” The latter means that if it is required to get permission from some undefined international authority in order to carry out space activities, those cannot be said to be “the province of all mankind.”

The Moon Agreement also outlaws **private property** in space, while the OST actually allowed property rights without claiming national sovereignty. The agreement also proposes the establishment of an international “regime” to ensure the “equitable” allocation of space resources. In 1979 the Moon Agreement was held in order to give more detail to the Outer Space Treaty. However, it is considered a failed treaty, because it was too prohibitive to be effective and there were only 18 states parties to the agreement and 4 signatories, none of them spacefaring at the time. The Artemis Accords take a fresh and pragmatic approach to lunar governance, and many States eager to explore, utilize, and develop the Moon have signed onto them. It is likely that they will be more influential in shaping the future of space exploration than the Moon Agreement

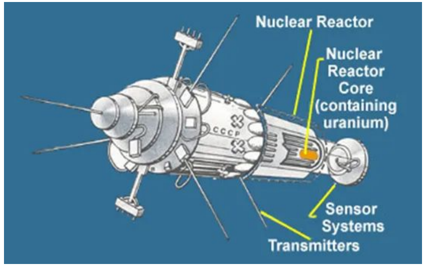


Dark Blue is for ratified countries, Blue for signatories

Liability Convention Req

1978 Soviet Cosmos' re-entry over Canada

On January 24, 1978, the Soviet satellite Cosmos 954 entered the earth's atmosphere intruding into Canadian airspace. On re-entry and disintegration, debris from the satellite was deposited on Canadian territory. The satellite in fact had a uranium nuclear reactor onboard and the USSR government had failed to give Canada notice of the possible re-entry. It was later determined that all but two of the fragments recovered were radioactive.



2021 Chinese Long March re-entry over the Indian ocean

On April 28, 2021 China had successfully launched their unmanned core module Tianhe. However, the Long March 5B rocket, that carried the module, fell for an uncontrolled reentry shortly after the launch. The possible crash site was not obvious, but it could fall anywhere between New York and Santiago de Chile.

Legal consequences

According to the Liability Convention, the USSR government had to be "absolutely liable to pay compensation for damage caused by its space object on the surface of the earth" The deposit of hazardous radioactive debris the Canadian territory, constituted "damage to property" within the meaning of the Convention. Canada billed the USSR for C$6M, but received only C$3M in two years. China remains unpunished as it didn't cause any harm.

Launch Licensing in the US

Commercial Space Launch Act

In the 1970s NASA started searching for means to somehow outsource the services needed for space industry and production of various parts of rockets. It was due to the improvement of space technologies and the increasing cost of modifying, maintaining and launching the launch vehicles of that time. The obvious benefits of utilizing private space companies led to the Commercial Space Launch Act being enacted and signed by Ronald Reagan on October 30, 1984

What it did:

1. Granted the private sector the right to develop and operate commercial expendable launch vehicles
2. Granted the private sector the right to operate private launch sites and services.
3. The Department of Transportation was designated the lead agency in the process of granting launch clearance
4. Led to creation of the Office of Commercial Space Transportation (OCST)
5. The OCST (currently FAA-AST) licenses launches after coordinating with all involved agencies (State, FCC, etc.)
6. Launch providers are required to purchase liability insurance. In theory, the government offers indemnification for any liability above the policy amount, but in practice there is no set amount, and it would require Executive action on a case-by-case basis.

Commercial Human Spaceflight

Amendments to the Commercial Space Launch Act

While the Commercial Space Launch Act made it possible for private activities and the **commercialization of space** to begin and grow, it didn't address all of the **legal and regulatory issues** associated with private space travel. It was later amended in 1988 to make it easier for contractors to obtain licenses and launch insurance. It was amended again in 2004, providing **needed changes** in the licensing procedure and allowing civilians called "spaceflight participants, to fly into space at their own informed risk.

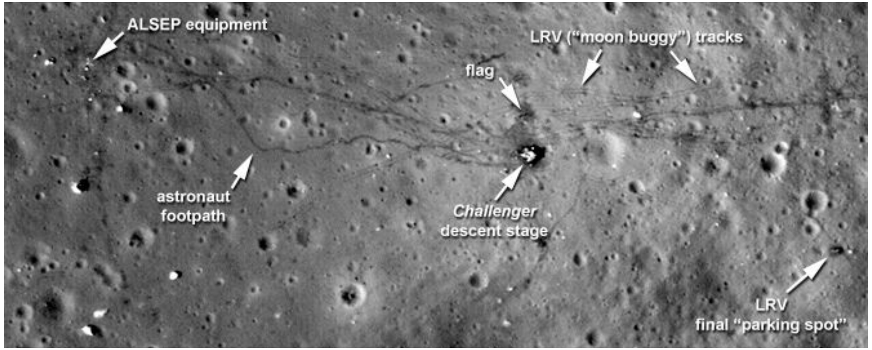
The 2004 amendment also legally defined the word "suborbital", which makes it a lot easier for lower-cost flights to be licensed. *"...**suborbital trajectory** means the intentional flight path of a launch vehicle, reentry vehicle, or any portion thereof, whose vacuum instantaneous impact point does not leave the surface of the Earth".*

Commercial Crew Program

The Commercial Crew Program (CCP) is NASA's **multi-phase program**, established in 2011 to develop private crewed spacecraft to transport astronauts to the International Space Station and decrease **NASA's dependence on** the **Russian Soyuz program**. It is a public-private partnership with American aerospace manufacturers Boeing and SpaceX. However, NASA has no authority to certify vehicles for non-NASA use.

Preserving Heritage Sites

Each of the lunar landing and similar sites in outer space are a fundamental part of our human story. They mark an achievement unparalleled in human history, and one that is common to all humankind. They also hold valuable scientific and archaeological information and serve as poignant memorials to all those who work — and have worked in the past — to evolve humans into a spacefaring species. In short, they are unique and irreplaceable cultural, historic and scientific resources. Accordingly, they must be protected from intentional or accidental disturbance or desecration. Current law governing outer space is silent about preservation. This must be rectified before humans or robots return to the Moon.



Source: For All Moonkind

FOR ALL MOONKIND™

For All Moonkind, Inc. is the only organization in the world focused on creating an effective system to safeguard our common human heritage in outer space, including humankind's very first Moonsteps.

Conclusions

- Space law formally began in January 1967 with the **Outer Space Treaty** and is still in the stage of development. The **Committee on the Peaceful Uses of Outer Space** (COPUOS), formed in 1959, is gathered annually.
- Private spaceflight in the United States was legalized in 1984 with the **Commercial Space Launch Act**, while similar processes were also going on in Europe and USSR.
- Some concerns about space legislation turned out to be justified, some not.
- There are a number of issues that need to be balanced and regulated. For example, there is a worrying uptick in military use of space and lack of coordination in LEO between commercial actors
- There are still major controversies in the space-legal community, especially around the **Moon Agreement**, adopted by a few nations in 1979.
- Space law, from policy aspects of planetary defense, to a host of commercial activities such as private commercial space tourism and commercial space stations, remains dynamic and unsettled due to the **increasing growth of technologies**, and the current impossibility of modeling space societies and their governance.

Economics of Space

September 2021

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Failed Ambitions of 20th Century

Since the end of the 19th century writers, artists, philosophers, and other people have dreamt of ambitious space projects, like going to Mars or space settlements. The first human steps on the Moon inspired people worldwide and fueled dreams and bright imaginations about humanity's space future.

NASA Predictions About Space Economy

In the 1970s, NASA predicted the rise of a space-based economy that would supply the demands of millions of humans living in space, dwarfing the space-for-earth economy (and, eventually, the entire terrestrial economy as well). Obviously, the realization of such a vision could change our lives profoundly. However, since that time, until September 2021, we never had more than thirteen people in space at any one time.

Space-for-Space Economy

The space-for-space economy covers goods and services produced in space for use in space. This includes mining the Moon or asteroids for space habitation needs, or transportation.

Space-for-Earth Economy

This covers goods or services produced in space for use on earth: telecommunications and internet infrastructure, earth observation capabilities, navigation, national-security satellites, and space manufacturing.

95%

In 2019, the space-for-earth economy created 95% of the estimated $366 billion in revenue earned in the space industry. This economy is booming.

Great Changes Are Coming In The Space Industry

The space industry is rapidly evolving, and so the space-for-space economy is going to boom as the space-for-space economy has. There are three main forces behind that process.

- **Decreasing launch costs**
- **Economies of scale**
- **Growing private sector demand.**

Source: Harvard Business Review

Space Activities were Historically Affordable Only by Governments

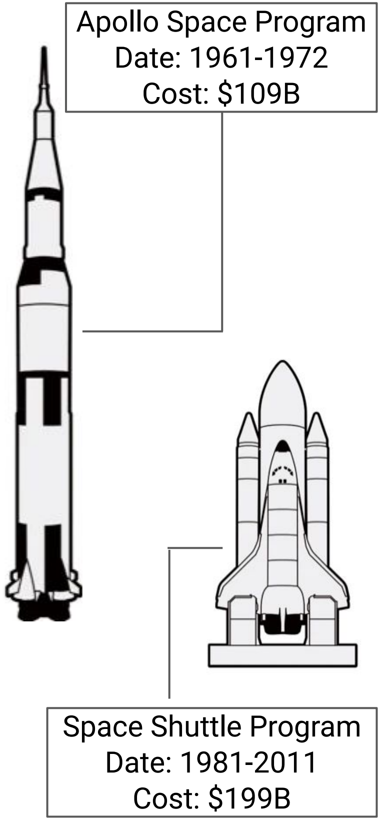
High costs have long been a deterrent to the development of the space industry. The costs were driven by a number of factors

Single-Use Rockets

Throwing rockets away after their first use has been the primary driver of sky-high costs as the rocket itself typically constitutes a high percentage of the entire launch cost. Propellant constitutes less than one percent.

Extremely Expensive Satellites

At these launch costs, a satellite has to be as light and compact as possible. In turn this means miniaturizing functions as much as possible, using exotic lightweight materials, and a lot of design time to package things as efficiently as possible. Moreover, it has to be highly reliable and long lived, to minimize the risk of having to replace it, which is even more expensive.



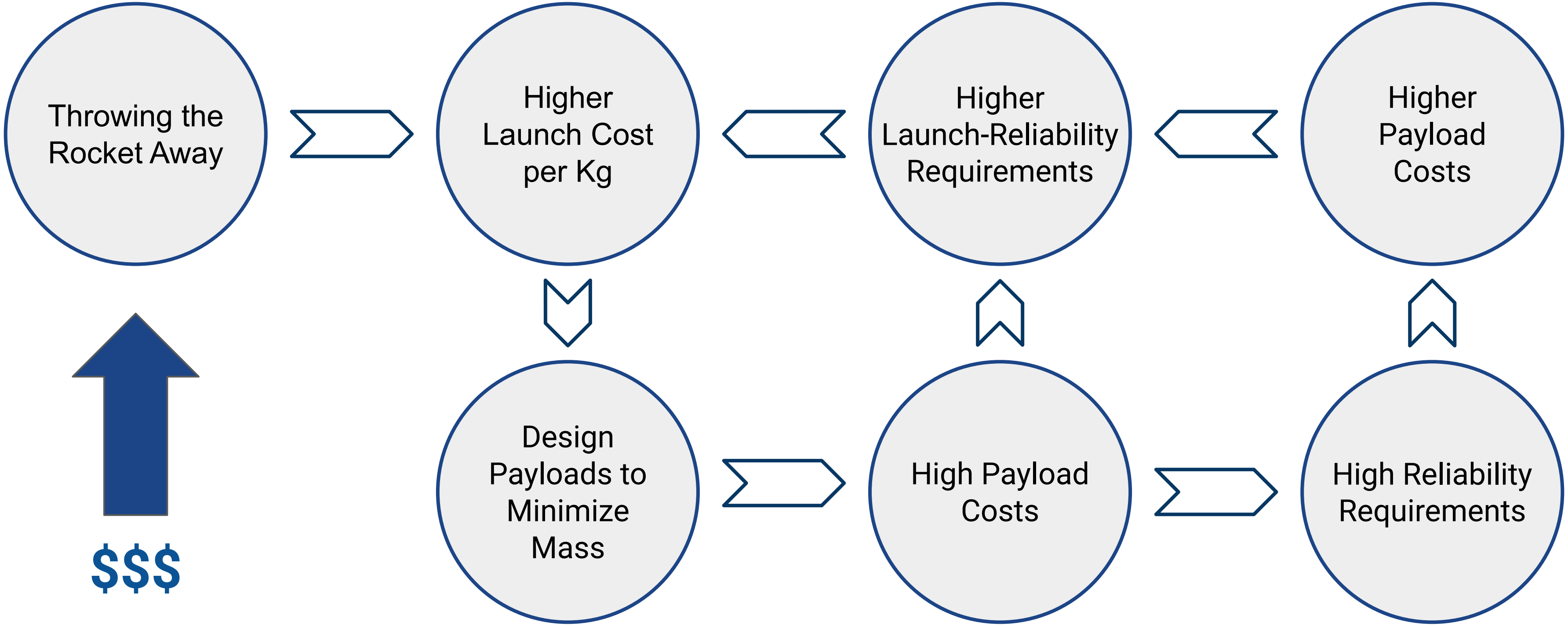
On the left are some of the most expensive space vehicles, historically. In the 20th century such high costs were affordable exclusively by large national governments. Each Apollo mission was about $10B, each Shuttle flight was about $1.5B.

In recent years, the industry has seen technology improvements that reduce the cost of production, and with increasing reusability, declining launch costs. SpaceX is leading this process and currently it is developing a fully reusable rocket (Starship/Superheavy).

As a result, the industry is seeing many new startups, developing numerous diverse solutions.

High Costs Beget High Costs

Throwing the rockets away results in a vicious cycle that reinforces high costs for both launch and building satellites. It appears that, after decades, SpaceX is finally breaking out of this cycle.



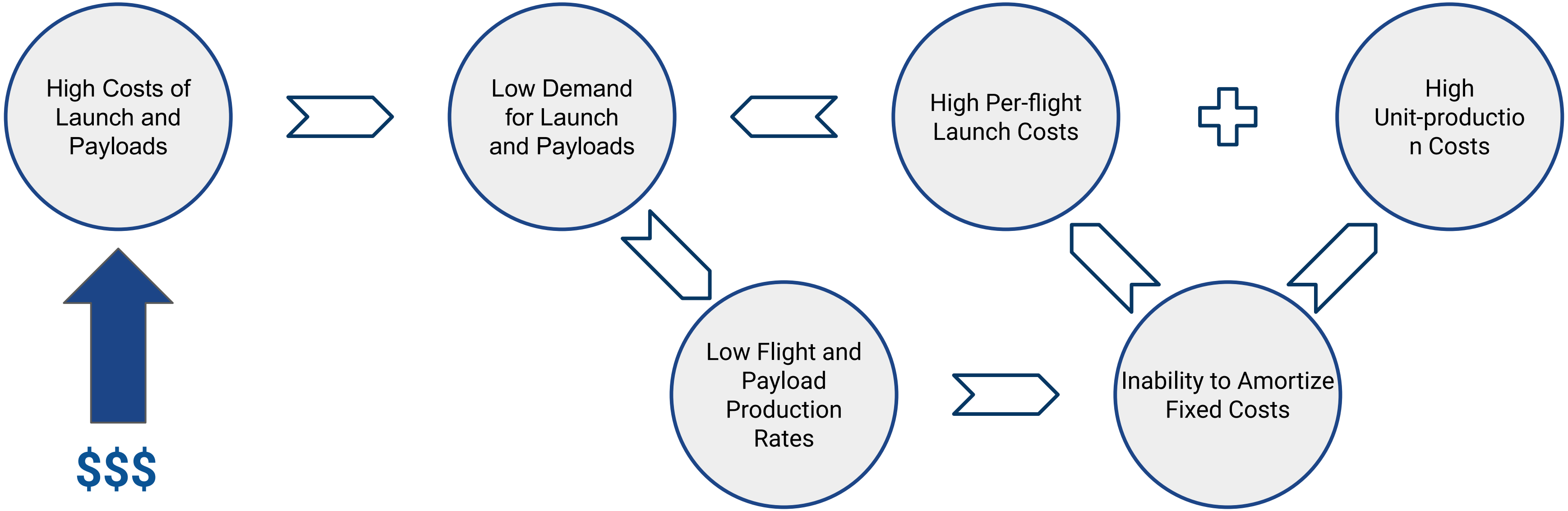
Markets and Demand Matter as Well

High Fixed Costs

There is a very high amount of fixed costs for facilities and personnel in the total launch infrastructure. This cost is largely independent of the flight rate.

Low Flight Rate

Due to the very high prices, the number of customers for satellite launch is low, resulting in a low flight rate. This low flight rate means a higher amortization cost per flight. This implies even higher launch costs, with corresponding higher payload costs, reducing demand further in another vicious cycle.



SpaceX Changed the Game

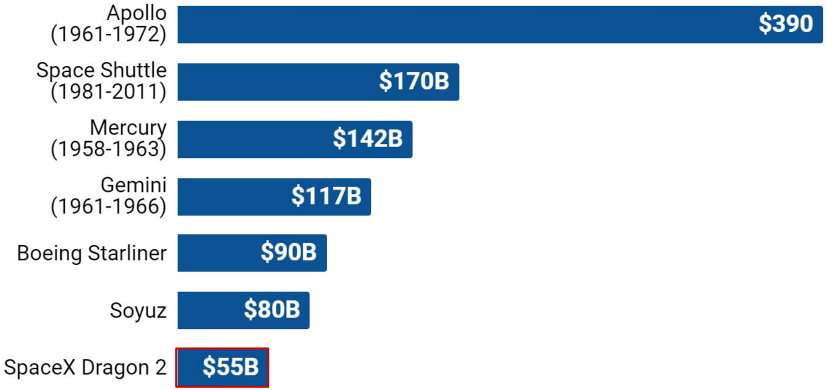
2015

The first successful landing of the first stage of Falcon 9 rocket

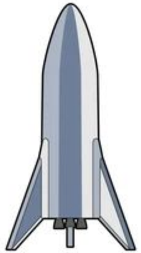
Elon Musk recognized that key to his dreams of going and sending humans to Mars required a dramatic reduction in launch costs, and that the key to reducing launch costs was to stop throwing the hardware away with every use. Today reusable rockets boosters have become routine. They have been recovering payload fairings as well, with a six-million-dollar savings per launch. The only part of the rocket they now cannot recover is the upper stage that delivers the payload to orbit.

SpaceX has the lowest prices and has thus secured the majority of the global launch market

Cost per Seat for Astronauts on Spacecraft



SpaceX is Developing a Fully Reusable Launcher



The company has been testing a new two-stage space transport, the largest rocket ever built, over 400 feet tall, that will be **fully reusable**. Like an aircraft, it should routinely require little maintenance between flights except refueling. The first stage is called Super Heavy, and the second stage, Starship.

Starship will Participate in the Artemis Program

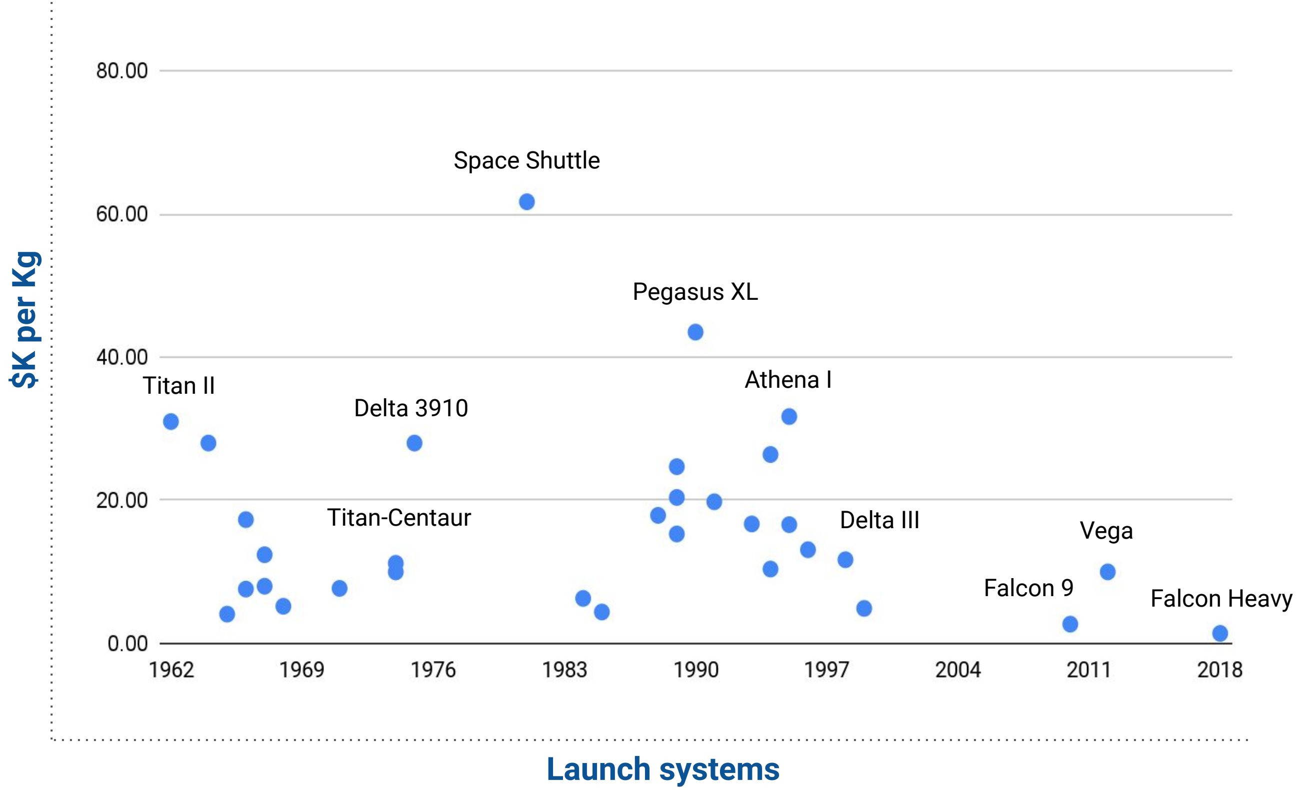
A version of Starship was recently selected by NASA as its lunar lander for the Artemis program to return NASA astronauts to the moon. The company's goal is to get it to orbit this year.

With in-space refueling Starship will be able to go all the way to the moon, Mars, and other interplanetary destinations.

ARTEMIS

Source: Forbes

Launch Cost per Kg is Decreasing



The graph shows the decreasing trend of launch costs in terms of $K/kg metric. However, this metric is not always appropriate. For example, Pegasus' advantage is in low per-flight cost.

SpaceX is ahead of the revolution and it going to drop costs even more by developing Starship. Ultimately the launch price could get as low as tens of dollars per kilogram.

Note:

The three most expensive and the oldest launch systems Vanguard, ($894.7k/kg), Delta E ($167.8k/kg), Scout ($111.8k/kg) were excluded to improve graph readability. Their first launches took place in 1957, 1960 and 1961 respectively.

Source: H. W. Jones "The Recent Large Reduction in Space Launch Cost"

Low Launch Prices Change Everything

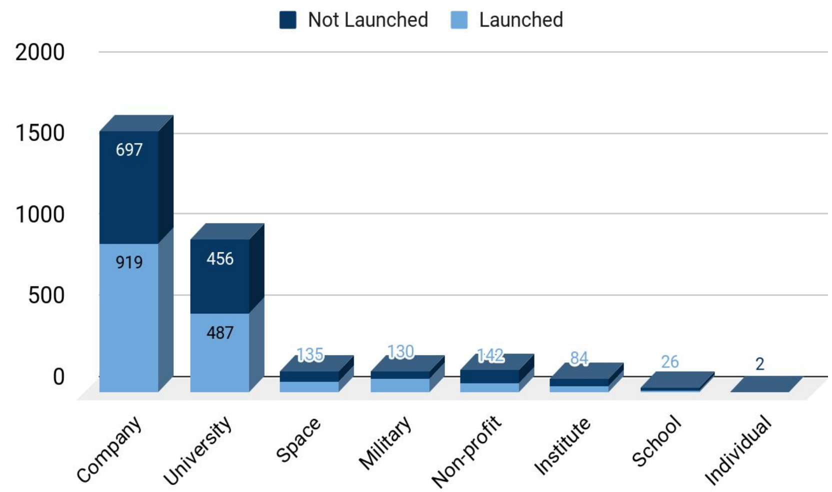
Spaceflight revolution

$10 M per flight

$100/kg

A fully reusable rocket could drop prices down to $10M per flight or $100/kg or less. Such costs will revolutionize existing paradigms of the space industry. Many space-related sectors will be profoundly affected, while new ones will emerge. Low prices change everything.

Nanosatellites are Becoming Accessible to Private Companies, Universities, and even High Schools



Source: nanosats.eu

Three Main Impacts

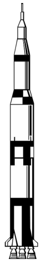
1. Low prices allow less-costly materials and more simplicity in satellite construction. It is becoming cheaper to replace satellites, reducing in lower program costs. Formerly unconceivable space projects could now become reality.

2. The SmallSat revolution is ongoing; satellite launches are becoming accessible for major companies, start-ups, universities, non-profits, etc., spurring more research and innovation.

3. The cost of a ticket to orbit could conceivably come down to a range of a few thousand dollars. Private space activities are going to grow rapidly (discussed further in the Private Spaceflight section).

Getting Mass Back from Space

Throwing rockets away makes it difficult to get payload back. Getting mass back from space requires entry capsules (which are also expensive to build and launch, for the same reason other satellites are) that are capable of much less payload than the rockets on which they go up. Thus, it costs much more to get mass back from space than to get it there in the first place.



Saturn V

Note that of the hundreds of tons of expendable Saturn V sitting on the launch pad during Apollo, the only payload returned from the moon was three astronauts and a few pounds of rocks. The much-higher cost of returning mass compared to delivering it has meant that the only commercially viable orbital payloads to date have been satellites that can deliver value back to Earth, packets of data, via massless photons, as communications and remote-sensing satellites do.

Cutting the cost of returning mass back to Earth will provide impetus to multiple space industry sectors: **space mining, space manufacturing, space tourism**, etc. Space mining will be the most complicated and ambitious field to develop, but with great potential.

Space Mining — Getting Resources from Space for Earth

Planetary Resources and **Deep Space Industries** were pioneers in space mining. But a lack of technology advancement, high costs, and low demand for space-mined products finally terminated their activities, and they were bought out. One more company, Moon Express, is struggling to survive.

But The Space-Mining Era Is Coming

- Many new companies are emerging and increasingly more people are willing to invest
- Further space expansion requires resource extraction in-situ
- New research and technologies are accumulating that will allow breakthroughs

Space Manufacturing Could Provide Higher Quality and Less Cost

Development of technologies enabling efficient return of payload back to Earth will spur the development of manufacturing in space, with its unique properties of weightlessness and cheap vacuum. Currently, the cost of getting mass back from space is too high, but that is changing. This is resulting in increased interest from companies who formerly couldn't see the business case.

Organs and Meat May Be Better Grown in Space

The heart, with its highly organized muscle tissue made of different types of cells is virtually impossible to print on the ground, as tissues printed and human stem cells collapse under their own weight. The first experiments on ISS have shown good results. For similar reasons, meat could be better grown in orbit for high-end markets, including space markets.

Free Fall is Perfect for Mixing Metals

Metals and other elements don't necessarily mix together well in one gravity, e.g. in the case of magnesium alloys, impurities settle to the bottom, and the upper layer becomes unusable. Even the main middle layer has imperfections. Weightlessness eliminates these issues.

Techshot Inc., a commercial operator of microgravity research and manufacturing equipment, developed the 3D BioFabrication Facility (BFF) in partnership with **nScrypt**. The bioprinter has successfully printed with a large volume of human heart cells aboard the International Space Station (ISS)

Aleph Farms is developing technology to growing steak directly from non-GMO animal cells. The company launched its 'Aleph Zero' program focused on cultivating meat for space settlement. In 2019, the company conducted a successful experiment of producing meat on the International Space Station, in collaboration with **3D Bioprinting Solutions**.

Techshot Inc. has partnered with a **University of Pittsburgh** team of researchers. They are conducting experiments in which an alloy composition will be melted in the high-temperature SUBSA furnace aboard the ISS National Lab in the weightless environment there, and then solidified for further analysis.

Other Space Products Could Improve Communications and Eyesight

More and more products are appearing to show significant improvements in quality when they are manufactured in the weightless environment. Thus, new horizons are now opening for the business and space industry.

Some say that the race to manufacture ZBLAN has begun

Fiber-optic Cable

ZBLAN* fiber-optic cable is made of fluoride glass and it is extremely effective in transferring digital information. However they are hard to make on Earth. The weightless condition of orbit is perfect to manufacture it, providing much better quality than Earth-made cables.

Redwire's **Made in Space, Fiber Optic Manufacturing in Space and Physical Optics Corp**., are going to produce ZBLAN fibers in low Earth orbit for terrestrial clients. The experimental production on ISS was successful.

Medical Implants

Implants are fragile elements. People suffering from retinitis pigmentosa and macular degeneration require a new retina. Anrtificial retina consists of more than 100 layers. Earth-gravity contributes to inefficient and irregular protein deposition, reduced implant homogeneity, and ultimately a lower-performing artificial retina.

LambdaVision has developed a protein-based retinal implant. However, the weightless environment of LEO enables manufacturing the implants with significant improvements in quality. Lack of sedimentation and convection currents resulted in increased homogeneity of layers with fewer to no defects.

Opportunities for Biomanufacturing in Low-Earth Orbit

In humankind's endeavor to explore beyond our planet and travel further into space, we are now at the threshold of an era in which it is possible to move to and from low Earth orbit (LEO) with increasing ease and reduced cost. Through the International Space Station (ISS) U.S. National Laboratory, investigators from industry, academia, and government can easily access the unique LEO environment on the ISS to conduct research and development (R&D) activities in ways not possible on Earth.

A key advantage of the LEO environment for life sciences research

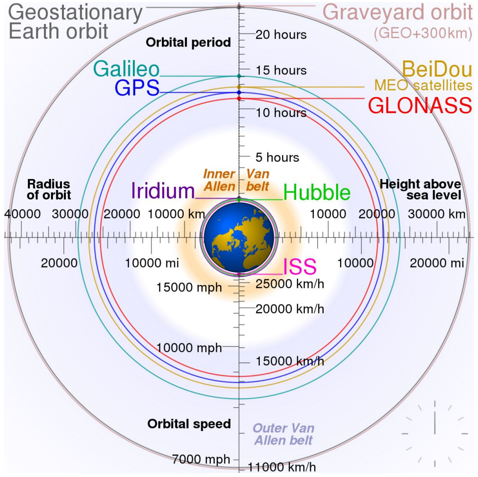
the ability to conduct experiments in sustained microgravity conditions

The ability to conduct long-term research in free fall enables opportunities for novel, fundamental studies in tissue engineering and regenerative medicine, including research on stem cell proliferation and differentiation, biofabrication, and disease modeling using microphysiological systems (MPS) that build on prior research using simulated microgravity conditions.

Source: Preprints

Over the last decade, space-based research has demonstrated that microgravity informs our knowledge of fundamental biology and accelerates advancements in healthcare and medical technologies (International Space Station 2019). The benefits provided by conducting biomedical research in LEO may lead to breakthroughs not achievable on Earth. We are now at a transition point, in which nations are changing their approach to space-based R&D.

Orbit size comparison of GPS, GLONASS, Galileo, BeiDou-2, and Iridium constellations, the International Space Station, the Hubble Space Telescope, and geostationary orbit (and its graveyard orbit), with the Van Allen radiation belts and the Earth to scale.

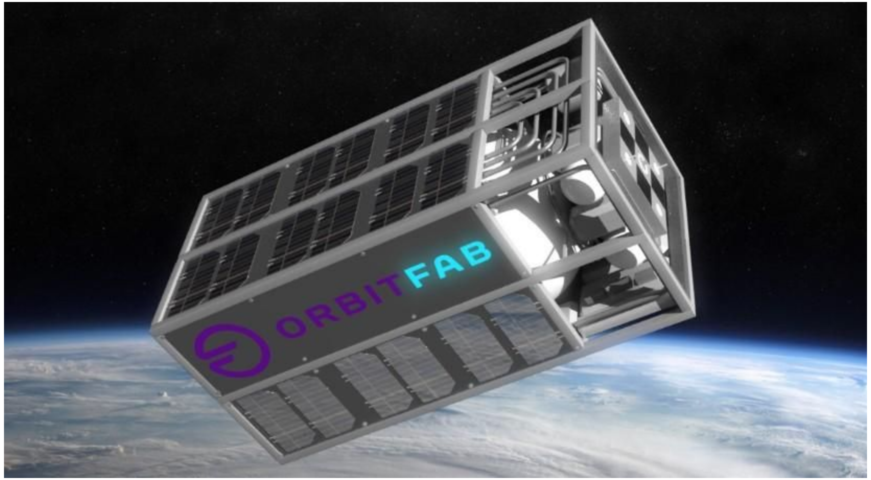


Refueling Changes The Economics Of In-Space Transportation.

Refueling - to Overcome Inefficiency

The rocket carrying payload should spend a huge share of fuel to carry the propellant needed at all stages of a fly. It could be compared to a truck on a long road with no gas stations. That truck would have needed to carry the fuel required to get the endpoint. Additionally, imagine throwing away that truck after the finish. How much would it cost?

Anyway, no point in a reusable vehicle if it can't be refueled, and there are no gas stations. Initially, the fuel will be delivered from Earth, just as remote stations are on earth, where the price is high (e.g. Alaska). Ultimately, we will mine the moon, planets, and asteroids for it so that getting around in space will become much more affordable. Again, SpaceX is ahead. It will be refueling Starships to get to the deep-space destinations (Moon, Mars, etc.)



Orbit Fab is paving the way. It offers a ubiquitous supply of satellite propellant in cislunar space, expanding the operational potential of new and existing space assets. In particular, the company has also now developed a “self-driving satellite” kit for docking. Total investment in the company has recently reached $6M.

Space Insurance Market

$4.5 B

2002

2012

The space insurance business was very profitable between 2002 and 2012 with over $4.5 B in underwriting profit earned primarily from the traditional large GEO satellite risks.

Bad Times in the Space Insurance Market

1. Low rates — this large profit attracted new players and rates were driven down to what was at the beginning of 2019 historically record low levels.
2. Reduction in an overall number of premium-heavy risks available to underwriters — the frequency of GEO launches has reduced due to competition with low earth orbit (LEO) constellations.
3. Competition — that reduction implied further competition amongst insurers and volatility in the space insurance market
4. 3 major failures occurred in 2019. Additionally, 2017 and 2018 also brought multiple costly incidents. One GEO launch failure could account for the entire premium base for the year

3 failures

Vega Flight VV15
Insured for **$444 M**

EUTELSAT 5 West B
Insured for **$112 M**

ChinaSat-18
Insured for **$250 M**

Total loss estimated:
$806 M

Space Insurance Changes

LEO constellations are becoming less risky and will constitute the bulk of space insurance market premium from launches. However, the number of satellites and debris in space may bring new risks and raise insurance rates. It might be tackled by **traffic management solutions** providing data to assess risk for different constellations and orbits. Investors and insurers will be fully aware of the space industry, its risks and returns.

Source: Gallagher

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Space Transportation Infrastructure

SpaceTech Analytics Contributors

Interplanetary Enterprises

Chris Lewicki

Introduction to Subsequent Sections

Spaceports

Overview and historical notes about the most active spaceports for launching spacecraft into suborbit, Earth orbit and for interplanetary missions in current operation.

Earth to Orbit Transportation

A section on how the history of orbital launch systems, how much it has changed in the past half century, and particularly in the past decade. It also provides an overview of the key market players and predictions for the future.

Cislunar and Deep-Space Transportation

This section is devoted to a description of cislunar space, that region contained by both our home planet and its moon, and an overview of current and planned means of moving around within it.

Space Traffic Management

An overview of the ever-growing problem of increasing traffic in low-Earth orbit, along with the key players, both government and private, addressing this issue and the primary agencies who will be responsible for policy.

What is Space Infrastructure?

What is infrastructure itself?

There are three types of infrastructure:

- **Hard:** Physical systems necessary for industry (roads, highways, bridges,transit buses, oil rigs/refineries)
- **Soft:** Institutions that help maintain the economy (emergency services, training services, banking)
- **Critical Infrastructure:** Essential to the functioning of a society

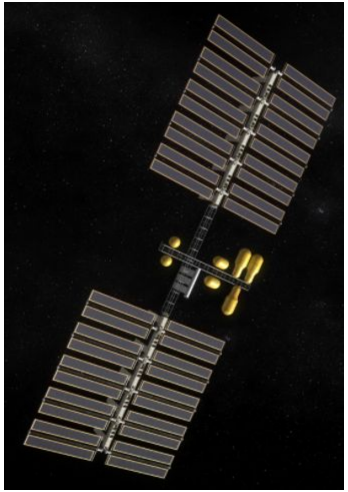
Current space infrastructure

Even though modern space infrastructure cannot be called considerable, compared to what the industry needs, it is very likely to become **critical** in a few decades. The spaceports all around the globe are built, mostly every year, scientific devices are launched into space constantly. Even those that were brought into space years ago, are still operating (f.e. LRRR on the Moon)

Several space technology companies are working on the development of space infrastructure. **MAXAR Technologies** design all kinds of infrastructural appliances from geospatial awareness devices to satellite-lifespan-prolonging robots. **Cislunar Space Development Company** plans on launching a propellant depot into space, that will help the industry vastly.

Possible space infrastructure of not-so-distant future:

- Propellant Depots
- Tug Services
- Landing Pads
- Energy Plants
- Test Facilities
- Repair/fail-over capabilities
- Rescue services
- Emergency Shelters
- Data Relay
- Space Traffic Management
- Orbit Situational Awareness



Satellite Transportation

Satellites provide a number of services to humankind in societal applications. To derive maximum benefits from the satellites, they have to be positioned into the right orbital slot in space. Space transport plays a key role in transporting the satellites from Earth and placing them in specified orbits, depending on their applications. With the limitations of the technologies available to date, transports have to be configured with multi-stages and the vehicle subsystems have to be totally autonomous and automatic.

In order to reduce the cost of launching satellites by a specified STS, the STS must deliver maximum payload mass into the specified orbit with very high accuracy.

The vehicle must be highly robust and this poses conflicting requirements on the design of each of the subsystems. The robustness demand of STS increases fold when the humans are on board, and in such cases, the transportation systems have to meet the stringent requirements of human rating.

Source: DHL

D-Orbit's ION Satellite Carrier is a flexible in-orbit transportation system for CubeSats and microsatellites. It can accurately place payloads where they need to be in orbit thanks to its inbuilt orbital propulsion system. The platform features a customizable 64U satellite dispenser capable of hosting a combination of CubeSats that fits the volume.

Spaceports

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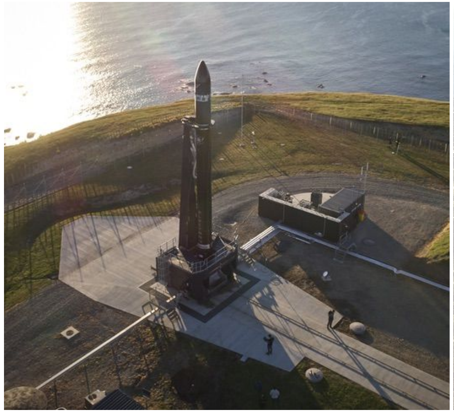
Spaceports

A spaceport or (for Russia) cosmodrome is a site for launching spacecraft for suborbital, orbital and interplanetary flights. They commonly have a rocket launch site, tracking stations, construction facilities, fueling infrastructure and, sometimes, processing facilities for solid propellants. The sites for receiving spacecraft either on Earth or Moon are also often referred to as “spaceports.”

Rocket launch sites are typically surrounded by large safety zones and may also include suitable sites to mount a transportable launch pad. Some spaceports have more than one launch complex, for different types of launch systems.

The space industry could not exist without spaceports, as they are key element of launch infrastructure. The quality and location of a spaceport can affect the success and the effectiveness of a launch. There has been a boom in construction and modernization of spaceports in America and Europe lately, which means that the flight rates of rockets can now dramatically increase.

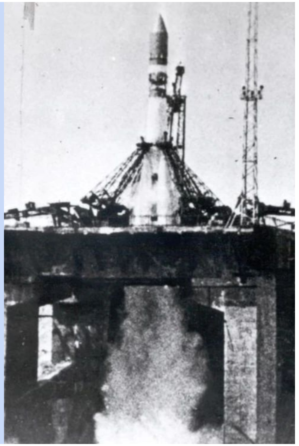


Early Spaceport Locations were Driven by National Needs

1949

Historically, rockets were expended and the first stages crashed downrange. The early **American spaceports** were put **on coasts**, so that the stages would fall in the ocean instead of on inhabited land. The first American orbital spaceport was built in **1949 in Cape Canaveral in Florida** and the first American orbital flight was done in 1958 from there.

1949



The first Soviet Union spaceport for orbital and human launches - the **Baikonur Cosmodrome** in southern Kazakhstan, started as a Soviet military rocket range in **1955**. The Baikonur Cosmodrome achieved the first launch of a human into space and orbit (Yuri Gagarin) in 1961.

1949

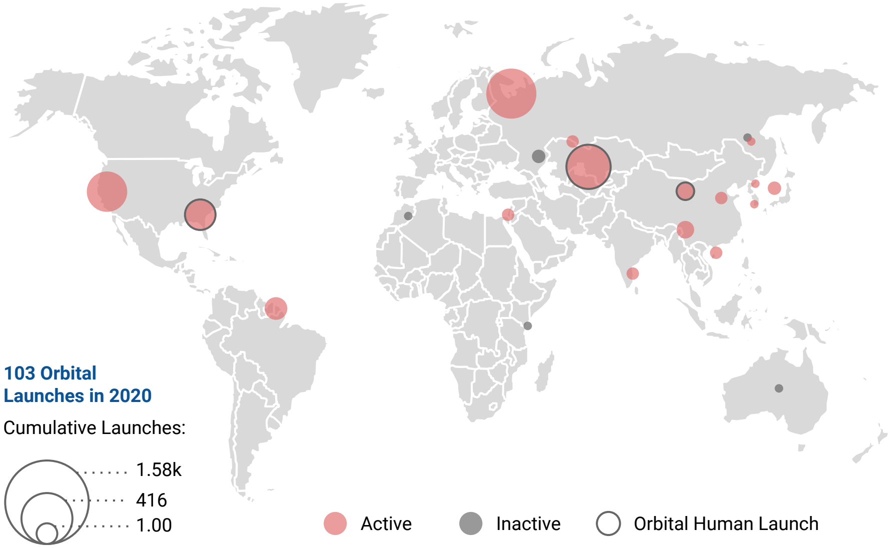
Established in **1958, Jiuquan Satellite Launch Center** is China's earliest launch site with state-of-the-art satellite launch facilities.

JSLC is mainly used to launch **scientific and recoverable satellite missions** with medium, low-Earth orbit and high inclinations.

Spaceport Location is A Function of Technology

Since the early days, the number of spaceports has dramatically increased. Today, there are eighteen spaceports that have been actively used in the last ten years.

Spaceports of the World (1957-2020)



Spaceports for lower-inclination orbits are built as close as possible to the equator, because this maximizes use of the Earth's rotational speed

Source: aerospace.csis

With the advent of reusability, in which launchers no longer shed parts downrange on nominal missions, and reliability is improved, it will eventually be possible to safely have **inland spaceports in America** and other places. This already has occurred for suborbital launches, with flights out of Mojave in California, Spaceport America in New Mexico, and west Texas on Jeff Bezos's ranch.

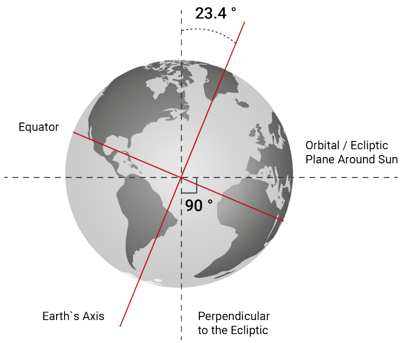
Spaceport Location Determines Which Orbits are Accessible

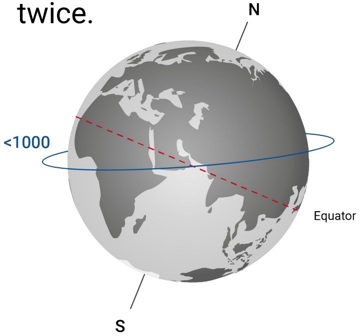
The inclination of an orbit is the angle between its orbital plane and the rotational axis of the planet.

An equatorial orbit has an inclination of zero degrees, and a polar orbit has an inclination of ninety degrees. Inclinations of greater than ninety degrees are called “retrograde” orbits, because the satellite orbits in a direction opposite to the planet’s rotation. When a rocket is launched into orbit, the orbit it can get to is constrained by the latitude of the launch site.

Canaria, Dentsu, Noiz, Space Port Japan Association

It ranges from difficult to impossible to get to an orbital inclination lower than that latitude, because the minimum inclination is achieved by launching due east, which makes a great circle on the planet that crosses the equator twice.





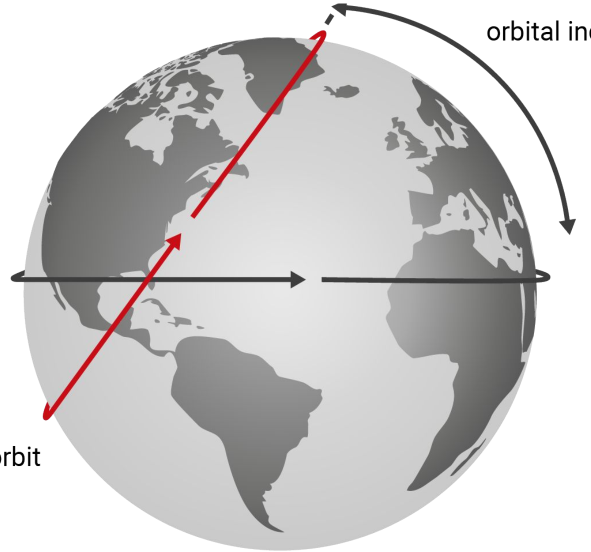
It is possible to get to an inclination higher than the launch latitude (though the payload is reduced because one isn’t getting full advantage of the planet’s rotation), but not lower.

The only location from which one can get to an equatorial orbit is from the equator itself, and the only inclination one can get to with a launch from a pole would be a polar orbit.

Spaceport Location Also Drives Launch Windows

For any orbital inclination, there are an infinite number of orbits, because one of the defining parameters of an orbit is the right ascension of the **ascending node (RAAN)**.

This is the longitude at which the orbit crosses the equator heading north. Thus, two orbits with the same inclination can be in very different orbit planes, and doing a plane change in space is very expensive, because of the **high velocity** whose direction must be changed. It also means that there could be high-velocity collisions between satellites **at the same inclination**, but different planes. Note that this is the case for every inclination except equatorial, which is unique. When one wants to launch into specific orbit plane, and not just to a given inclination, this can only be done once (or sometimes) twice a day, because the launch cannot occur until the launch site **has rotated to line up** with that orbit plane, and if the window is missed, it will have to wait another day for the planet to turn again. Only equatorial orbit does not have launch windows, because no matter when you launch, you will be in that orbit plane.



Some companies deliberately build their launch sites with specific orbital inclinations in order to launch into specific orbits. For example **Alaska Aerospace's** Pacific Spaceport Complex that is designed to launch vehicles into polar orbit.

Spaceports Can Be Mobile

Keeping in mind everything previously mentioned about launch sites' location, those sites **don't have to be stationary**. There are also ways to launch vehicles from either sea platforms, or from mid-air.

Sea launch sites

Launching from sea has been implemented in the past. In 1995 four companies from Norway, Russia, Ukraine and the United States established a company that built a buoyant space-rocket complex that was mobile and could launch rockets from the equatorial waters, providing orbital launch services starting in 1999. Unfortunately, it ceased to operate in 2014 after the Russian military intervention in Ukraine, but this project has proven the idea to be effective, and SpaceX plans it for Starship/Superheavy.

Air launch possibilities

Spacecraft air launch methods were also developed during the 1990s. Such launches typically involve two vehicles: a winged carrier aircraft and an upper-stage spacecraft. It provides much wider launch windows and allows single-orbit rendezvous.

Earth to Orbit

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The First Step of Any Space Voyage is Getting into Orbit

Launch System is the First Step

Regardless of the ultimate destination, a launch system is necessary to get payloads or people into space.

High Launch Cost is the Main Constraint

High launch costs have been the greatest limiting factor to date to expanded space exploration and utilization. For most of the space age, getting into orbit has been beyond the financial reach of anyone except governments and very lucrative businesses, such as communications and remote sensing.

That is about to change

The average cost to launch a kilogram of payload into LEO on the space shuttle remained constant at about $54,500. Now, the cost per kilogram is $2,720 on a SpaceX Falcon 9 rocket.

Robert Heinlein

Once you're in low-Earth orbit, you're halfway to anywhere [in terms of velocity].

1970

2010s

2020s

$54500

$2720

Cost per Kilogram

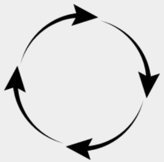
We Have Been Launching Satellites into Orbit for Over Six Decades

Starting with Ballistic Missiles

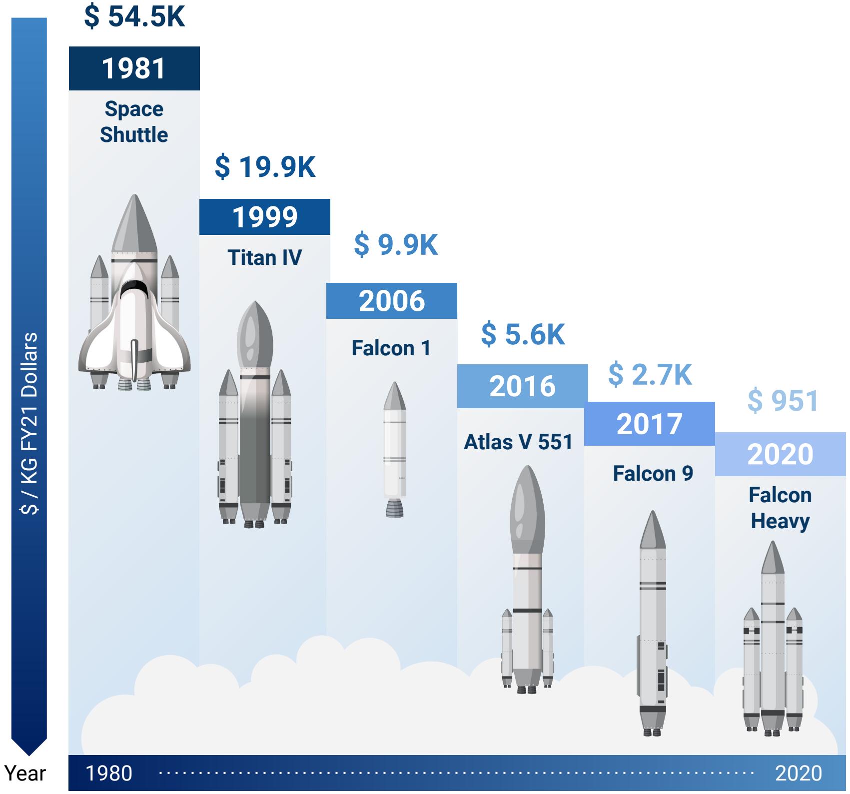
- Early rockets were largely derived from ballistic missiles. A great deal of effort had to be taken to make them more reliable for launching expensive satellites and humans
- Space was an unexplored and unpredictable area to a great extent and so it complicated the development of the industry
- In turn, as discussed previously, the flight rate was relatively low
- Moreover, the rockets were singles-use for decades
- They could not carry a lot of payload and/or humans aboard

Vicious Cycle of High Costs

As discussed in the section on Economics of Space, this created a vicious cycle of high costs of both spacecraft and transportation from which we are only now starting to escape



Cost per lbm to Launch Payloads to Low Earth Orbit



Source: Opportunities for Biomanufacturing in Low Earth Orbit: Current Status and Future Directions

Heavy-Lift Launch Fleet Like the Past, Except With Higher Reliability

Launch Systems Classification

All the launch systems are categorized by NASA according to low-Earth orbit payload capability.

Class	Payload
Small-lift	< 2000 kg
Medium-lift	2000 – 20000 kg
Small-lift	20000 – 50000 kg
Medium-lift	50000 kg >

Heavy-Lift Launch Fleet

	Operational	In Development
USA	Delta IV Heavy, Falcon 9, and Heavy	Vulcan / Centaur, New Glenn, Vulcan / ACES
Russia	Proton-M, Angara-A5	Angara-A5V
EU	Ariane 5	Ariane 6
China	Long March 5/5B (CZ-5/5B)	–
India	–	HLV, SHLV
Japan	–	H3 Heavy

Private Launchers

SpaceX	Falcon 9, Heavy and Starship
arianeGroup	Ariane 5, Ariane 6
Blue Origin	New Glenn
Mitsubishi Heavy Industries	H3 Heavy
ULA United Launch Alliance	Delta IV Heavy, Vulcan / Centaur, Vulcan / ACES

Smaller Satellites Have Resorted to Ride Sharing

Ridesharing Boosts the Market of Small Satellites and Reduces Costs

Small satellites are quite light and may mass as little as 30 kg. It is generally no affordable to launch a single small satellite. However, launching dozen or hundreds of satellites greatly reduces costs, making space more accessible for smallsats.

$57M
Per SpaceX launch

VS

$2.5
Per 150 kg smallsat launch

Problems of hitchhiking

- No control over schedule
- Has to have desired destination
- Navigation becomes more complicated

Opportunities of hitchhiking

- Creates a market for dedicated small satellites
- Emergence of new markets (like space-burial services)
- Empower new industries like space imagery, small-satellite communication, etc.

SpaceX Set A Record

January 24, 2021

143 satellites were delivered on one mission. Beside the communication, space imagery and other satellites, it carried capsules of human ashes (by Celestis).

Previously, the record was set by an Indian company carrying 104 satellites on a single rocket

Source: SpaceNews

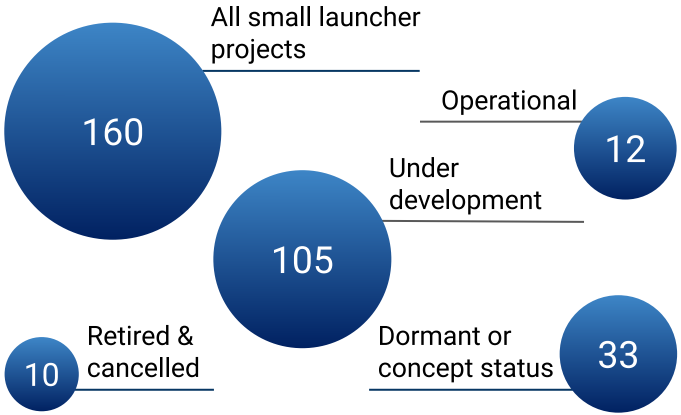
Many Smallsat Launchers in Development

Table of Operational Small Launchers

Logo	Organization	Launcher	Launches	Price per kg
	Northrop Grumman	Pegasus	44	126400 $/kg
	CASIC / ExPace	Kuaizhou-1A	10	20000 $/kg
	Rocket Lab	Electron	19	25000 $/kg
	JAXA	SS-520-4	2	–
	LandSpace	lv	1	–
	One Space	OS-M	1	–
	i-Space	Hyperbola-1	2	16700 $/kg
	China Rocket	Smart Dragon-1	1	–
	CASIC / ExPace	Kuaizhou-11	1	10000 $/kg
	Virgin Orbit	LauncherOne	2	40000 $/kg
	Astra Space	Rocket	1	25000 $/kg
	Galactic Energy	Ceres-1	1	–

Source: NewSpace Index

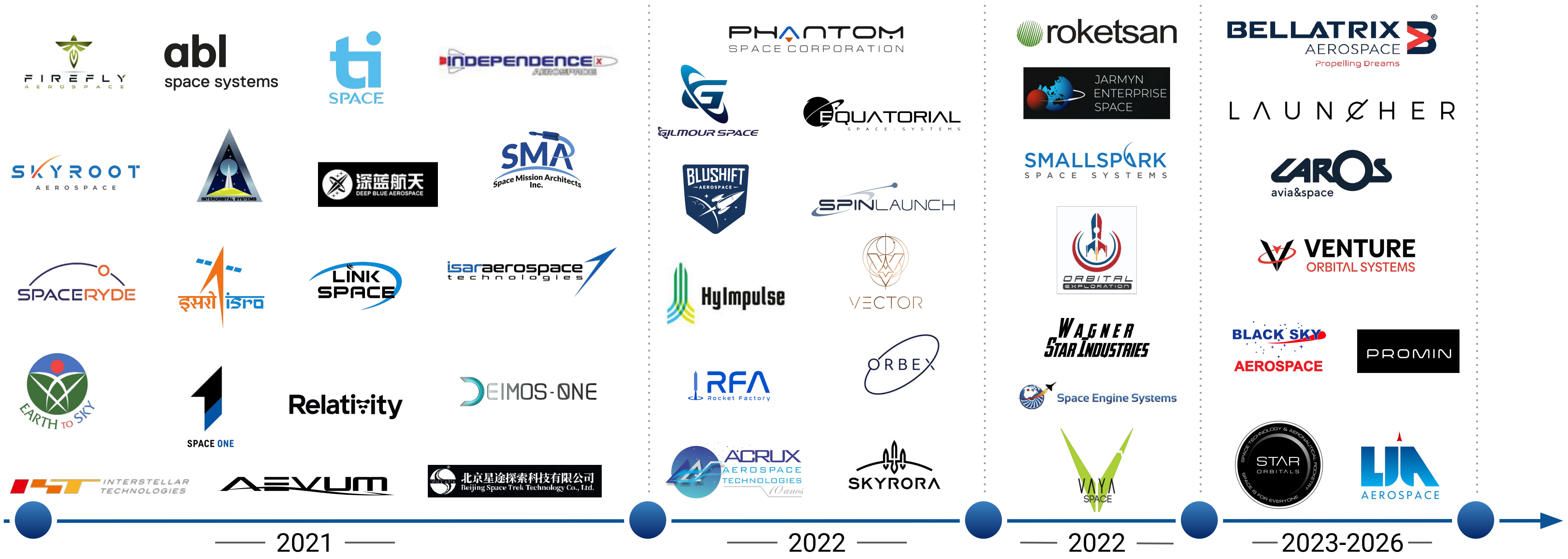
The space industry is experiencing a boom in the development of smallsat launchers; recently, the number of such projects reached 160. Ten of these projects have been cancelled or retired, with twelve operational. All the other projects are under development or dormant. Most of them are planning first launch in the years 2021-2026. There will be a shakeout in the industry.



Timeline of Smallsat Launchers in Development

45 Companies are Going to Launch Rockets in Near Future

There are 105 companies with smallsat launchers under development. Most of them do not have precise deadlines for first flight. However, 45 of them are planning first launch in the next five years. **Relativity** and **Firefly** are among the most promising contenders. The graph below shows the planned dates of first flights.

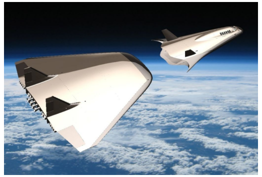


The Future of Commercial Space Transportation

Today, commercial space transportation primarily means launch to Earth orbit. In the near future, it will include **commercial in-space transportation systems** and their support infrastructure. In fact, there are commercial in-space transportation companies now. One can book payload delivery to the Moon on expendable commercial lunar landers today with **Astrobotic for $1.2 million per kilogram**. In addition, Momentus is offering expendable space tug services in Earth orbit for small payloads. Reusable space tugs and Moon shuttles with propellant depots and on-orbit refueling are coming. Commercial space transportation is evolving to more diverse and more reusable launch systems as well as expanding to encompass orbit transfer vehicles and Moon landers.

Phantom Express: Boeing

Skylon: Reaction Engines



AstroClipper: Exodus

Momentus intends to use a **multi-pronged approach** to become a provider of three critical functions in the **new space economy**.

Commercial in-space transportation is in its infancy. Astrobotic has a posted price for delivering small payloads to the Moon. **Momentus Space** is offering to move payloads to higher Earth orbits from ISS or when attached to a payload at launch. **Orbit Fab** is testing hardware on ISS for Earth-orbiting water depots. Altius is developing hardware to enable on-orbit servicing and mating. Interglobal is defining intraorbital transportation architecture systems to service co-orbiting space stations. **Cislunar Space Development Company** is defining reusable cislunar vehicles for transportation from LEO to the lunar surface and all points in between. Reusable space tugs will have the same economic impact benefits that reusable boosters have today.

SpaceX has Massively Disrupted the Launch Market

SpaceX Brought the Commercial Launch Market Back to America

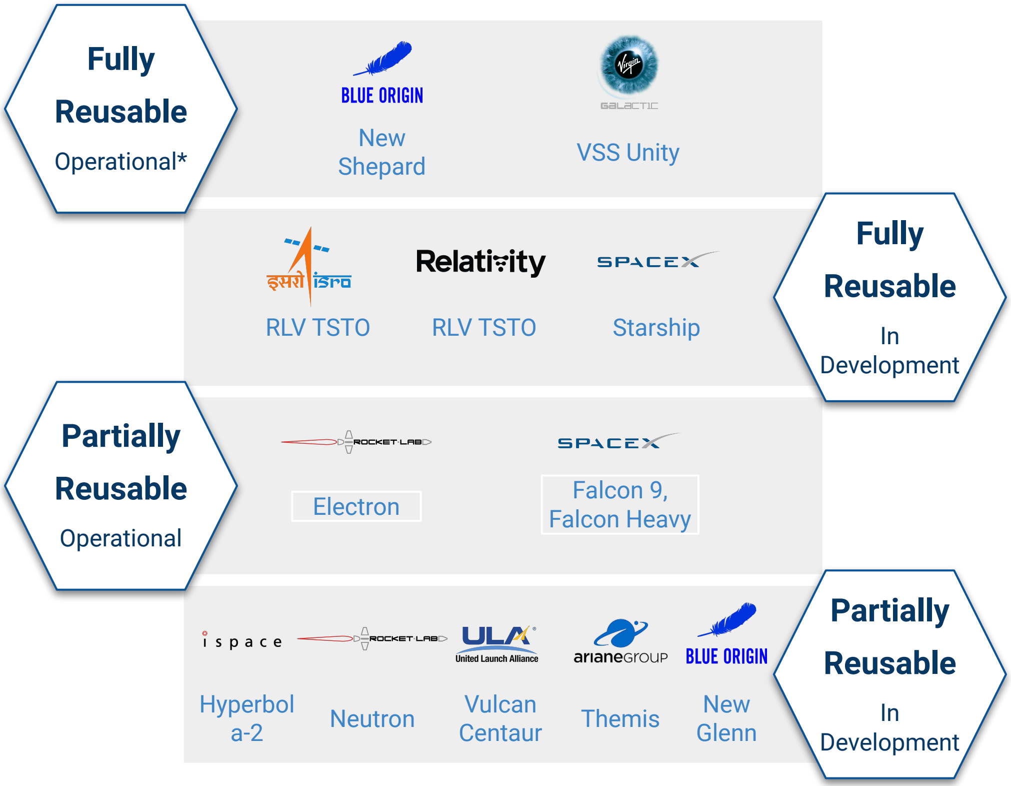
Even before it started reusing its first stage, the Falcon 9 was undercutting the competition, both domestic and international. Eventually, it managed to bring the commercial launch market back to America after it was lost in the 1990s to foreign competition due to high costs of legacy rockets as was presented on previous slides.

Reusable Rockets Have Entered the Mainstream

Everyone is starting to copy SpaceX's reusability approach: China, Arianespace, New Zealand, India, etc.

With Starship/SuperHeavy, SpaceX is about to disrupt both the launch and satellite market further, almost beyond recognition (as was described in Economics of Space section).

Reusable Rockets



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Cislunar & Deep-Space Transportation

SpaceTech Analytics Contributors

Cislunar Space Development Company

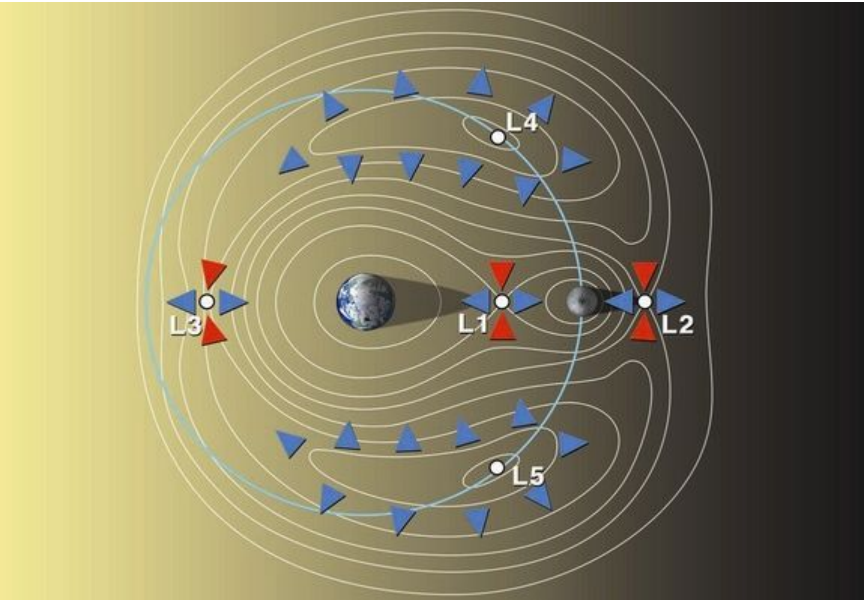
Dallas Bienhoff

Interplanetary Enterprises

Chris Lewicki

Cislunar Space

Cislunar space is the volume outside Earth's atmosphere, including LEO, GEO and Lagrange points, that goes on to the Moon's orbit. The outer border is considered to lie on the L2 Lagrange point. The Moon and its surface are also considered to be inside cislunar space.

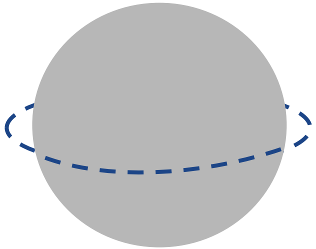


Types of Lunar orbits

Low lunar orbits

Orbit period: 2 hours

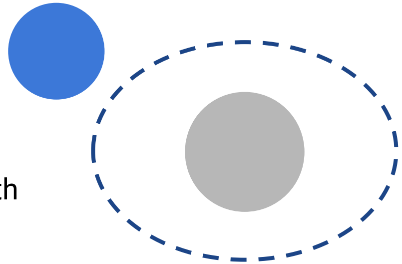
Optimal for surface reconnaissance, but difficult to maintain



Distant retrograde orbits

Orbit period: 2 weeks

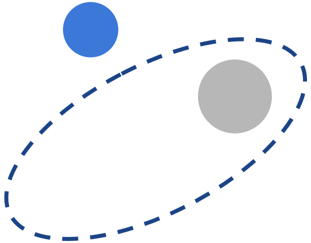
Large, circular, stable orbits. Far from lunar surface, but close to Earth



Halo orbits

Orbit period: 1-2 weeks

Mostly around Earth-Moon Lagrange points. Fuel efficient and close to the surface. It is the type of orbit that is mostly used for Lunar missions.



How Do You Get to the Moon?

The first vital step

Obviously it is impossible to just launch a rocket right away after one has decided to launch some payload to the Lunar surface. There is a formidable step that requires planning, scheduling, calculating and estimating before the mission itself.

Launch

The most effective way to launch a rocket to the Moon is to do a regular vertical launch,it is not obligatory to have a right angle, but the deviations don’t usually exceed 18 degrees. After that, a rocket has to reach around 40,300 kilometers per hour in order to reach Low Earth Orbit.

Trans-lunar injection

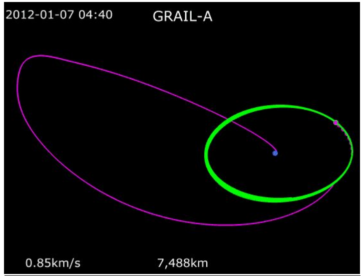
The type of orbit the spacecraft is launched into depends on the spacecraft itself. Surface surveying satellites take on a low lunar orbit as well as some landing vehicles. Most of the landers, however, are launched into halo orbits, as they are more stable.

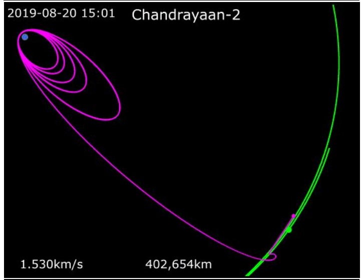
Lunar orbit

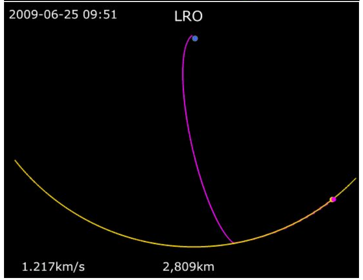
There comes the trans-lunar injection (TLI), which is a propulsive maneuver to reach lunar orbit. They come in different forms and shapes (as shown on the right) and sometimes are called GTOs, which means that they begin on a geostationary orbit.

Landing

After being on a stable orbit for some time in order to check the systems, the vehicle slows down and “falls” on the lunar surface.







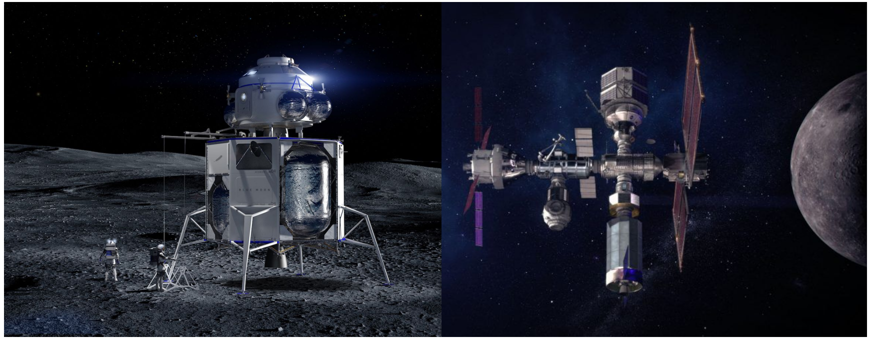
Artemis Lunar Program

Artemis is an international program, led by NASA, designed to land the first base on the surface of the Moon, as well as construct an in-space base in cislunar space, that will provide support for the mission. As part of it, NASA also intends to have the first woman on the Moon by 2024, though this schedule is unlikely at this point. As part of this, NASA will perform more in-depth exploration of the lunar surface than ever before. The program also envisages collaboration with private partners to develop payloads, landers, robotics etc.

The space station is called **Gateway** and it is planned to be launched to lunar orbit between **Artemis II** and **Artemis III** missions. The station serves numerous functions: science laboratory, short-term habitation module, communication hub and holding area for rovers and other robots. It is still in development and mostly JAXA, ESA, CSA and **Northrop Grumman** are working on the project.

The Artemis program involves several national space agencies, including space agencies from the US, Japan, Italy, Australia, UK, Canada, Luxembourg, UAE and Ukraine.

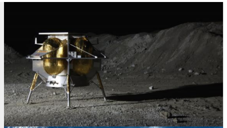
Artemis I	Uncrewed capsule that will orbit the Moon for 25 days and then return to Earth. Originally planned for 2022
Artemis II	First crewed flight in the program. It is intended to be a flyby of the moon on a free return trajectory.. Planned for 2023
Artemis III	A flight with a landing on the moon. Two astronauts will stay on the moon for about a week. Planned for 2024, but all dates likely to slip.

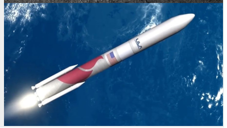


Other Leaders in Moon Exploration

NASA isn't the only governmental organisation planning lunar exploration. Roscosmos, the China National Space Agency, the Indian Space Research Organisation and ESA are developing their own projects for lunar missions. But there are also private companies planning such projects.

United Launch Alliance will launch **Astrobotic's** first lander to the Moon in late 2021. That is supposed to be the first commercial mission to the Moon.

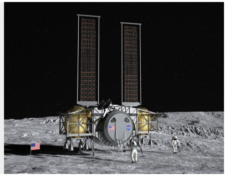




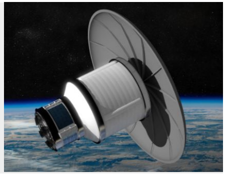
SpaceX's lunar lander was initially chosen for the Artemis lunar program.

Blue Origin was also developing a Human Landing System for NASA.

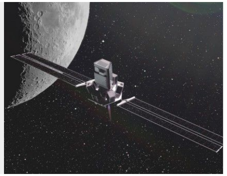
Dynetics was the third contractor with NASA to develop HLS and they still continue.



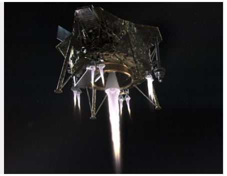
Tugs by **Cislunar Space Development Company** will deliver payloads from LEO to GEO.



Momentus and **Qosmosis have** agreed to deliver two cubesats to low lunar orbit as early as 2024.



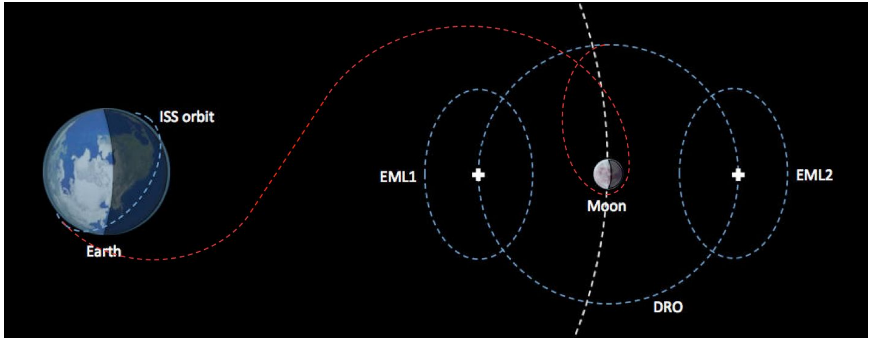
Firefly has signed a contract with **SpaceX** to deliver their BlueGhost lander to the Moon.



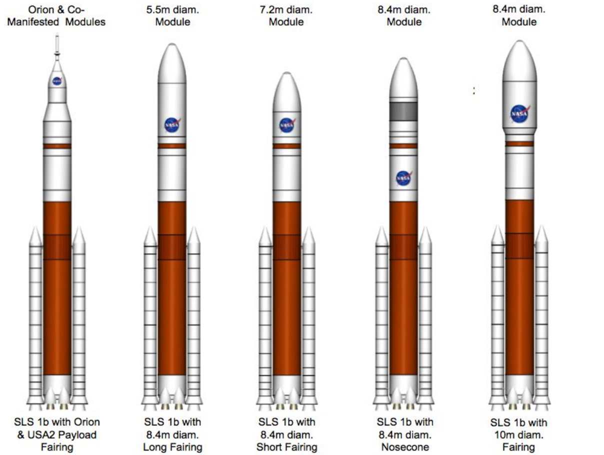
Deep-Space Transportation

Human missions beyond LEO considered include the establishment of a deep space habitation capability in the cislunar vicinity. Cislunar typically refers to a location between the Earth and the Moon, such as the Earth-Moon.

The lunar DRO is the baseline destination for the concepts presented here because it is a stable orbit that requires little orbital maintenance, and was identified as the final destination for recent asteroid retrieval mission scenarios.



Cislunar Vicinity. The Lunar DRO is the final destination for each configuration depicted



SLS Co-Manifested And Dedicated Payload Vehicle Configurations. Five payload configurations were explored to accommodate a variety of habitat options for this study.

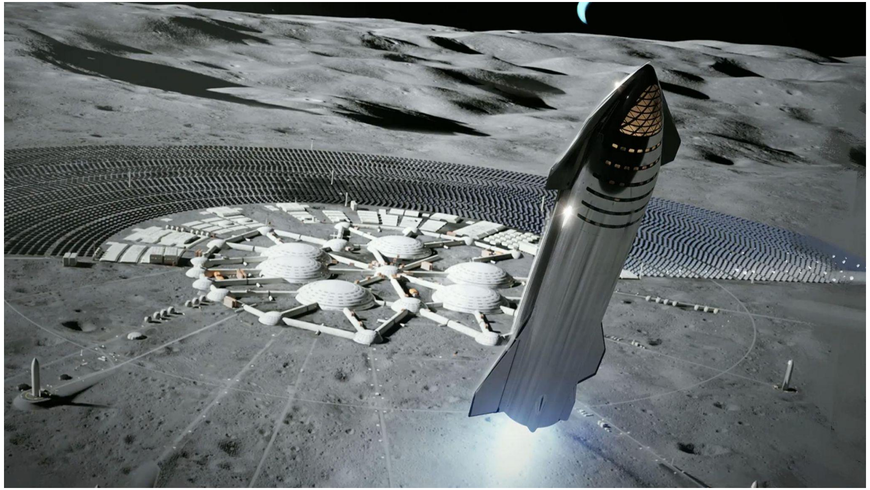
SLS will provide a capability, albeit expensive, in the 2020s to launch habitable volumes as co-manifested payloads with the crew using the Orion and its service module for propulsion, and dedicated payloads without the crew using built-in or attached propulsion elements. The payload mass difference between the two approaches is on the order of 10 mt for co-manifested payloads, and 40 mt for dedicated payloads delivered on trajectories to cislunar space.

Starship/Superheavy May Make Humans Multiplanetary

SpaceX Starship is a reusable crewed spacecraft developed by SpaceX since 2012. The Starship launch vehicle of the same name, which includes the first Super Heavy stage, is designed to launch a spacecraft with more than 100 tons of payload into Low Earth Orbit (LEO).

Starship can be used for the following purposes:

1. Low Earth Orbit (LEO) launches.
2. Long-term missions to deep space.
3. Mars exploration, including both cargo dispatch missions and passenger missions.
4. According to Elon Musk, technological "descendants" of the spacecraft will be able to make interstellar flights.
5. Point-to-point commercial flights on Earth.

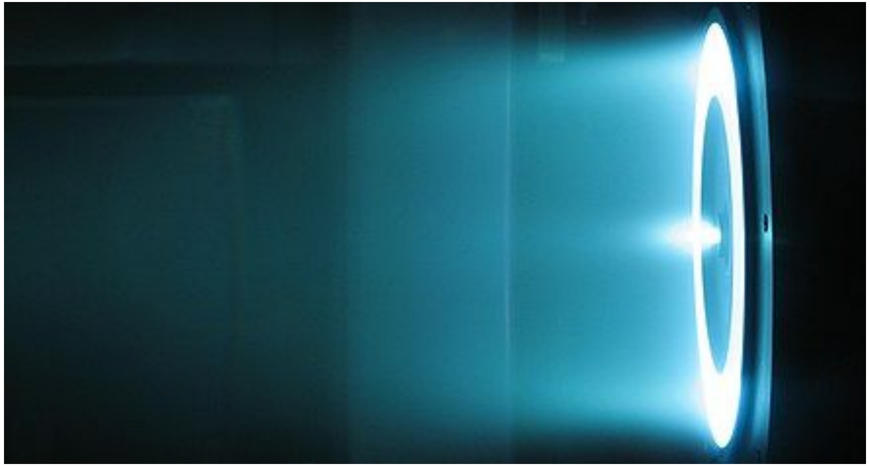


SpaceX Starship human lander design that may carry the first NASA astronauts to the surface of the Moon under the Artemis program.

Elon Musk: A Million Humans Could Live on Mars By the **2050s**

Non-Chemical Propulsion for Modern Spacecraft

Rather than relying on high temperature and fluid dynamics to accelerate the reaction mass to high speeds, there are a variety of methods that use electrostatic or electromagnetic forces to accelerate the reaction mass directly. Usually, the reaction mass is a stream of ions.



6 kW Hall thruster in operation at the NASA Jet Propulsion Laboratory.

Electromagnetic methods for non-chemical propulsion

Ion thrusters	Electrothermal thrusters	Electromagnetic thrusters
Electrostatic ion thruster	DC arcjet	Plasma propulsion engine
Gridded ion thruster	Microwave arcjet	Magnetoplasmadynamic thruster
Field-emission electric propulsion	Helicon double-layer thruster	Electrodeless plasma thruster
MagBeam		Pulsed inductive thruster
Hall effect thruster		Pulsed plasma thruster
Colloid thruster		VASIMR
		Vacuum arc thruster

NASA Commercial Lunar Payload Services Awardees

In November 2018, NASA awarded nine companies Indefinite Delivery Indefinite Quantity contracts with a combined maximum value of $2.6 billion over the next ten years for lunar payload delivery. Payload capacity varies from 35 to 500 kilograms. Each company received an unspecified amount of funding to develop its payload users guide.

DEEP SPACE SYSTEMS

DRAPER

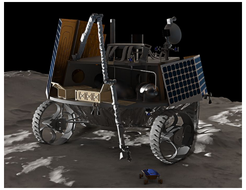
Masten

ASTROBOTIC

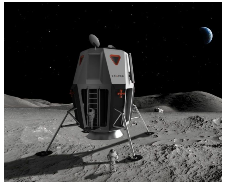
LOCKHEED MARTIN

INTUITIVE MACHINES

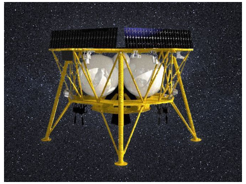
Peregrine: Astrobotic



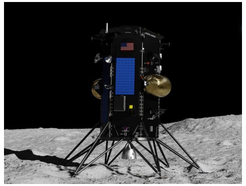
SLPC Rover: Deep space



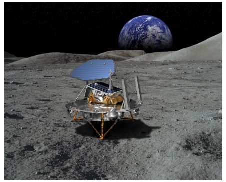
Artemis-1: Draper



Genesis: Firefly Aerospace

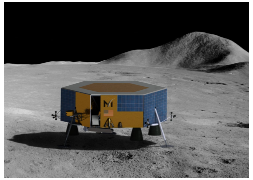


Nova-c: intuitive machines



McCandless: Lockheed Martin

Z-01 Lander: Orbit Beyond



X-1 Lander: Masten Space Systems

MX-1E: Moon Express

Source: Astrobotic, Lockheed Martin

Strategic Principles for Sustainable Exploration

1

Implementable in the near-term with the buying power of current budgets and in the longer term with budgets commensurate with economic growth;

2

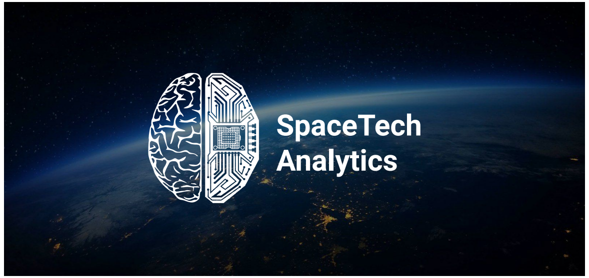
Exploration enables science and science enables exploration, leveraging robotic expertise for human exploration of the solar system

3

Application of high Technology Readiness Level (TRL) technologies for near term missions, while focusing sustained investment on technologies and capabilities to address challenges of future missions;

8

Continuity of human spaceflight is essential to sustain progress; we will establish a regular cadence of crewed missions to cislunar prior to the end of ISS .



4

Near-term mission opportunities with a defined cadence of compelling and integrated human and robotic missions providing for an incremental buildup of capabilities for more complex missions over time;

7

Substantial new international and commercial partnerships, leveraging the current International Space Station partnership while building new cooperative ventures.

6

Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique major developments, with each mission leaving something behind to support subsequent missions; and

5

Opportunities for U.S. commercial business to further enhance the experience and business base;

Source: HSF Transition: ISS, LEO and beyond to cislunar space

September 2021

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SpaceTech Analytics

Space Traffic Management

SpaceTech Analytics Contributors

SPACE ECONOMY RISING

Kevin O'Connell

CONFERS

Ian Christensen

After Over Six Decades of Spaceflight, It's Getting Crowded Up There

New Space Economy: The Phantom Menace

Space traffic management is one the most urgent issues that must be resolved with the coming New Space Era. Satellite operators are racing to secure valuable orbits. Numerous debris objects are floating randomly in space. Thousands of satellites are going up in different orbit planes with the new broadband constellations. The number of satellites and debris is increasing, so the potential for collisions is rising. This issue threatens the New Space Economy, as current space monitoring systems cannot handle the traffic adequately.

Moriba Jah

Outer space may be infinite, but the region of space around the Earth where we put stuff is very limited

Moriba Jah is an American space scientist and aerospace engineer known for his contributions to orbit determination and prediction especially as related to space situational awareness and space traffic monitoring.

The Largest Accidental Collisions in Space: 2009 and 2021

2009

The Collision of Iridium 33 and Cosmos 2251

It was the **most severe accidental fragmentation** on record. The collision produced more than 1800 pieces of debris (approximately 10 cm and larger). Some debris from both satellites will remain in orbit through the end of the century.

2021

The Collision of Yunhai and Zenit-2 rocket's debris

A Chinese military satellite collided with space debris on March 2021. It was the first major orbital collision since 2009. Although Yunhai 1-02 survived it's unclear if the satellite can still do the job it was built to perform. This collision has become an alarming signal for the entire industry.

Space Traffic Management

The Potential for Collisions is Rapidly Increasing

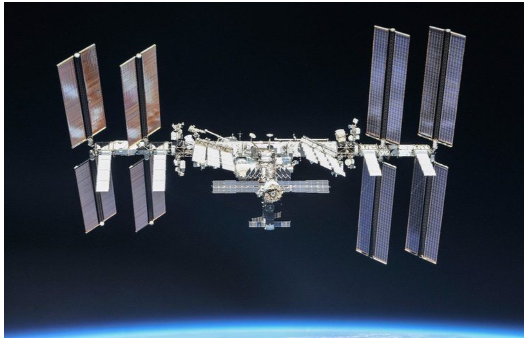
4000+ active satellites	Starlink plans to launch up to 42,000 satellites by mid-2027. Other companies have ambitious plans too
30000+ actively tracking debris	Their size is larger than 10 centimeters. Two objects slamming into each other at terrific speeds, creating numerous bits of new debris. It can result in the **Kessler syndrome**
1000000+	An estimated number of small particles (1-10 cm)
330M+	An estimated number of very small particles (less than 1 cm)
10 km/s (22,000 mph)	With such an **average speed** a 1 centimeter paint fleck is capable of inflicting the same damage as a 550 pound object traveling 60 miles per hour on earth. A 10 centimeter projectile would be comparable to 7 kilograms of TNT

"Kessler syndrome" may cause an orbital apocalypse

Kessler syndrome is a cascading series of collisions that could clutter Earth orbit with so much debris that our use of, and travel through, the final frontier is significantly hampered, if not made impossible.

What about ISS?

International Space Station (ISS) is one of the largest artificial objects in orbit. Thus, it is quite vulnerable.



According to NASA policy ISS has to maneuver away from an object if the chance of collision exceeds 1 in 100,000. The ISS maneuvers by firing thrusters to raise the orbital altitude. It is expected to execute similar maneuvers about once a month to maintain orbital altitude.

UN Space Office Seeks Consensus on Space Traffic Management

The United Nations Office for Outer Space Affairs is poised to assist the international community in **tackling the challenges** posed by an increasingly diverse set of actors launching and operating spacecraft.

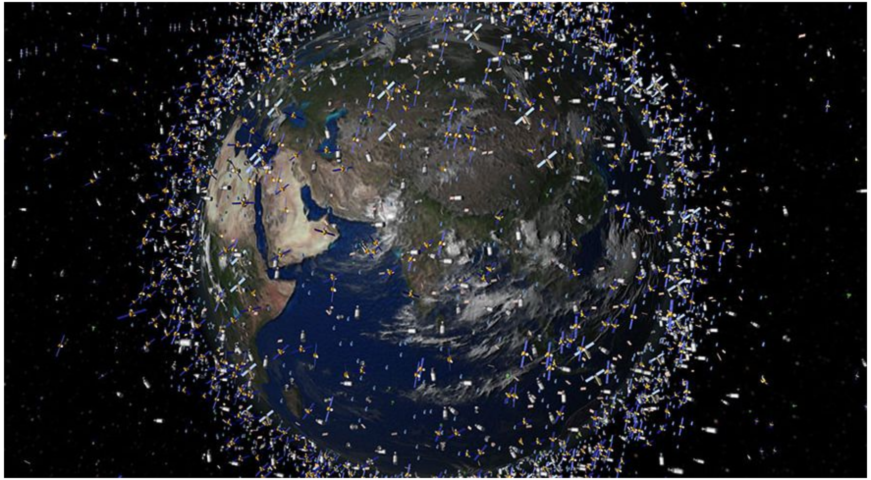
"There is a huge need to stabilize global space operations through norm generation and multilateral consensus,".

"We must future-proof activities now to deliver a safe, secure and sustainable space environment for tomorrow."

Simonetta di Pippo,
director of the UN Office for Outer Space Affairs, said Sept. 7 at the Satellite 2021 conference.

Many nations beyond the traditional space powers are recognizing the importance of space traffic for scientific discovery, technological advancement, economic opportunities, and even climate change.

The growing population of satellites and debris in orbit make improving space traffic management a key issue that should be addressed now, a panel of experts recently argued.



Space Traffic Management (Private Sector)

As the value of space has grown, space operators and entrepreneurs have worked together to develop tools to mitigate risk to their systems and to promote continuing investment and innovation. Realizing the importance of space traffic management and related risks, plenty of companies work on collision avoidance, debris removal, maneuver planning, orbit optimization, etc.

Companies are Developing New and Different Ways to Cope with Debris and Other Activities in Multiple Orbits

ExoAnalytics' telescope network enables persistent high-altitude SDA (Space Domain Awareness) – the ability to monitor, understand and predict natural and man-made objects in orbit around the Earth. **LeoLabs** uses network of ground-based, phased array radars to produce high-resolution data on objects in low Earth orbit (LEO). **NorthStar** plans to monitor space, from space, via a constellation of satellites.

Companies like **COMSPOC**, **Slingshot Aerospace**, and others are working to provide a continuously updated picture of the space environment for decision-making and channels for increased communications between space operators. **COMSPOC** provide different type of software for space operations. **Slingshot** applies machine learning, computer vision, and collaborative tools to data from earth and space.

200+

the early participants (companies) in an emerging space safety industry.

Common to all of these companies is their leverage of state-of-the-art cloud computing, communications, advanced analytics, and other advanced technologies, continuous recapitalization of their capabilities, and innovation.

Space Sustainability

As traffic increases, there have been occasions that inflicted some harm on the accessibility of space.

2009 Collision between Iridium and Kosmos

On February 10, 2009, the active commercial Iridium 33 and the derelict Russian military Kosmos-2251 accidentally collided at a speed of 11,700 m/s. The collision created at least 1000 pieces of debris larger than 10 cm and many more smaller ones. The cause of the accident was a mistaken estimate of the collision probability. The satellites were expected to miss by 584 meters.

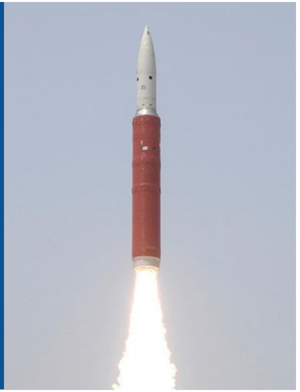
Anti-Satellite Tests Concerned The World

The first anti-satellite weapon (ASAT) was tested in 1985, when an air-space missile was launched from a jet and destroyed the Solwind P78-1 satellite. In 2007 China tested an ASAT, creating more than 2300 pieces of debris. It was followed by another US test in 2008, and an Indian test in 2019, each producing about 400 pieces. This is a matter of concern, because ASATs can lead to the **Kessler Effect**.

Kessler Effect

The Kessler Effect is a theoretical scenario in which the number of objects in low-Earth orbit is so great that collisions are highly likely to occur, cause a cascade in which each collision generates space debris that increases the likelihood of further collisions. It could result in making space inaccessible for decades or even generations to come. Current projects like SpaceX's Starlink raise concern about increasing the possibility of this scenario..

The launch of an Indian interceptor PDV MK-II

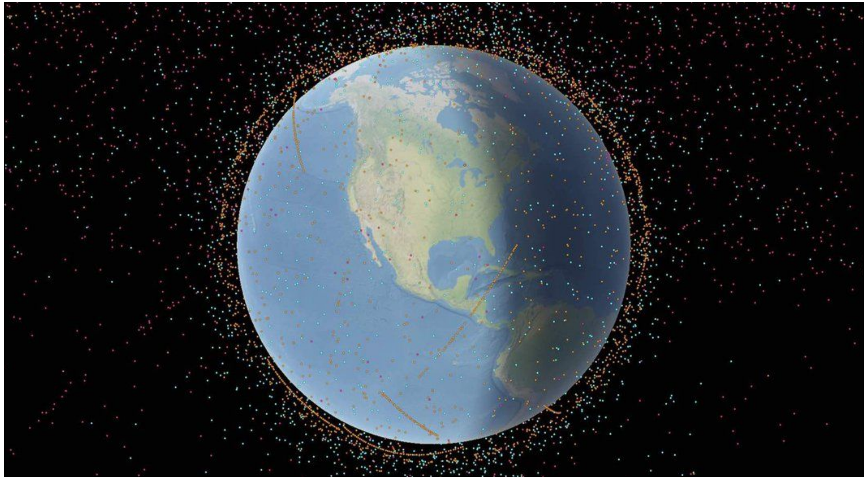


An F-15A Eagle launches the rocket at the Solwind P78-1

Space Traffic Management

Major Players to Tackle Space Traffic Management Issues

U.S. Space Force Space Surveillance Network	New Zealand Space Agency	Astroscale
It is considered as the most capable entity in the world. However, it is not sufficient on its own.	Integrates exhaustive information about bodies on LEO into regulatory processes in an innovative way	Leading orbital debris removal company



Possible Solutions

Professor Moriba Jah is leading a crowdfunding project **AstriaGraph** that displays the positions of all actively-tracked objects in the sky

He also launched Conjunction Streaming Service showing how close objects get to one another as they whip around the planet in real-time

Removing space debris from orbit with technology innovative tools: nets, harpoons, or lasers

Deorbiting a satellite at the end of its life

Imposing obligatory **tax per each satellite launch** for the clean-up of space debris. It would require changes to international law, under the OST.

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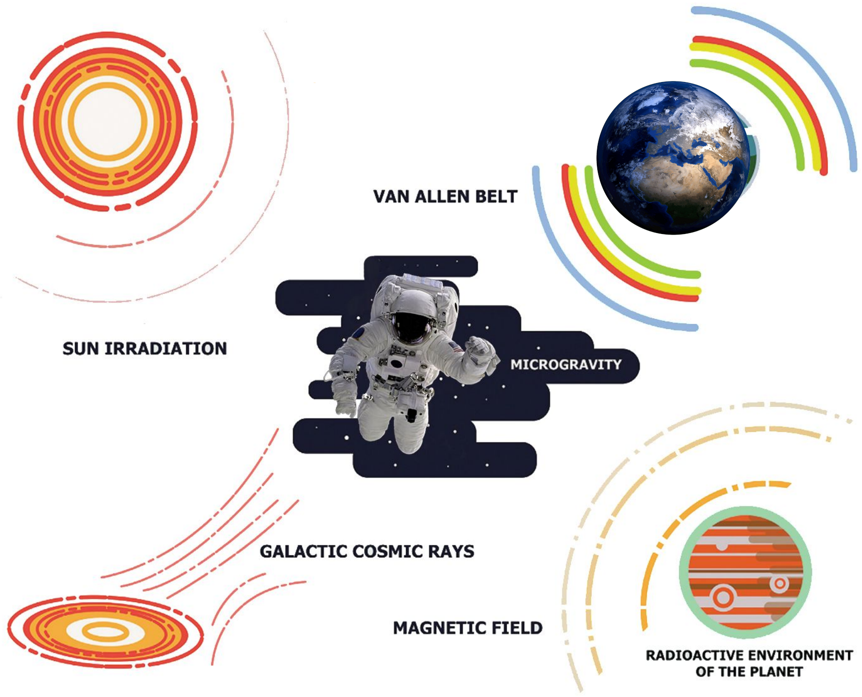
The Issue of Aging in Space



Source: SpaceTech Analytics - Blog

Spaceflight presents immensely difficult challenges. **Weightlessness, partial gravity, planetary dust, and space radiation** pose a significant threat to humans in both spaceflight and living in planetary habitats, which can result in the rapid development of life-threatening diseases in astronauts. In addition, the closed environments can create additional stress on a space crew's work performance and mental wellbeing.

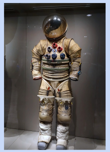
The word “**weightlessness**” is used in this report to describe the condition that astronauts experience in different locations of altered gravity during the space flights. The term “**microgravity**” has its limitations as it is basically means one millionth of the Earth gravity and it is incorrect to apply to the conditions that astronauts undergo during the space missions.

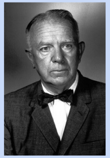
Advancements in Longevity are crucial for the future of space exploration. As more private companies continue to expand the space economy, **the viability of space-longevity research substantially increases.** Space tourism is gaining popularity, and new heavy-lift low-cost launch vehicles are being developed at an unprecedented speed. However, life-support systems have not been advancing at a fast a pace. Humanity needs to develop new personalised medical approaches that can be applied in space to ensure the well-being of space travelers and settlers and become a multi-planetary civilisation.

Key Space Medicine Achievements of the 20th Century

1931- 1948

The term **"space medicine"** was coined by **Hubertus Strughold**, he also developed a **pressure suit** that gave rise to modern concept of **spacesuits**. The first full **pressure suit** was designed by engineer **Ciann Downes in Leningrad in 1931.**





1961

Yurii Gagarin's flight debunked medical worries that **exposure to an orbital spaceflight environment would be fatal**.

1967

NASA's **Gemini Program** was undertaken many **physiological measurements and life support to extravehicular activities.**

1973

During NASA's **Skylab Program** the effects of space flight on the human bones, cardiovascular, systems along with diet, hygiene and waste management were investigated.

1984

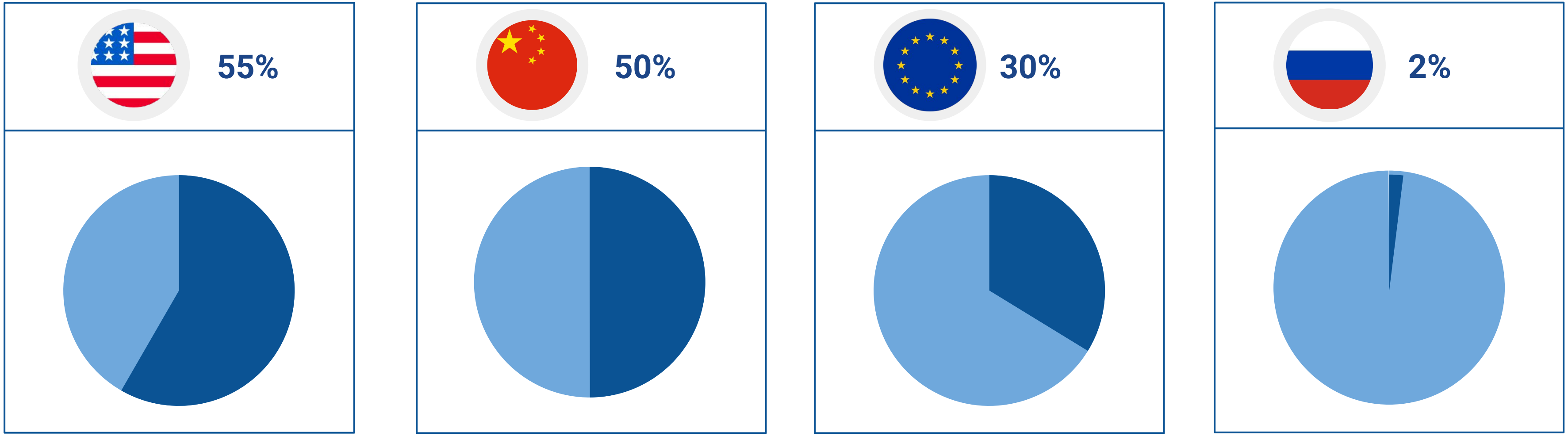
The **first private biomedical research** has been carried out by **Charles D. Walker** - first non-governmental individual in space. He presented the **McDonnell Douglas Corporation** as a Payload Specialist during **Space Shuttle**, performed early **protein crystal growth experiments** and participated in numerous medical studies.

1986

The Mir space station was constructed for extended stays by cosmonauts. It revealed that the **space environment affects individuals differently**, and not even every astronaut is suitable for it.

Growing Interest in Private Research in Space Medicine

Today, more and more space startups are arising and promoting private research in space. Giving the current rising interest, commercial research is increasingly taking over the market.



55% of the U.S. space market is coming from the **private sector.** The second country by the number of private space initiatives is **China** with **half of the market** dedicated to **commercial R&D. The European Union** holds third place with **30%** of the space projects initiated by **private companies**. Though historically Russia has the most experience in space research, space commercialization only began there in 2018. Since then **only one Russian company has carried out private research in space** - 3D Bioprinting Solutions.

Sources: NASA, Vedomosti, ESA

Top Companies Advancing Space Medicine

United States

Biogen Inc
Cambridge, Massachusetts, United States

MicroQuin
Cambridge, Massachusetts, United States

Amgen
Thousand Oaks, California, United States

490 BioTech
Knoxville, Tennessee, United States

RevBio
Lowell, Massachusetts, United States

Tympanogen, Inc.
Richmond, Virginia, United States

Angiex
Cambridge, Massachusetts, United States

Eli Lilly
Indianapolis, Indiana, United States

Kernal Biologics
Cambridge, Massachusetts, United States

SP8CEVC, Venture Capital
New York, New York, United States

Merck
Kenilworth, New Jersey, United States

60% of companies shown have their headquarters in the **U.S.**, with **Israel, France and Switzerland** sharing second place (**30%** of all private companies). Other companies are distributed equally among the **UK, Netherlands** and **Italy**.

Source: Mitochondria in Longevity and Space Medicine

Israel

SpacePharma
Herzliya Israel, Courgenay Switzerland

Pluristem Therapeutics Inc.
Haifa, Israel

France

Sanofi
Paris, Ile-de-France, France

Medes
Toulouse, Midi-Pyrenees, France

United Kingdom

AstraZeneca
Cambridge, Cambridgeshire, United Kingdom

Netherlands

OrgaNext Research
Arnhem, Gelderland, The Netherlands

Italy

Kayser Italia
Livorno, Toscana, Italy

Switzerland

Nova Space Biotechnology
Zürich, Zurich, Switzerland

Novartis
Basel, Basel-Stadt, Switzerland

Supporting Commercial Life Sciences Research - CASIS

Since 2011, when NASA engaged **the Center for the Advancement of Science in Space (CASIS)** to manage the ISS National Lab, CASIS has partnered with academic researchers, other government organizations, startups, and major commercial companies to take advantage of the **unique weightless lab**.

One of the main areas of focus for NASA is life sciences. **Studying the effects of weightlessness** on astronauts' physiology, microbiome, genetics, and life-support systems, including food-production systems, provides data for future space exploration and settlement.

By 2025, CASIS plans to attain a profit approximately **equal to the current annual US costs of maintaining the ISS**, which is:

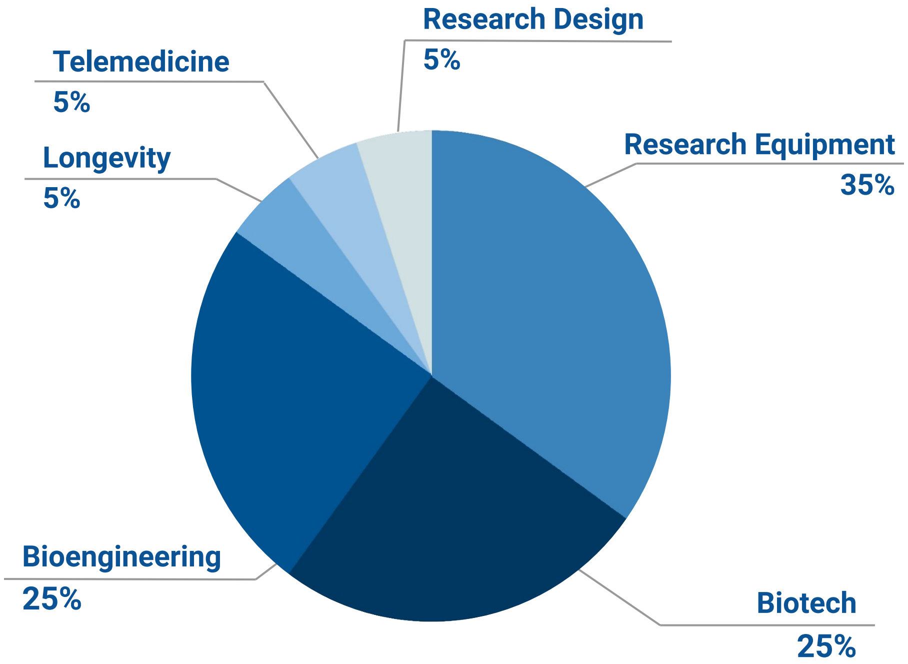
$4 Billion

From 2016 CASIS began a robust outreach to the pharmaceutical community, which takes advantage of the weightless environment on the ISS to develop and enhance therapies for patients on Earth. Companies such as **Merck, Eli Lilly & Company,** and **Novartis** have sent several payloads to the space station, including investigations aimed at studying diseases such as osteoporosis, and examining **ways to enhance drug tablets for increased potency** to help patients on Earth.

Source: CASIS

Services to Enhance Space Medicine Industry

Number of Companies in Each Sector



25% of the marketplace is dedicated to **bioengineering** solutions for astronauts to adverse age-related degenerative conditions: eye and bone implants, or medical hardware to analyse and support astronauts' health. Another **25%** of the space medical market is focused on **the biotechnology** industry dealing with space-related disorders and *in situ* amino-acid production.

More than **35%** of space-related companies **provide research equipment for the ISS.**

5% are dedicated directly to human longevity in space. In particular, a new venture-capital fund called **SP8CEVC** has been established to place a laser-tight focus on the intersection between space technology and human longevity.

Source: Mitochondria in Longevity and Space Medicine

Cost of Private Research on the ISS has Increased

In April 2021 after discussions with stakeholders about the current market growth, and in anticipation of future commercial entities capable of providing similar services, the new NASA commercial marketing pricing policy was formed and **prices went up significantly**.

	upmass	downmass	1h of crew member time	per person per day for life support, toilet and other supplies including food and air
2019	**$3,000**	**$6,000**	**$17,500**	**$33, 750**
2021	**$20,000**	**$40,000**	**$130,000**	**$88,000 - $164,000**

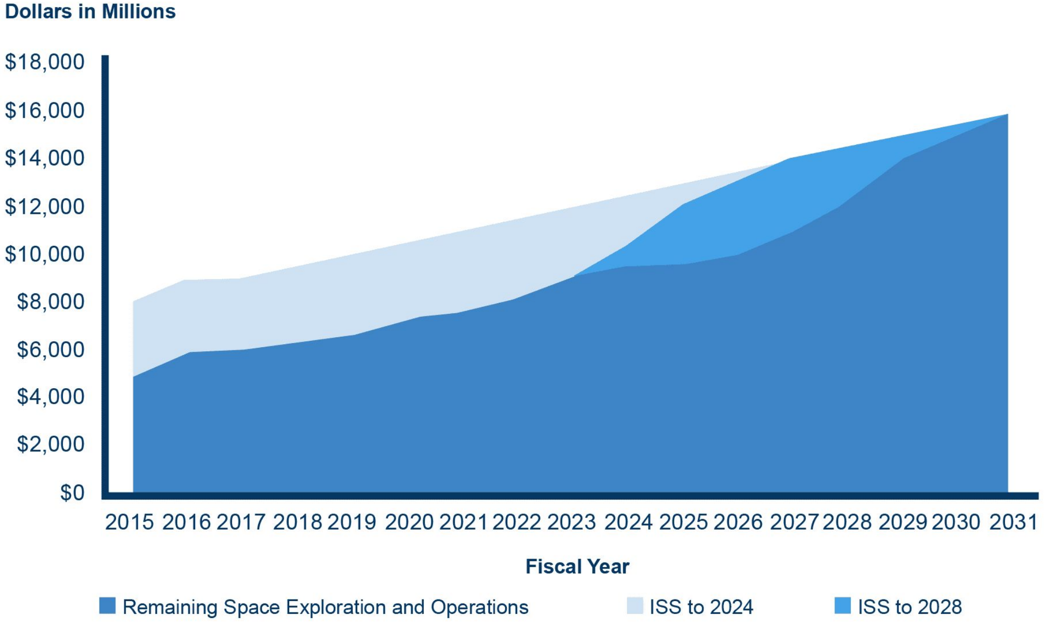
“The pricing policy from June 2019 **did not reflect full reimbursement for the value of NASA resources**; it was intended to stimulate the market and was planned to be adjusted”

- says Michael Johnson Chief Technologist of the Engineering and Technology Directorate at NASA

Source: SpaceNews, NASA

Supporting ISS for Weightless Research is Currently Very Costly

Supporting the ISS to 2028 will require additional funding **from other parts of the NASA budget**. Thus further cooperation with the private sector is urgently needed to ensure other NASA space activities, such as exploration beyond low-Earth orbit.

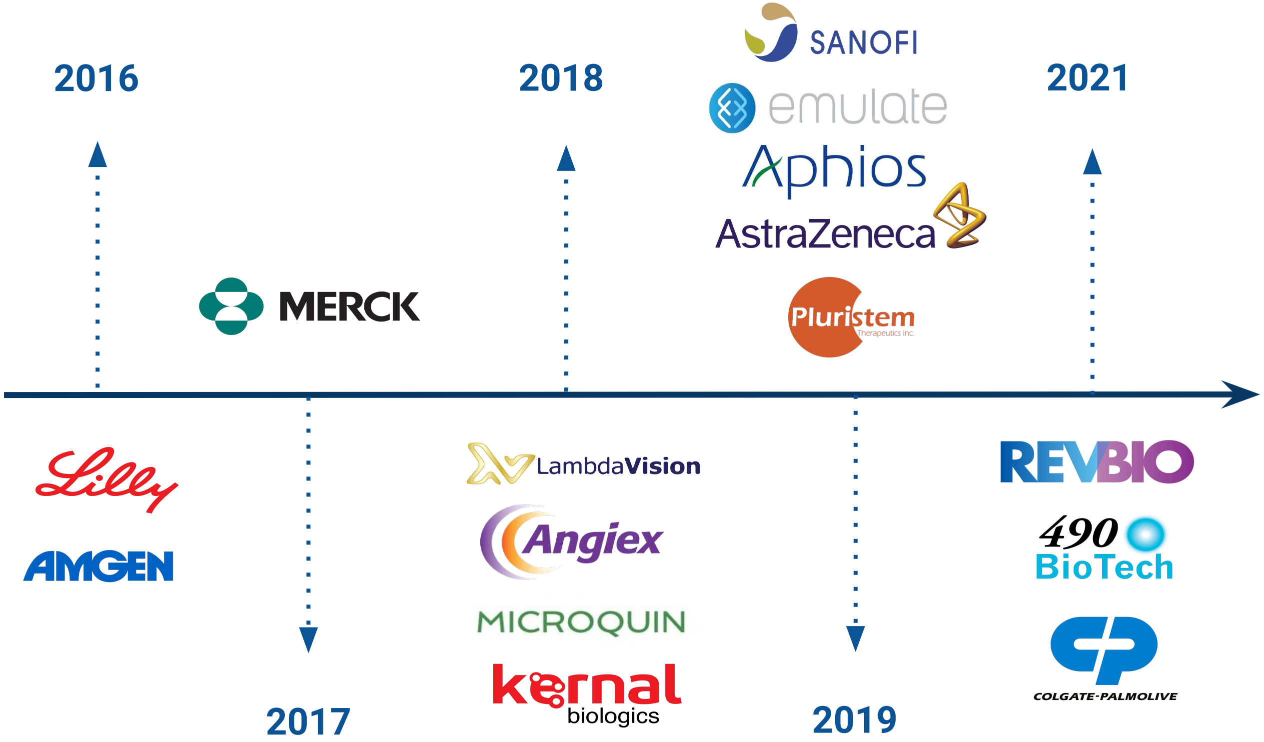


Assuming funding for NASA's human exploration program remains constant, a continuation of ISS funding through 2028 will require either **increased funding in the 2020s** to develop exploration systems needed for Moon and Mars missions or will require the Agency **to push out the timeline for its lunar/Mars exploration plans.**

NASA's CFO claims that a 4-year extension of the ISS to 2028 **could push out the schedule for NASA's Mars plans by at least 3 years.**

Source: NASA

Timeline of Private Biological Research on the International Space Station



ISS became available to private companies beginning in 2016.

Most of the investigations were carried out by pharmacological companies and studies were related to pharmacokinetics and drug delivery systems.

Due to the pandemic, no private research was carried out in 2020.

Source: The Scientist

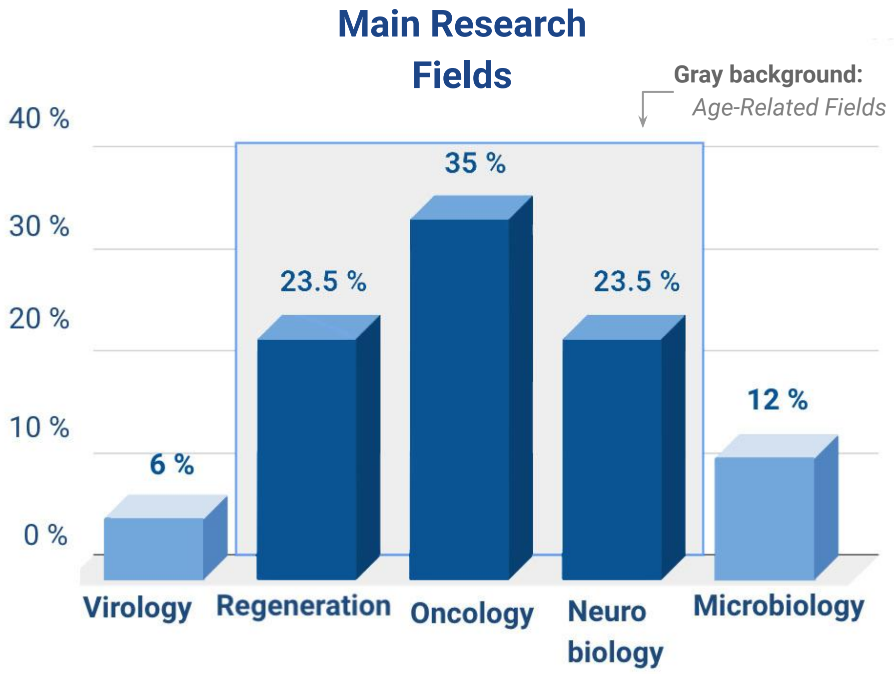
Private Age-Related Research in Space

Low-Earth orbit (LEO) is a unique environment for investigation of novel approaches to mitigate age-related disorders.

35% of all private research on the ISS dedicated to drug-delivery systems to conquer **cancer.**

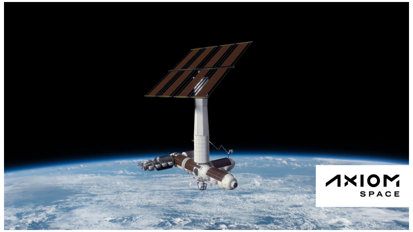
Another **47%** of applied sciences are equally focused on **neurodegenerative disorders therapy**, mainly Alzheimer’s, and **regenerative medicine**: muscle and bone restoration, using human-cell culture.

As microbes in space change their metabolism, and cause serious harm to astronauts, almost **12**% of private research is dedicated to microbiology and **6**% to viral replication and production studies, including the development of vaccines for space.



Source: Mitochondria in Longevity and Space Medicine

The Coming Era of Private Habitable Space Facilities



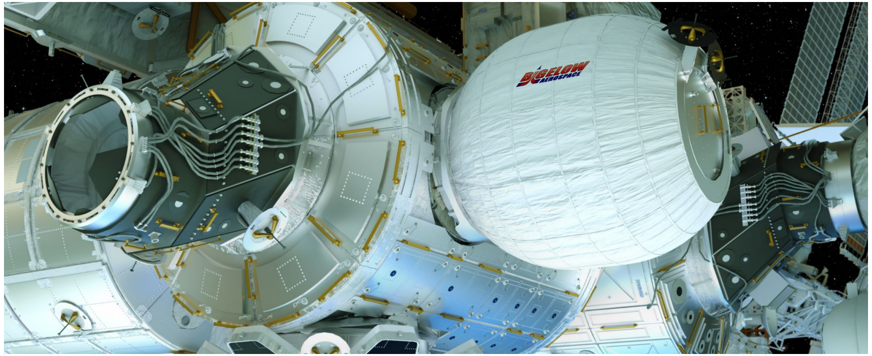
NASA **awarded Axiom** the right to attach one of its own crew modules to a docking port on the ISS—and a **$140 million contract** to make it happen. The company's plan is to launch its first module to the space station by 2024 and expand from there. In addition to the crew-habitation module, CEO Suffredini says Axiom is planning for at least two others: One will be a laboratory and manufacturing facility, and the other will be a panoramic observatory similar to the ISS cupola.

Thales Alenia Space, a Joint Venture between **Thales** (67%) and **Leonardo** (33%), and **Axiom Space** of Houston, Texas (USA), have signed the final contract for the development of **two key pressurized elements of Axiom Space Station**. Scheduled for launch in **2024 and 2025** respectively, the two elements will originally be docked to the International Space Station (ISS), marking the birth of the new Axiom Station segment. The value of the contract is **110 Million euro**. Thales Alenia Space and the Italian Air Force have ratified a Memorandum of Collaboration, aiming to promote access to low earth orbit in favor of institutions, the scientific community, industry, and commercial operators.

The Large Integrated Flexible Environment (LIFE) habitat is under development by the engineers for **Sierra Nevada Corporation**, and a ground prototype is being used to evaluate how crew members could perform mission tasks in outer space. **The LIFE habitat** is meant to travel into space furled inside commercial launch vehicles and will then inflate on-orbit to its full size to house **four astronauts and their equipment. The three stories of space includes science labs, robotics work stations, medical and sick bays, sleep and hygiene quarters, exercise equipment, a plant growth system, and more.**

Sources: Axiom Space, Thales Group, Bigelow Aerospace

The Coming Era of Private Habitable Space Facilities

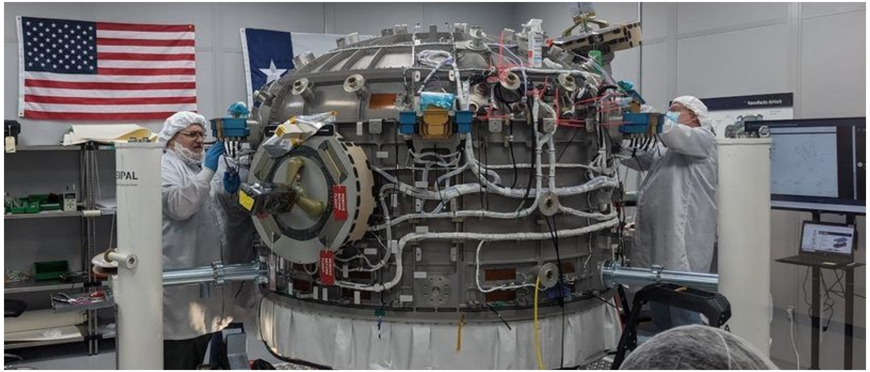


NASA offers a docking port for commercial use

Since 2016 NASA is positive about lending a docking port on ISS for commercial use only. It is occupied by the Bigelow Expandable Activity Module (BEAM) by **Bigelow Aerospace** that had to stay there until 2020, but NASA prolonged the lifetime of module until 2028. However, in March 2020, Bigelow Aeropsace laid off all 88 of its employees, and stated it was due to the COVID-19 pandemic.

Commercial space habitats

There are companies that are willing to build space stations on their own. **Axiom**, mentioned above, are doing the ISS mission in order to train astronauts for the station of their own will nearly double the useable volume of the International Space Station. **NanoRacks** have several projects for space innovations including the first commercial airlock and a **commercial space laboratory,** that will be used to conduct experiments with plants mostly. That shall help in the fields of AgTech, climate science and sustainability.



Sources: Axiom Space, Thales Group, Bigelow Aerospace

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Off-Planet Construction

SpaceTech Analytics Contributors

KLEOS

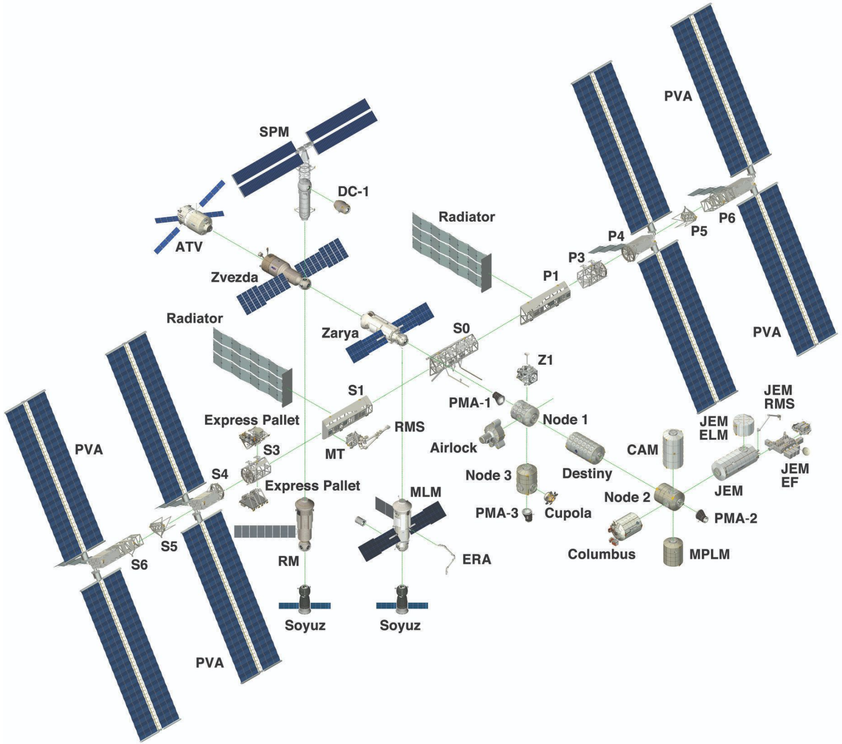
Melanie Delannoy

Why Orbital Construction?

In the last century, the size of the fairing of a rocket determined the maximum dimensions of a satellite. As long as this remained the case, space hardware was limited in size to what would fit in the rocket.

The ISS is Largest In-Space-Assembled Construction

This started to change when the International Space Station started to be assembled over two decades ago. It simply could not have been launched as a single piece, for reasons discussed in the Economics of Space section. Note that ISS weighs 400 tonnes and covers an area as big as a football pitch. It took about a decade, but the Space Shuttle delivered most of the pieces need to build it in orbit (some hardware was delivered by Russia).



That Was Just the Beginning

Once we start assembling facilities in space, there will be no limit to how large they can be. And if SpaceX's Starship lives up to its promise for low cost and high flight rate, they will be capable of being assembled very quickly, just like a skyscraper.

Source: ESA

Robots Will Do Most of the Work

MAXAR TECHNOLOGIES

Maxar Technologies was awarded a $142 million contract from **NASA** to develop an orbital spacecraft assembly with a new robotic arm that would be assembled in space for use on low-Earth orbit spacecraft.

TETHERS UNLIMITED

Firmamentum (company's subdivision) is developing technologies to enable on-orbit fabrication of large spacecraft components: antennas, solar panels, trusses, and other structures. It will enable using small, low-cost launch vehicles to deploy systems dramatically larger than possible with current technologies.

In-space Assembly Companies

MADE IN SPACE

Made in Space is developing Archinaut, additive manufacturing for space that enables autonomous in-space manufacture and assembly of backbone structures for telescopes, repair, augmentation, or repurposing of existing spacecraft, and unmanned assembly of new space stations. In 2019, it was awarded a $73.7 million contract from NASA.

KLEOS

Kleos is going to produce huge carbon composite 3D structures in space. It has a technology that can manufacture long composite beams with embedded power and data cables.

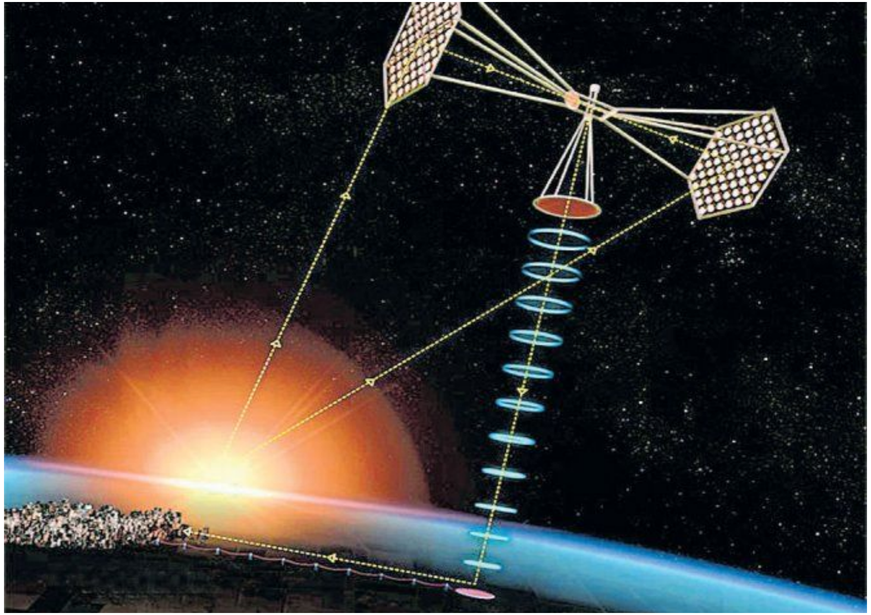
In-Space Systems Will Profoundly Impact the Industry

In-Space Assembly Opportunities

Bulk cargo like aluminum beams, or solar panels, don't care about acoustics, so a designer will have the choice of either building a more robust structure at the lower cost per pound, or building it in space, where it can be gossamer light. As a result, there will opportunities for revolutionary new structures.

1. Huge multipurpose satellites will be built entirely in space.
2. Small specialized and very cheap satellites (e.g. cubesat)
3. We will build powerful telescopes outperforming Hubble or James Webb
4. We will be able to build arbitrarily large structures, such as large space-based arrays for radioastronomy
5. Constructing satellites to collect the endless solar power in space and beam it to earth might become a reality

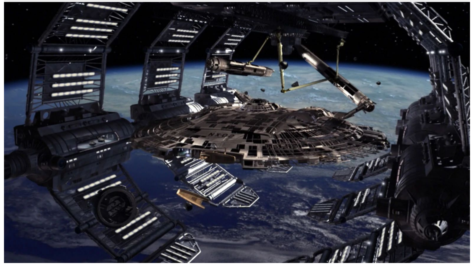
Development of in-space systems will be the next step to revolutionize how things will be done in this industry.



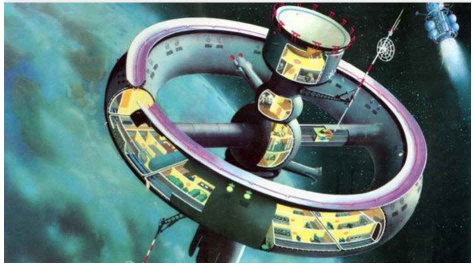
What We Will Build

In-Space Construction

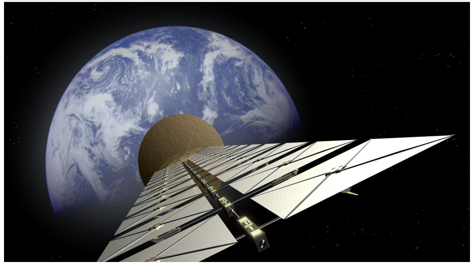
Assembly hangars (space "dry docks")



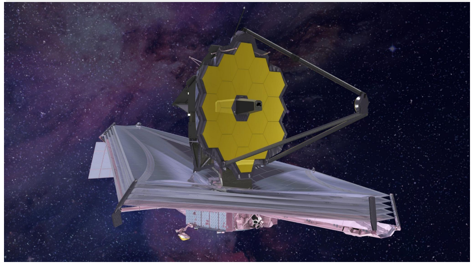
Rotating space habitats for artificial gravity



Solar power satellites

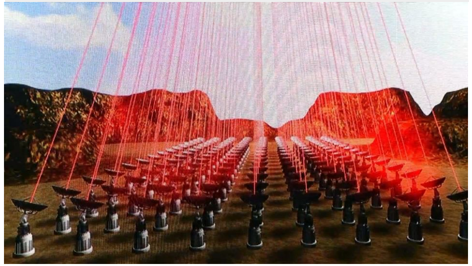


Large space telescopes



Space antennas

Lasers for solar-system propulsion with lightsails



Where We Will Build

Small Companies with Large Ambitions

There are a few more companies besides the companies mentioned previously, who are also planning to transform the industry.

SKYCORP

Skycorp is developing Orbital Logistics Vehicle (OLV) with a core idea to be completely assembled in space environment (on ISS).

UNITED SPACE STRUCTURES

United Space Structures aims to build the large self-sustaining facility that will house hundreds of people on or beneath the Lunar or Martian surfaces. The first one could be ready by 2031.

ORBITAL ASSEMBLY

Orbital Assembly (Gateway Foundation) has ambitious goal to accelerate the space-construction industry. The company is going to build any structure in space quickly and with precision.

Potential Building Sites

- Low-Earth Orbit
- Equatorial Low-Earth Orbit
- Cislunar Space Around Lagrange Points
- Lunar Surface
- Farside for Radio Telescopes
- Upper Clouds of Venus
- Mars Surface
- Mars Orbit
- Other Body Surfaces (e.g., Ceres)
- Other Body Orbits

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Satellite Servicing

SpaceTech Analytics Contributors

the Armor Group, LLC

Jim Armor

ORBITFAB

Daniel Faber

CONFERS

Ian Christensen

Historically, Few Satellites have Been Serviced

Satellite servicing was considered from the early days of the space era, as any machine needs some kind of service. It is usually understood as servicing of a satellite by robotic spacecraft or by human astronauts, but it didn't first occur until 1984.

There Numerous Current Obstacles to Repair and Service Satellites on-Orbit

- Most older satellites were in locations inaccessible to crewed missions (e.g. GEO) or high-inclination sun synchronous. There are more than 400 satellites in GEO.
- Most were not designed to be serviced.
- The technologies didn't allow service by robotic spacecraft, while crewed missions were hazardous and expensive.
- Thus, it was unreasonably expensive to deploy a distinct mission to repair a satellite in space.

One Way Ticket

Eventually, when satellites failed, or ran out of propellant for stationkeeping or attitude control, their life was over. In the 20th century the space industry was driven by government, so satellite servicing had to become a government funded effort too.

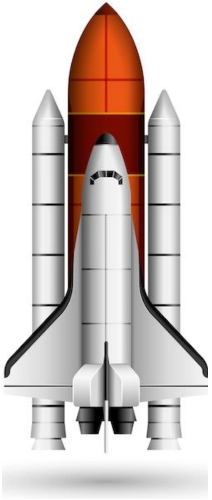
1984	NASA achieved the first successful service of a satellite on-orbit
1993 – 2009	A sequence of five Space Shuttle flights to service Hubble Space Telescope (1993, 1997, 1999, 2002, 2009)

These missions were extremely expensive and the human role was crucial. Later projects aimed to take the human element out and make servicing cheaper. For example::

- Demonstration of Autonomous Rendezvous Technology (DART)
- Orbital Express (a DARPA program)
- Robotic Refueling Mission (RRM)

Currently, the private sector is leading the servicing revolution

The Space Shuttle Started to Change Things



Space Shuttle Changed the Game

It was the first ship capable not only of delivering satellites on orbit but bringing them back.

Palapa/Westar Rescue in 1984

Palapa and Westar satellites had malfunctioned thrusters and could not reach the appropriate orbit. The crewed mission on the Space Shuttle grabbed these satellites on the ship and brought them back to relaunch. Astronauts also used robot arm and jetpack

Hubble Space Telescope

It was the first satellite designed to be serviced. The Hubble design paid off immediately after launch when it was discovered that it needed different optics due to the mirror being ground precisely wrong.

30 Years Old

Still flying and taking pictures three decades later. It is expected to be in use until 2030-2040.

Hubble Servicing

During 1993-2009 the Space Shuttle participated in five missions to repair, upgrade or replaced systems on the telescope. It remains the most prominent example of consistent satellite servicing that saved a lot of money and advanced technologies considerably.

Sources: NASA

Philosophy is Beginning to Change

For reasons partly described in section on the Economics of Space, and for others, including technology advancement, there will soon be a transition from long-lived expendable satellites to semi-permanent serviced structures.

Robotics has Advanced a Great Deal

New technology makes it easier to rendezvous, dock, and grapple if the satellite has equipment for it (and in some cases, even if not).

Space Assembly

Space assembly of large structures means that upgrades or repair will make more sense than replacement

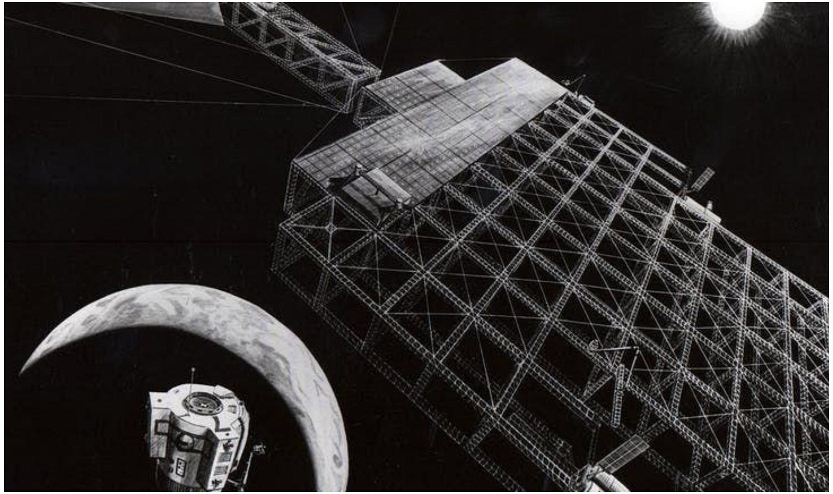
Reusability

Launch systems are becoming reusable making it cheaper to service satellites. Thus satellites and space structures will become longer lived as well, with servicing.

Soon, it will be cheaper to extend life than to replace a working satellite

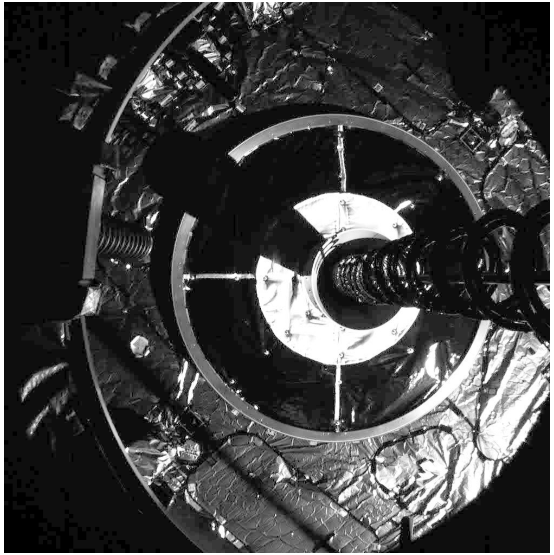
Consider GEO "Antenna Farms"

Only transponders would upgraded or added. Just as buildings aren't razed when out of date, the farm would get a renovation. The needed technologies and capabilities are in development, and available soon.



The Post-Shuttle Satellite-Servicing Era Has Begun

In early 2020, history was made when a life-extension vehicle named MEV-1 docked with a dead communications satellite not designed for docking, by putting a probe into its rocket nozzle and grabbing the engine bell. The client satellite was Intelsat 901, that had fulfilled the estimated period of work and ran out of fuel, but was still fully functional.

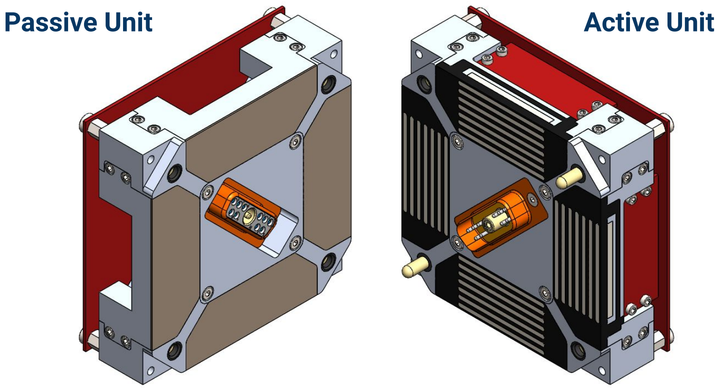


The satellite was moved from its "graveyard" orbit back to a GEO orbit slot, where its life has been extended for half a decade, allowing it to generate millions more in revenue. The rescue vehicle provides propulsion and navigation for the entire assembly and will put the client back to its "graveyard" orbit after 5-6 years. The Mission Extension Vehicle by SpaceLogistics is designed to operate for 15 years, so it is possible to be used for prolonging the lifetime of other satellites. MEV-2 was launched on August 15, 2020 and docked with the Intelsat IS-1002 satellite on April 12, 2021.

The manufacturing company Northrop Grumman works actively with American governmental organisations in order to improve the technology. Using the advanced robotics and high-power solar propulsion, they plan on implementing such services as inspection, repair, enhancement or replacement of parts and/or systems and in-orbit assembly of space structures

New Technologies are Being Developed for Servicing

Voyager Holdings' Altius Space Machines is developing a "magtag" technology that can be used as a mechanical, electrical, and/or fluid interface with a satellite. The technology uses electropermanent magnets (EPMs) that combine the characteristics of both permanent magnets and electromagnets. That means that those magnets don't consume any energy while in stable state and also could be turned off or even have their polarity changed. Such "magtag" works well for satellite servicing purposes such as fluid, energy or data transfer and can also be used as a modular upgrade or enhancement interface. The company has been awarded the second phase of The Small Business Innovation Research by the US government after the successful completion of the first phase in cooperation with NASA Langley Center. The technology's TRL has increased up to 5 with a great potential to grow even more on completion of the second phase. It is small enough to fit on a maintenance cubesat and powerful enough to be useful for a multi-ton client spacecraft. A prototype has already been tested on the ISS.



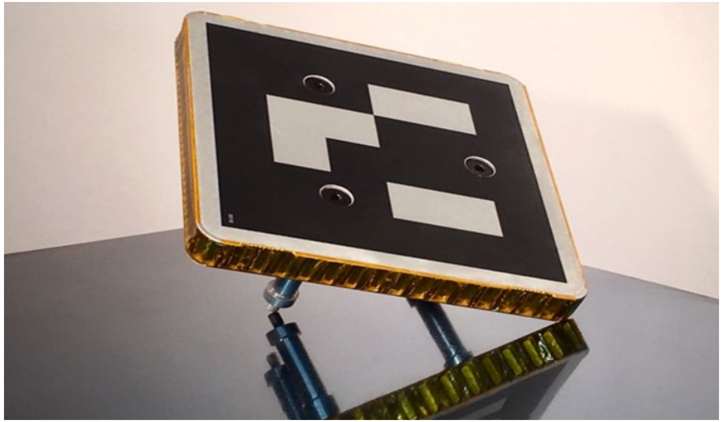
Source: Altius Space Machines

New Technologies are Being Developed for Servicing

Voyager Holdings' Altius Space Machines has also developed a "dogtag" universal grapple fixture. Dogtags are designed for magnetic grappling mostly, but they are also compatible with a variety of grapple methods such as electrostatic adhesion, Gecko adhesion, mechanical grasping and harpoon grappling. This will allow satellites that have them installed to be more easily captured and serviced. There may be industry resistance to adding the extra mass to the satellite, but it will increasingly become a standard for those owners who want their satellites to be serviceable.

VOYAGER SPACE HOLDINGS

Altius Space Machines is acquired by Voyager Space Holdings



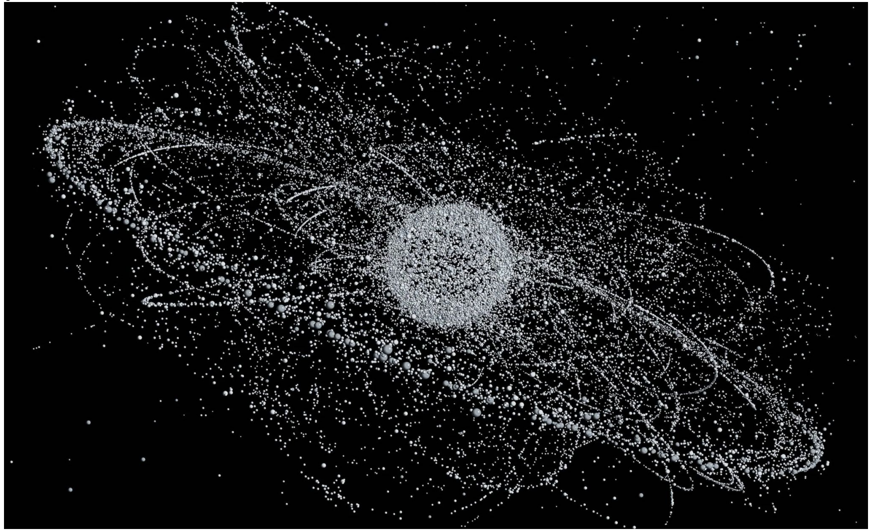
The technology helps solve the space-debris problem as it makes it easier to dock non-functioning satellites and deorbit them. It can also be used to tug functional satellites to new orbits, act as an anchor point for satellite servicing, and capturing and stowing various payloads. Dogtag includes a durable optical fiducial marker to simplify relative navigation during servicing operations

Such a dogtag was launched for the first time on January 14th this year abroad OneWeb's satellites. Altius is supposed to produce such fixtures for all the satellites in OneWeb's planned constellation.

Source: Altius Space Machines

New Technologies are Needed for Non-Cooperative Satellites

As discussed in the Space Traffic Management section, Earth's orbit is slowly becoming a teeming place full of non-operational satellites and debris. In addition to the hazard to other space objects, according to NASA, on average one hundred tons of junk falls back to Earth each year, some of which makes it to the ground. There are some potential solutions to these issues.



Obstacles that make deorbiting space junk challenging

- Many objects in space are parts of vehicles that don't have any structure to grab onto.
- Some debris and satellites are tumbling due to explosions or thruster malfunctions.
- Some satellites are very far from Earth, which makes it very expensive to deorbit them.
- Deorbiting a object doesn't currently bring in any revenue.

New satellites have to have decommissioning devices installed. A company called **D-Orbit** produces light effective independent solid-rocket propulsion devices that are used for deorbiting. In addition, special deorbiting vehicles are being developed. **Astroscale** is a company that provides End-of-Life services with their vehicles.

Adding “Bustle” to the In-Space Economy

2019

First private company to resupply the International Space Station with water

2021

Launch of the world’s first in-space fuel tanker

2023

Expect to see satellite refueling become routine

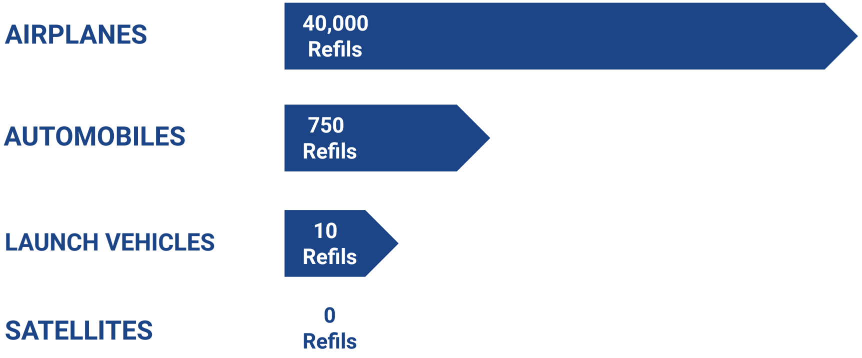
Daniel Faber believes that humanity's future is in space. But an in-space society can only develop when a bustling economy exists there that can support permanent jobs. Commerce, trade, and the interaction of people and equipment will depend on a reliable supply of propellant. We need to get out of the mindset of “single-use spacecraft” and stop throwing the hardware away when the fuel runs out. Today, reusable rockets have become routine. Tomorrow, refuelable satellites will be routine too.

Orbit Fab has brought to market the only satellite fueling port that can be used for in-orbit refueling.

Orbit Fab is a Petrochemicals Company

The company has licensed technology from Rice University to transform water into High Test Peroxide (HTP), a rocket propellant with extremely high energy density. When it comes online later in the decade, the *Fuel Factory in Space*™ will produce industrial chemicals for propellant and other uses.

A Paradigm Shift is Coming in Satellite Reusability



US Space Force Desperate for Mobility

Orbit Fab has eight contracts for the RAFTI fueling port with the USSF, who are eager to make their assets considerably more mobile to survive in a contested environment.

With in-space refueling, Space Force assets will be able to respond quickly to threats anywhere in cis-lunar space.

Throwing Away Satellites Means Throwing Away Money

Asset Life Extension

Twenty satellites are terminated every year when their fuel tanks run dry. Despite many being fifteen years old, they are usually fully operational and have paying customers. With additional fuel, most can operate for years to come.

Effect of lack of fuel: Lost revenue opportunity up to $20M per year, each.

Lost Asset Recovery

AMC-14, SES Americom's $300M GEO ComSat was deployed into the wrong orbit due to a launch vehicle failure. Without fuel to move the satellite, SES Americom declared it a complete loss. This is not unique.

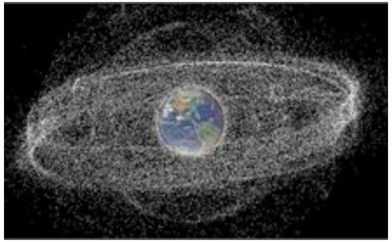
Effect of lack of fuel: Complete write-off. Unable to realize billions in expected revenue.

Improved Asset Utilization

ESA's Galileo constellation's 5th and 6th satellites were placed into useless orbits after a launch vehicle malfunction. 75% of propellant reserves were burned for realignment, shortening operational lifespan.

Effect of lack of fuel: Delayed service introduction of the entire $12Bn constellation.

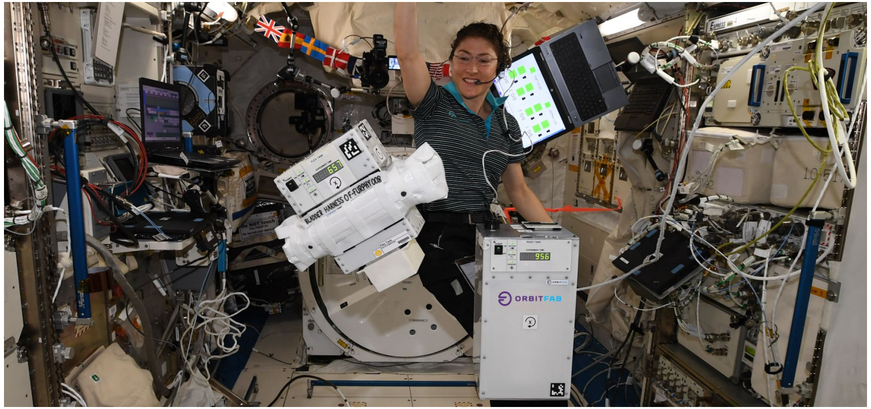
Sustainability



Many of the thousands satellites will become debris when they run out of fuel or their electronics fail. Cascade collision risk is real. Debris removal needs significant quantities of fuel for end-of-life operations.

Effect of lack of fuel: Unsustainable practices threaten industry viability.

Gas Stations in Space™



And Keep Moving Fast.

The world's first satellite fuel depot, Tanker-001 Tenzing, was built in just six months. It is currently in Low-Earth Orbit, offering High Test Peroxide (HTP) propellant to commercial customers.

"A propellant provider could charge up to **$400,000/kg** and still result in USSF achieving 50% savings on replacement capabilities."

A. Jehle and G. Sowers, Orbital *Sustainment and Space Mobility Logistics Using Space Resources*, Space Force Journal, issue 2-4, 2021

Proving SpaceTech Companies Can Start Fast...

Starting from a napkin sketch, Orbit Fab developed two tanker test-beds and qualified them to NASA's highest level crew-rated safety standards in under 5 months. The company is unique among startups in having gone from concept to flight in one year.

CONFERS

The Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) is an industry led initiative to research, develop, and publish non-binding, consensus-derived technical and operations standards for commercial satellite servicing activities. CONFERS has 50 members from across the globe. CONFERS seeks to enable a vibrant commercial servicing ecosystem. It has published Guiding Principles for Commercial Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS) and Recommended Design and Operational Practices. They had their most recent satellite-servicing forum on September 29-30

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SpaceTech Analytics

In-Situ Resource Utilization

SpaceTech Analytics Contributors

Colorado School of Mines — Earth • Energy • Environment

George Sowers

Interplanetary Enterprises

Chris Lewicki

Secure World Foundation

Christopher Johnson

Daniel Sax

Cislunar Industries

Gary Calnan

In-Situ Resource Utilization

The use of in situ resources is in space exploration and it is defined as the collection, processing, storage and use of materials encountered during space exploration. As a result, the need to deliver them from Earth disappears. Such resources can be used for life support systems, rocket fuel production, construction materials, energy for spacecraft.

Currently, the only BIS method is to use solar energy using photovoltaics. Others did not use it during space missions, although several tests have been conducted.

Space resource infrastructure that will be in common with space resources consumers	
Position-Navigation-Timing	Repair/failover capabilities
Data Relay	Rescue services
Landing Pads	Emergency Shelters (Solar storms, other failures)
Energy Plants	Space Traffic Management / Orbit Situational Awareness
Test Facilities (artificial gravity)	Virtual Infrastructure - Digital Twins

In-Situ Resource Utilization is Critical to Opening the High Frontier

The purpose of In-Situ Resource Utilization (ISRU) is to harness and utilize resources at the exploration site to create products and services that can enable and significantly reduce the mass, cost, and risk of near-term and long-term space development. The ability to make propellants, life support consumables, fuel cell reagents, and radiation shielding can significantly reduce the cost, mass, and risk of sustained human activities beyond Earth. The ability to modify the landscape for safer landing and transfer of payloads, creation of habitat and power infrastructure, and extraction of resources for construction, power, and in-situ manufacturing can also enable long-term, sustainable exploration of the solar system. Since ISRU can be performed wherever resources may exist, both natural and discarded, ISRU systems will need to operate in various environments and gravitations. Also, because ISRU systems and operations have never been demonstrated before in missions, ISRU concepts and technologies must be evaluated under relevant conditions (gravity, environment, and vacuum) and anchored through modeling to regolith/soil and environmental conditions.

Space settlement is even harder:

1. No usable atmosphere
2. Radiation environment
3. No supply chain
4. Variable gravities
5. Biological challenges
6. No indigenous foods
7. The most expensive labor

Useful Space Resources Come from Many Locations

ISRU includes commercial applications, robotic planetary exploration, human exploration, and space development and settlement. The immediate goal of ISRU is to greatly reduce the direct expense of humans going to and returning from the Moon and Mars, to build toward self-sufficiency of long-duration crewed space bases used to expand science and exploration efforts and enable the development settlement of space.

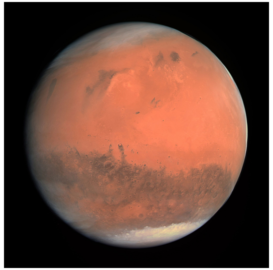
The image on the left depicts ISRU reverse water gas shift testbed (NASA KSC).

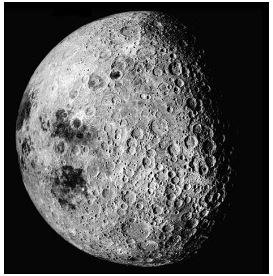
The WGSR is an important industrial reaction used in the manufacture of ammonia, hydrocarbons, methanol, and hydrogen.

Source: Science Direct

Asteroids

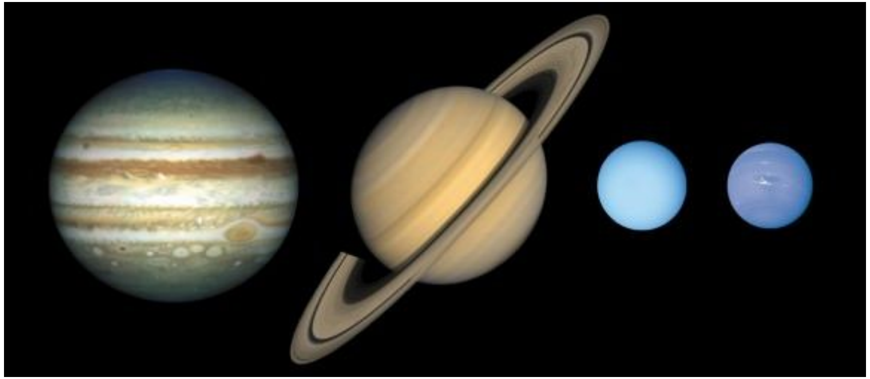
Mars





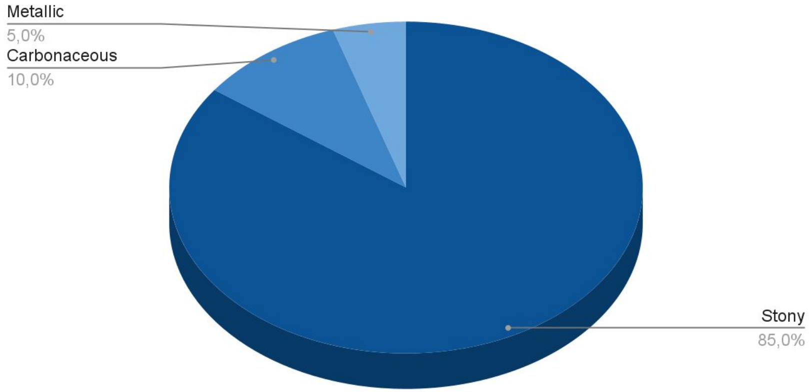
Lunar

Outer planets



Asteroids Have a Wide Variety of Resources

All known near-Earth asteroids composition



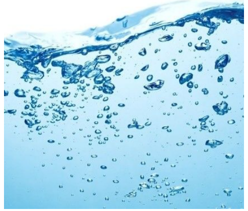
The industrial development of asteroids involves extracting raw materials on asteroids and space bodies in the asteroid belt and especially in near-Earth space (in terms of velocity to get to them).

Various minerals and volatile elements found in the rocks of an asteroid or comet can serve as a source of iron, nickel and titanium. In addition, it is assumed that some asteroids contain in their composition water-bearing minerals, from which you can get water and oxygen necessary to support life, as well as hydrogen - an ideal rocket fuel for use in space when combined with oxygen. Space development will not occur without the use of space resources.

Resources that can be mined from asteroids

PGM

Carbon



Water

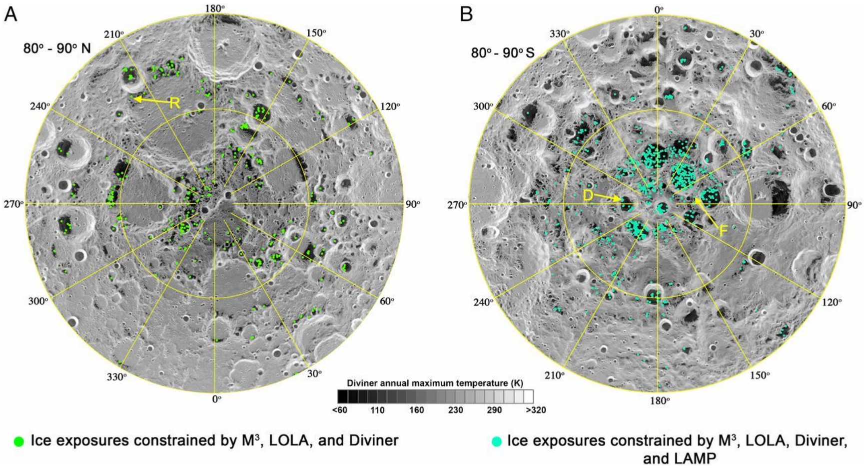
Iron

Nickel

Earth’s Moon Has Volatiles in Addition to Minerals

The Moon bears substantial natural resources which could be exploited in the future. Potential lunar resources may encompass processable materials such as volatiles and minerals, along with geologic structures such as lava tubes that might enable lunar habitation. The use of resources on the Moon may provide a means of reducing the cost and risk of lunar development and settlement.

Insights about lunar resources gained from orbit and sample-return missions have greatly enhanced the understanding of the potential for in-situ resource utilization (ISRU) on the Moon. Still, that knowledge is not sufficient to fully justify the commitment of large financial resources to implement an ISRU-based campaign.



Lunar Agriculture Water Use Case Model

Stage 1
Ice-Laden Regolith Mining / Tagging / Storage

→

Stage 2
Ice-Laden Regolith Delivery to Logistics Center / Refinery

→

Stage 3
Regolith Processing, Volatile Extraction & Refining

→

Stage 4
Water Preparation & Delivery to “Agricultural Spiral”

→

Stage 5
Agricultural Water Use & Recycling

Sources: NASA

Future Mars Settlement May Face Different Challenges

Factors complicating settlement

The acceleration due to gravity on Mars is about 3.71 m / s2, that is, 0.38 g.	It is still unknown if this is sufficient to avoid the health problems associated with weightlessness.
Mars is further from the Sun.	The amount of solar energy reaching its surface is only 43% of this value for the Earth.
The surface temperature of Mars is much lower than that of the Earth - on average -63 ° C.	A human cannot live normally at such temperatures.
The orbit of Mars has an eccentricity six times greater than that of the Earth.	This increases the annual fluctuations in planetary temperature and solar energy.
Atmospheric pressure on Mars is less than 1% of Earth's.	This is too little for people to survive without a pneumosuit.
The radiation level on Mars is 2.5 times higher than the one on the International Space Station.	This is very close to the established safety limits for astronauts.
The liquid found on Mars is a concentrated salt solution.	This casts doubt on the possibility of growing terrestrial plants in Martian soil without additional experiments.
Mars does not have a magnetic field generated by a mechanism similar to that of the Earth.	Mars' magnetic field is unable to protect living organisms from cosmic radiation.

Sources: Science Direct

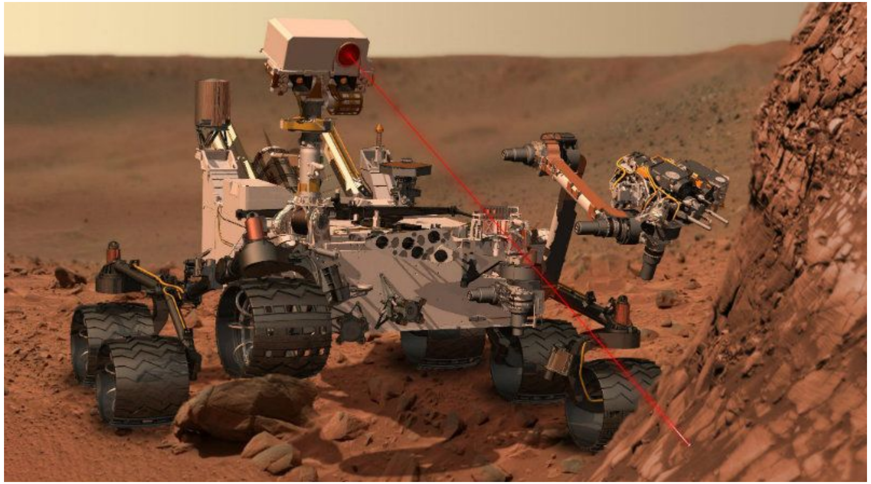
Mars Has Resources as Well, but Some Toxic

Fragmentary porous rocks and aeolian sands represent them. The main components of MP% are iron (up to 14% in some samples), calcium, aluminium, silicon, and sulfur. There are also strontium, zirconium, rubidium, titanium, and boron. A characteristic feature of the surface of Mars is the presence of the cryosphere - H2O ice in the polar caps and the soil. In particular, the minerals goethite and jarosite, formed in the presence of water, were found. The spacecraft "Curiosity" of the American space agency NASA has found large deposits of quartz in Martian rocks. There are also plentiful mineral resources, including iron, titanium, nickel, aluminium, sulfur, chlorine and calcium.

Martian soil composition

- **CO2**
- **Water**
- **Iron and other minerals**
- **Toxic perchlorates**

Mars 2020 Rover



Sources: NASA

The Outer Planets Have Resources Rare on Earth

Jupiter

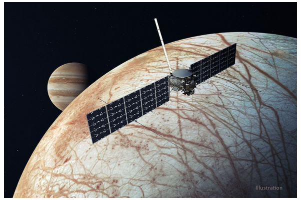
There has been great interest in studying Jupiter's icy moons in detail because of the possibility of subsurface liquid oceans on Europa, Ganymede, and Callisto. Funding difficulties have delayed progress. NASA's JIMO (Jupiter Icy Moons Orbiter) was cancelled in 2005.

Saturn

Saturn has at least 62 known moons, although the exact number is debatable since Saturn's rings are made up of vast numbers of independently orbiting objects of varying sizes(primarily icy).

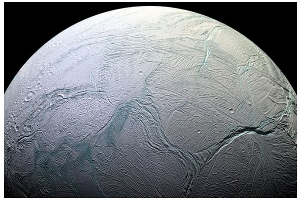
Europa Clipper Mission, October 2024

NASA is going to launch a mission to Europa using the SpaceX Falcon Heavy rocket.



Enceladus Mission

There are plans, public and private, to explore Saturn's moon to seek life signs in its internal aquatic ocean.



Sources: NASA

Earth's Moon

The Moon has water ice in surprising abundance that settlers can consume and process into rocket fuel. Moreover, it contains methane and ammonia that could be tapped for their carbon and nitrogen. The latter can create an Earth-like atmosphere.

Asteroids

Mining there is quite complicated though it might bring plenty of iron, platinum, gold, silver, palladium, etc. Asteroids are the most perspective outer space objects to be mined. At least, among discovered.

Helium

While one of the most abundant elements in the universe, it is rare on Earth due to misguided government policies.

Resources

- Water
- Methane
- Ammonia
- Helium
- Iron
- Platinum
- Gold
- Silver
- Palladium
- Others

Note:
Water remains the most valuable resource to ensure further space settlement and space exploration programs.

The Solar System Contains Enough Resources for Trillions of Humans

1. Metals are mainly in the asteroid belt.
2. Ices are mostly in the outer solar system: moons of gas giants and objects beyond Neptune.
3. Solar energy is from the center of the solar system.
4. Smaller quantities of resources can be found in special reservoirs, like ice at the poles of the Moon and even Mercury.
5. Silicate materials are found mainly in the rocky planets, including Earth's moon.
6. Hydrogen and helium are mostly in the outer gas giant planets.

Growing Human Civilization Off Planet

Understanding the resource locations, we can devise strategies to use our entire solar system and take human civilization to the next higher level. We should start with the resources that are easiest to reach, first, on Earth's moon. Humanity evolved on Earth, and civilization has grown so large that it is starting to strain the home planet's resources. Opening off-planet resources can relieve that burden and expand humanity into the solar system. The following most accessible resources beyond the Earth are the Near-Earth Objects (NEOs). Those resources are limited reservoirs, being in the dry inner solar system, but fortunately, they are large enough to start a healthy space-industrial economy. Once in place, a transportation network can be established to begin utilizing the asteroid belt beyond Mars and eventually the outer planets to access the billion-fold more significant resources and create vast wealth for humanity and all terrestrial life in the home solar system.

Many Ways to Utilize the Resources

In-Space Manufacturing, Robot Arms

MADE IN SPACE

TETHERS UNLIMITED

On-Orbit Propellant Depots

ORBITFAB

Materials Processing

CISLUNAR INDUSTRIES

Metal Based Propulsion

NEUMANN SPACE

Commercial Space Stations, Hosting, & Logistics

ARKISYS

AXIOM SPACE

Nanoracks

An In-Space Industrial Ecosystem is Emerging

Government Customers

DEFENSE INNOVATION UNIT

JAXA

AFRL THE AIR FORCE RESEARCH LABORATORY LEAD | DISCOVER | DEVELOP | DELIVER

NASA

DARPA

esa European Space Agency

UNITED STATES SPACE FORCE

Satellite Servicing, Space Robotics, Space Logistics, Debris Removal

Astroscale

MAXAR TECHNOLOGIES

ALTIUS SPACE MACHINES

ATOMOS

AIRBUS

NORTHROP GRUMMAN

clearspace today

Space Mining will be Done with Robots

Terrestrial mining is already moving to robotic mining to reduce cost and risk to human miners. Furthermore, robots developed for terrestrial mining will probably be electric rather than internal combustion, so they don't get CO and CO2 fumes in the mines. They will be usable in space. Eventually, people will use robots for hard work in all extraterrestrial activities:

1. Build landing pads
2. Excavate underground habitats
3. Manufacture basic structures and solar cells
4. Make potable water, breathable air, and rocket propellant
5. Produce electricity
6. Extract water ice and materials

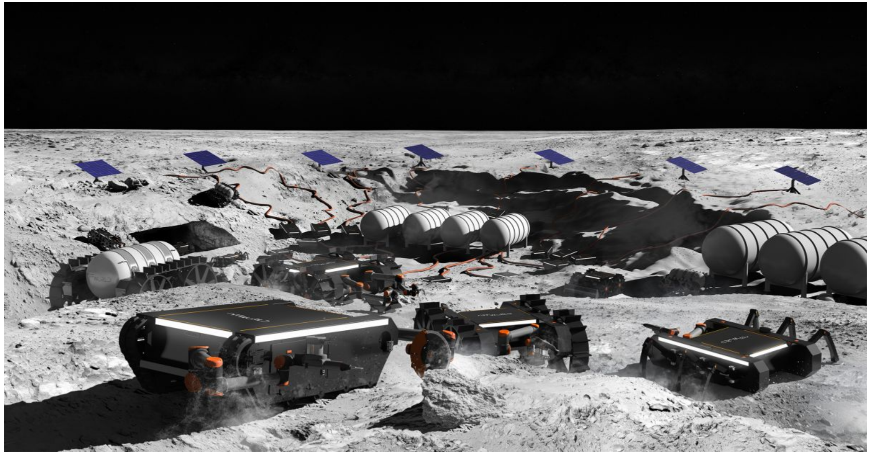
Source: Offworld

“**OffWorld**”’s robotic workforce for heavy industrial jobs on Earth, Moon, asteroids & Mars

Benefits of Robotic Workforce Utilization

Human settlers will need to endure deep space travel, battle harsh radiation, operate in lower gravity levels, and breathe in artificial atmospheres. Getting help from Earth could take days on the Moon and months if you find yourself on Mars.

Artist's impression of OffWorld robots working in swarms on the lunar surface.



Source: Offworld

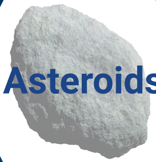
The best way to reduce the extraordinary risks involved in establishing a permanent presence on other planetary surfaces is to have a local robotic workforce do the heavy lifting. Based on AI-driven algorithms, the robotic workforce will expand their capabilities and the range of tasks that robots can tackle, opening up new applications in mining, construction and other industries.

New generation of robotic workforce	
1	Ultra low cost
2	Thousands of robots
3	Solar system standard
4	Autonomous ops
5	Modular configuration
6	Reduced hazards and risk to h umans

Different Mining Locations Present Unique Challenges

Moon

- Hard vacuum
- Limited solar power
- Temperature extremes
- Dust
- Low gravity



Asteroids

- Little gravity, hard to grapple
- May not be solid (gravel pile)
- Accessibility if not Earth crossing

Mars

- Low atmospheric pressure
- Toxic regolith
- Low gravity
- Temperature extremes

There are Still Many Unknowns, Both Known and Unknown

1 **Remote Sensing and Spectroscopy**
For the most part, our only data comes from remote sensing and spectroscopy, or space objects that have fallen to Earth. We need to get physical samples from other locations to establish ground truth.

2 **Uncrewed Missions**
To date, other than Apollo, our only physical samples have come from robotic missions.

3 **Crewed Missions**
We gathered several hundred pounds of rocks in Apollo, but only on the final mission was there a trained geologist.

4 **Probes**
Altogether, have sent about 170 probes to planets, moons, asteroids to gather data.

NASA's Mars Sample Return Campaign plans to bring samples of Martian rocks and soil to Earth

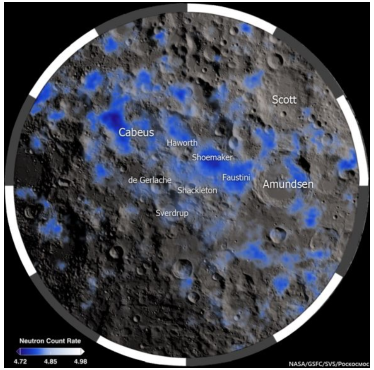
August, 2021

NASA's Mars rover failed to collect its first rock core but succeeded on a second attempt

Conclusions
We drill on Earth to discover deposits. However, we've never drilled on the Moon and barely scratched the surface of Mars. Thus, we are pretty far from doing serious prospecting and assaying to utilize resources.

Refining Different Products Requires Different Techniques

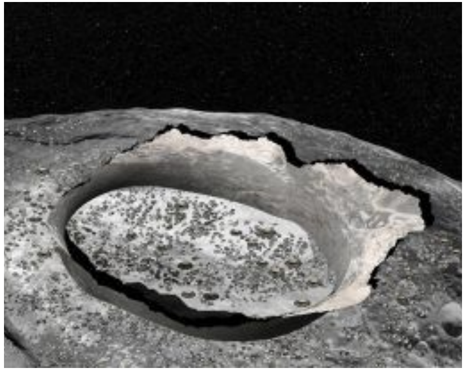
Lunar Ice



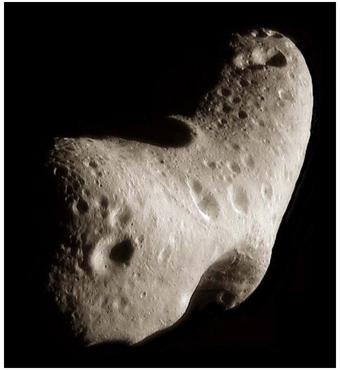
Melting for water

Electrolysis to separate oxygen and hydrogen

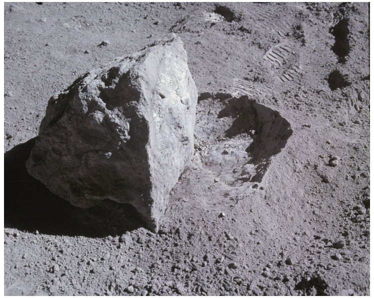
Carbonaceous Asteroids



Stony Asteroids



Lunar Regolith



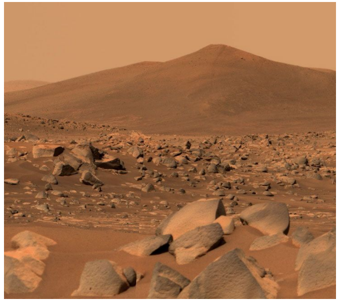
Melting to break down to constituent elements (aluminum, titanium, silicon)

Baking under tent to liberate volatiles

Dragging magnets to collect iron

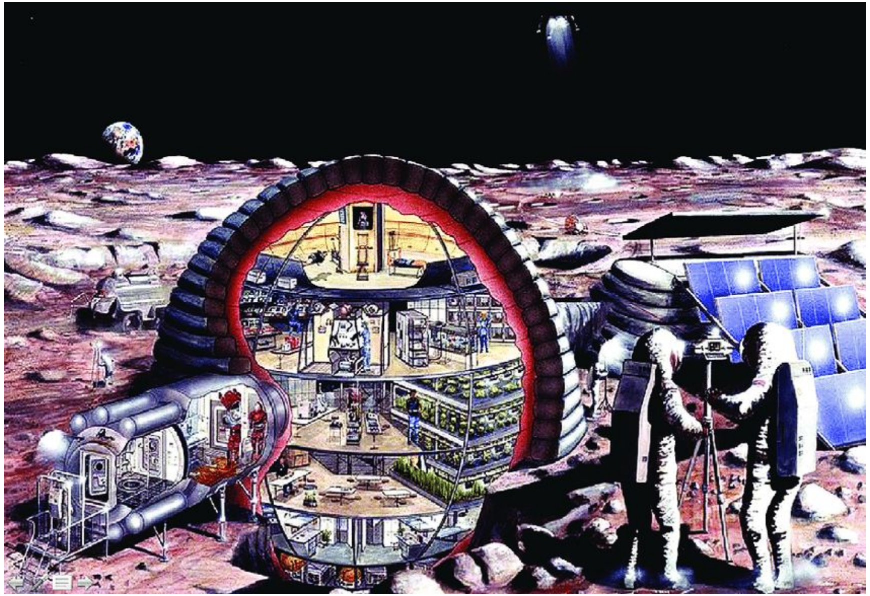
Nickel-Iron Asteroids

Mars



Some Utilization Doesn’t Require Refining

Moon, asteroids and Mars have regolith in abundance. Unprocessed regolith can be used for shielding on the Moon and Mars to provide radiation protection. It can also protect from meteoroids if they are not too large. In addition, it is an excellent thermal insulator so that regolith will find abundant applications.



Permanent Lunar Habitats

The most recent research supports plans for regolith utilisation for radiation protection. The research delivered the following results:

100 cm of regolith shielding	This habitat’s shield (with a density of 1.6 g/cm3) provides an effective dose equivalent under 150 mSv for 180 days.
Multilayer shield	8.5 cm of highlands regolith compressed to 2.7 g/cm3, followed by 3 mm of aluminium and 5 cm of polyethene, gives adequate protection.
Shelter requirements	The shield must provide a multilayer structure with at least 405 g/cm2 of regolith. That corresponds to 150 cm of 2.7 g/cm3 regolith and 5 cm of polyethene
Solar-Flare occurrences	The shelter area has to be designed with large margins (with the option of adding more layers inside the habitat) due to the unpredictability of solar-flare occurrences in future solar cycles.

Converting to Millstock will be Necessary for Non-Liquids

The bulk of material for in-space use can be extraterrestrial, with trace elements (e.g., doping for semiconductors) imported from Earth.

- **Sheets of metals**
- **Silicon for glass and semiconductors (e.g., solar panels)**
- **Metal bar stock**

The initial industrialization of outer space should consist of several basic infrastructural systems:

- **A "pipeline" system to move material to and from the Moon**
- **Raw material bases on the Moon**
- **Lunar refining facilities designed for partial gravity**

The mill stock produced from these will provide the basis for strategic space industrialization, and there will be no human expansion in space without this infrastructure. Once in place, it will provide the construction materials needed to develop habitats and other factories, on the Moon, throughout cislunar space, and eventually beyond.

Startups to Tackle Core Martian Settlement Issues

Carbon Utilization

Cemvita Factory is working on carbon utilization solutions, developing technology to capture carbon from the atmosphere. It would allow the production of carbon-based products, including food, pharmaceuticals, and construction materials. The technology could also be used for terraforming on Mars.

Mars' atmosphere is 95% carbon dioxide compared to 0.04% on Earth

CEMVITA FACTORY

Oxides Utilization

Helios develops technologies to extract oxygen and various metals from oxides in Martian and lunar surfaces. It has designed a reactor that can turn the metal into infrastructure components. Also, this technology can be used to provide people and homes with oxygen and convert oxygen into propellants.

Carbon Utilization

UP Catalyst also develops technologies to extract oxygen and valuable carbon nanomaterials from carbon dioxide on the Martian surface. The shortlist of possible applications: battery and ultracapacitor technologies, conductive and strengthening coatings, polymer formulations, water filters, etc.

Each extra kilogram significantly increases transportation costs. In order to successfully establish a settlement, provide it with all the necessary resources and maintain a settlement on the Moon or Mars, it is extremely important to obtain resources and materials in situ.

HELIOS

UP CATALYST®

Source: Space Foodsphere

Majority of Space-Mined Products will be Used in Space

Cost of Getting Material to Earth from Space

Getting mass back to Earth is currently an extremely costly process. However, it will become less so with the development of vehicles like Starship, which will return more mass than any previous system. But even then, it will impose limitations on using space-mined products on Earth for economic reasons.

One of the critical obstacles is the absence of clever solutions (e.g., manufacturing titanium lifting bodies dropped into the ocean with their cargo). Thus for most applications, the cost of getting material to Earth from space will exceed the price of terrestrial products and be uncompetitive.

The myth of “trillion-dollar platinum asteroids”

“Trillion-dollar platinum asteroids” is an economic myth that ignores the price plunge that would occur with that much commodity dumped on the market.

New Industrial Perspectives

However, if prices of some precious metals came down sufficiently, they would find new terrestrial, industrial uses (imagine cheap gold).

Some Exceptions

Some exceptions for rare elements with high value per mass: rhodium, lanthanides, scandium, yttrium and others.

Hayabusa2 mission

- Spent [6 years]
- Spent [$157M]
- Brought [1 gram] of material from the asteroid Ryugu

Source: Lockheed Martin

Issue of Property Rights Remains Uncertain

As noted in the Space Law section, the Outer Space Treaty is the foundation of international space law. Many believe that it doesn't allow the utilization of space resources, but it does not prohibit it. Several nations have passed legislation to enable their citizens to mine, beneficiate, and sell products made from extraterrestrial resources, but proponents of the Moon Agreement will continue to fight it.

The Outer Space Treaty Balances

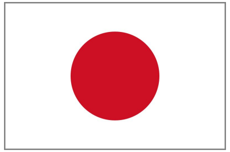
Article I	**Freedom of Exploration and Use**
Article II	**Principle of Non-Appropriation**
Article VI	**State Obligations of International Responsibility; Authorization and Supervision; And Assurance that National Activities Conform with international law.**

National Space Legislation on Space Mineral Resources

US Commercial Space Launch Competitiveness Act (2015)

Law on the Exploration and Use of Space Resources (2017) / Law on Space Activities (2020)

Federal Law on the Regulation of the Space Sector (2019)



Space Activities Act (2018) / Space Resources Act (2021)

Conclusions

- It will be necessary to utilize off-planet resources to open the solar system to development and humanity.
- Means of beneficiation the mined material are in development in laboratories.
- Researchers drill on Earth to discover deposits. However, they have **never drilled on the Moon** and barely scratched the surface of Mars. Thus, they are pretty far from doing serious prospecting and assaying.
- The most recent research supports lunar regolith utilization for radiation protection.
- Potential lunar resources may encompass processable materials such as **volatiles and minerals and geologic structures such as lava tubes** that together might enable lunar habitation. The use of resources on the Moon may provide a means of reducing the cost and risk of lunar exploration and beyond.
- The **industrial development** of asteroids involves extracting raw materials on **asteroids and space bodies** in the asteroid belt and especially in near-Earth space (in terms of velocity to get to them).
- Since ISRU can be performed wherever resources may exist, **natural and discarded**, ISRU systems will need to operate in various **environments** and gravity levels.
- Terrestrial mining is already moving to robotic mining to reduce cost and risk to human miners, and the robots are electric to avoid creating hazardous fumes. These robots will work in space as well.
- Refined resources will enable mass **human habitation and space industrialization** without the need for massive imports from Earth.
- This will be the beginning of an age of abundance for both inhabitants of Earth and those living off-planet.

September 2021

www.spacetech.global

SpaceTech Analytics

Private Spaceflight

SpaceTech Analytics Contributors

Space Tourism Society

John Spencer

Commercial Launch has been a Dream by Many for Decades

Commercial launch in the United States began in 1962 after the Communications Satellite Act, when private companies were allowed to operate their satellites using only governmental launch vehicles. That changed in **1984 after the Space Launch Act**, which broke that limitation and companies could finally build their **rockets and even spaceports**. Similar processes occurred in the Soviet Union and Europe. Even though the commercial companies were developing slowly, there was some evidence that the private sector grew steadily.

1962	Telstar 1 the first satellite to be used commercially, is launched by **AT&T** and **Nokia**
1975	**OTRAG**, the first company to attempt private development of space propulsion systems, is founded in Stuttgart
1982	Conestoga I,the first privately owned and operated rocket to reach space is launched by **Space Services Inc.**
1983	European **Arianespace** becomes the world's first commercial launch service provider
1989	**Space Services Inc.** launched the first rocket to launch with a commercial launch license from the Office of Commercial Space Transportation
1990	Pegasus, by **Orbital Sciences Corporation**, Pegasus became the first launch vehicle fully developed by a private company to reach space and the first air-launched rocket of any kind to reach orbit.
2001	The first space tourist Dennis Tito goes on on a trip to the ISS arranged by the **Space Adventures**

The list goes on and on. Every decade, a couple of private companies reach some heights for the first time in humanity's history. Today there are thousands of **private space-related companies**, dozens of launch service companies, various space tourism companies, and the market grows every year.

Space Tourism is Gaining Momentum

Advances in getting mass back to Earth empower **space tourism** amplified by decreasing launch costs, although prices remain high.

high costs of returning back from space → **high prices** → **low demand** → **low flight rates** → **low prices**

On June, 2021, **Axiom Space** signed one more deal with **SpaceX**. In total, they currently plan four flights that will send private crews to the ISS for a 10-day voyage.

In September, SpaceX flew a Crew Dragon space capsule for a three-day **Inspiration4** mission (private orbital spaceflight) financed by Jared Isaacman.

SpaceX's Starship will support the **DearMoon** project, an art project conceived and financed by Japanese billionaire Yusaku Maezawa, in which several people will orbit the Moon and return.

A pioneer of space tourism, **Space Adventures**, has also arranged with SpaceX to fly private citizens on the Crew Dragon free-flyer mission.

Starliner is **Boeing's** class of reusable crew capsules expected to transport crew and space tourists to the International Space Station. Thus, Boeing intends to become a second company launching Commercial Crew operations to the ISS

Blue Origin and **Virgin Galactic** are offering short-duration suborbital space tourism experiences and research, for far less cost than orbital missions. They both had their inaugural flights in 2021.

Recent and Upcoming Space Tourism Missions Between 2021 - 2023

2021

NEW: July 11th Virgin Galactic first passenger flight with Branson onboard. It was a real success and generated worldwide media coverage.

July 20th Blue Origin's - first crewed mission to sub-orbit with Bezos, his brother Mark/others onboard. It was a success with worldwide media attention.

September 16th Inspiration4 - first all-private orbital SpaceX Crew Dragon mission to low Earth orbit on Jared Isaacman. Mission duration: 3 days.

December Japanese billionaire Yusaku Maezawa booked a ride to the station aboard a Russian Soyuz rocket. Maezawa booked through Space Adventures.

2022

January 2022 - Axiom's first Crew Dragon mission. Designated Ax-1, will be commanded by veteran NASA astronaut Michael López-Alegría. Three wealthy businessmen will join him for an eight-day stay on the space station.

In addition, SpaceX has signed a deal with Axiom Space for three more fully commercial Crew Dragon missions to the ISS beyond Axiom's first Dragon flight in early 2022.

2023

Two of Axiom's commercial Crew Dragon flights to the ISS.

The DearMoon project is a lunar tourism mission and art project conceived and financed by Japanese billionaire Yusaku Maezawa.

It will make use of a SpaceX Starship on a private spaceflight flying a single circumlunar trajectory around the Moon. The passengers will be Maezawa, 8 civilians, and one or two crewmembers.

Economics of Space Tourism

The Ultimate Goal is to Reduce Prices

The companies and individual enthusiasts invest billions of dollars in space travel programs. The ultimate goal is to make space travel relatively affordable for people and profit from it. Market supply of space tourism services is rapidly growing as well as demand. Thus, in the following years, a boom in the space tourism market is expected. Nevertheless, the space tourism market is still in a formative phase with a lack of comprehensive data.

$1B — Jeff Bezos spends around **$1B per year** to fund Blue Origin.

$100M — Blue Origin announced it has already reached **$100M** in private sales.

$1B — Virgin Galactic said it was losing approximately **$190M** each year

$3-4B — Costs a year to maintain and run ISS.
It may be partially covered by **space tourism**.

Space Tourism Prices

$300 000 - 450 000	Blue Origin's and Virgin Galactic's price per seat (~10 minutes suborbital flight)
$25 M*	Price for a few-day flight to ISS onboard Russian Soyuz spacecraft (halted in 2009)
$55 M*	Axiom & SpaceX's price per seat (8 nights in ISS). That includes the $35,000 per-night cost
$55 M*	Space Adventures & SpaceX's price per seat (5-day voyage in orbit)

* the given prices are an approximate estimate formed on the basis of open information in the media.

Market Size of Short-Duration Trips

Blue Origin and Virgin Galactic Competition

Both of these companies had inaugural suborbital launches with spaceflight participants in 2021. They lasted **~10 minutes**, while the ticket price is estimated to be about **$200K - 250K**. Nevertheless, both of them will have to reduce costs to make them more affordable for the broader market. Virgin Galactic claims that the market potential is remarkable with some estimates.

$1.78M	$5.07M
An estimated number of people having a net worth of more than **$10M** that could hypothetically afford a **$100K** ticket	An estimated number of people having a net worth of more than **$5M** that could hypothetically afford a $50,000 ticket

$178B

Maximum potential market size for **1.78M** of consumers

Maximum potential market size for **5.07M** of consumers

$507B

The payback period is currently difficult to estimate

Source: Nasdaq

September 2021

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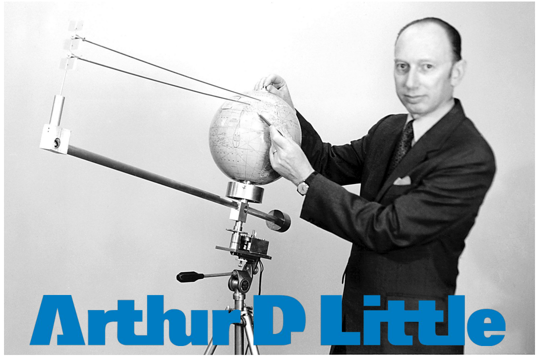
Space Solar Power

SpaceTech Analytics Contributors

MANKINS SPACE TECHNOLOGY

John Mankins

The Concept of Space Solar Power (SSP) is Over Half a Century Old

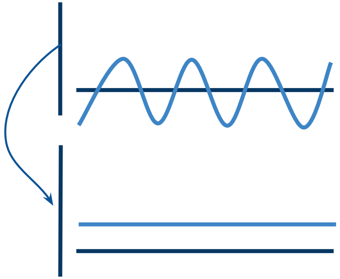


In **1968**, **Dr. Peter Glaser** at Arthur D. Little proposed building large satellites in geostationary orbit to **collect solar power** and beam it to Earth via microwaves.

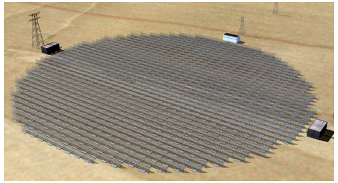
Space Solar Power is a sustainable energy concept:

- ✓ Baseload power, because sun always shines in space, with no clouds (except for a couple hours near the equinoxes).
- ✓ No greenhouse gases or emissions of any kind.
- ✓ Frequency selected to minimize losses through the atmosphere.

Satellites in GEO, **focus sunlight onto photovoltaic panels**, where photons are converted into direct current energy.



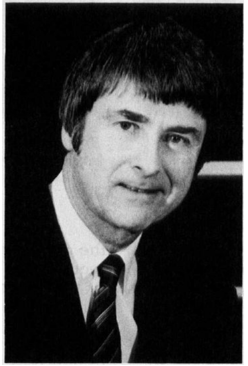
The DC energy is then converted into **radio frequency** (RF), or microwaves.



RF is then beamed to Earth with a large (kilometers diameter) "**rectenna**" and converted from DC to high-voltage alternating current energy for the grid.

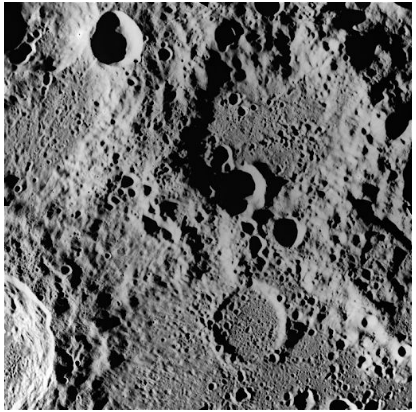
Source: NASA.gov

In the 1970s it was Proposed that SPS be Built From Lunar Materials



Gerard O'Neill - Professor of Princeton University

Professor Gerard O'Neill proposed **that *In-Situ* Resource Utilization Be applied to solar power satellites** from lunar materials.



13
Al
Aluminium
26.982

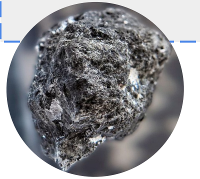
14
Si
Silicon
28.0855

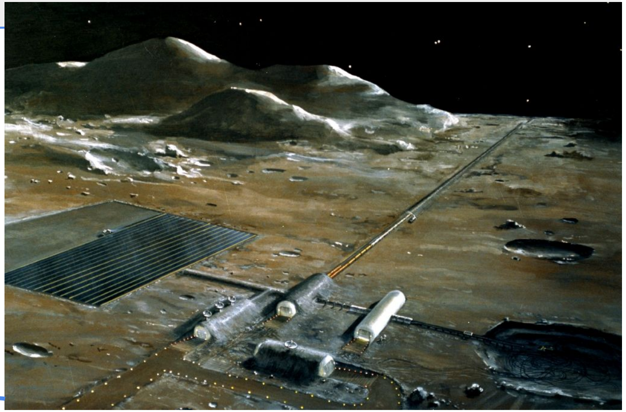
Lunar regolith

contains **aluminum**, **silicon**, and other materials, which could be used to build structure, antennas, and solar panels.

Lunar material would be thrown into space from the lunar surface with a **"mass driver" -** a **linear electric motor** to accelerate and **catapult payloads** up to high speeds.
The payloads **would be caught in cislunar space** (e.g., L-2 Lagrange point).

This approach would **reduce the cost** of launching all the material from Earth and provide a revenue stream for building space settlements.





Source: IEEE

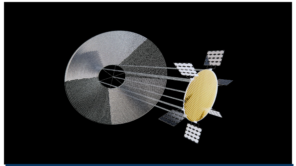
Space Solar Power: How Would it Work?

The Sun

- Can power 2,880 trillion light bulbs
- 1.4 million kilometer diameter
- The Sun has enough hydrogen fuel for billions of years

Ground Station

- ~6km diameter (elevated 5-10 m)
- Outside metro areas
- Mesh RF 'Rectifying Antenna' system
- Uses batteries to modulate supply to the existing electricity grid



SPS-Alpha / Space-based Harvesting

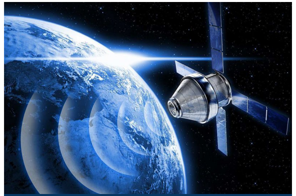
- ~6 km reflector array
- ~1.8 km solar PV panels + wireless power transmitter array
- ~7 km backbone structure
- Modular, robotic construction
- Cheap to launch; less than $1,000/kg
- 99.95% Available Power

Existing Infrastructure

- DC or AC fed into the local grid
- Resembles Hydroelectric Power – but…
- "Always" available
- "Shareable" across markets

Homes and Businesses

- Base Load low cost electricity
- No carbon emissions
- Supports use at all hours of the day

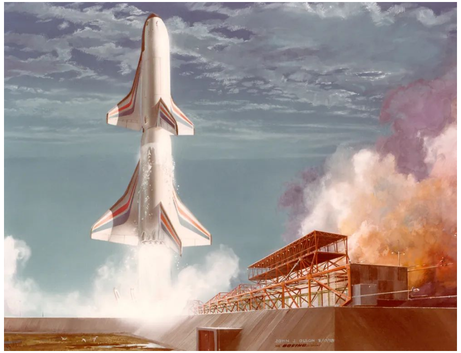


Microwave Energy Transfer

- Precisely controlled transmission of energy
- Less than 20% of summer sunlight
- Can be "shared" across receivers and coordinated with ground-based solar

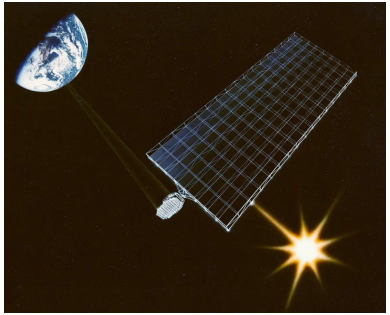
Studied by NASA and the Department of Energy in the Late 1970s

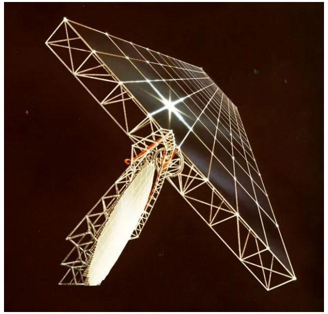
In October 1976, the U.S. **Department of Energy (DOE) and NASA** began a three-phase, four-year joint study of the SPS concept along with **Rockwell International**. Total study cost was **$19.6M**, of which DOE paid **60%**.



The material would be launched in a heavy-lift reusable Boeing vehicle called “**Space Freighter**”. Its Orbiter would have delivered 420 metric tons of cargo to a staging base in low-Earth orbit (LEO). *For comparison, **the largest single-launch U.S. payload** ever put into LEO, the Skylab Orbital Workshop, weighed **77 metric tons**.

The concept would have been a sizeable planar aluminium structure to collect the power and large circular antennas for the phased-array power beaming. 10.5 kilometres long by 5.2 kilometres wide and had a mass of 50,000 tons. **60 such structures** with a total capacity of **300 gigawatts** could satisfy **projected U.S. electricity demand in 2000-2030.**





Source: WIRED

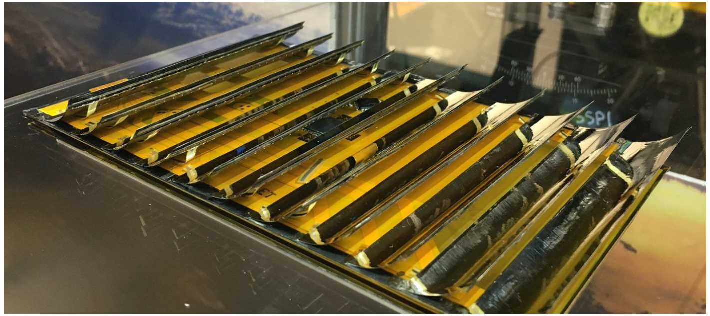
New Hope For Space Solar Power Technology

In 2013, Caltech in Pasadena established the **Space-based Solar Power Project** (SSPP), which is designing hardware to harvest solar energy in orbit and beam it to Earth.

2015 The SSPP received an **anonymous donation of over $100M**. In 2020, Caltech announced the **money came from Donald Bren** and his wife.

2015 From **2015 to 2018** the Caltech had been receiving investitions from **Northrop Grumman Corporation** cumulatively raising **$17.5 million** for SSP technology.

117.5 million project



One proposed solution is to develop a swarm of thousands of smaller satellites that will come together and configure to form a single, large solar generator. In 2017, researchers at the California Institute of Technology outlined designs for a **modular power station** consisting of thousands of ultralight solar cell tiles. They also demonstrated a prototype tile weighing just 280 grams per square metre, similar to the weight of card.

Source: WIRED

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Space Settlement

SpaceTech Analytics Contributors

SPACEBORN UNITED

Egbert Edelbroek

FemTech Analytics

FemTech Analytics

Visions for Space Settlement Go Back to the 19th Century

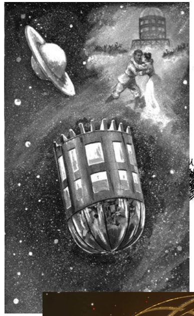
In 1894, the American inventor **John Jacob Astor IV** wrote the science-fiction novel *"Journey in Other Worlds: A Romance of the Future"* about life on Saturn and Jupiter in the year 2000. He compares Greeks with humanity in this work because just as Greece became too small for culture, Earth could get as small for civilisation. It is one of the earliest known visions of space settlement.

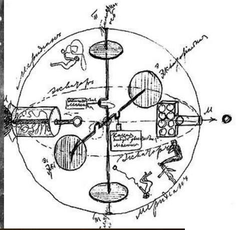
Konstantin Tsiolkovsky envisioned space settlements with space elevators between Earth's quator and geosynchronous orbit thousands of miles above it. He thought through the issues associated with habitats in a vacuum. He developed the concepts of airlocks and closed-cycle biological environments that could provide food and oxygen for residents of space colonies. He was also one of the first to work out the mathematics of rocketry in 1903.

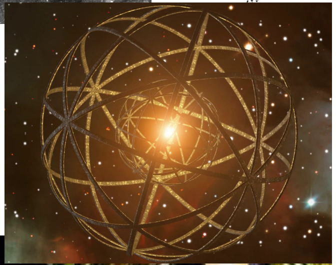
In 1919 H. G. Wells wrote: *"Life, for ever dying to be born afresh, for ever young and eager, will presently stand upon earth as upon a footstool, and stretch out its realm amidst the stars."* His hope was that after the ending of WWI, humanity will stop fighting and begin building in peace.

The author of "A Space-Traveler's Manifesto" and the Dyson Sphere idea **Freeman Dyson** reasoned: *"It is in the long run essential to the growth of any new and high civilization that small groups of men can escape from their neighbours and from their governments, to go and live as they please in the wilderness. A truly isolated, small, and creative society will never again be possible on this planet".*

In 1969 Gerard K. O'Neill, along with students from Princeton University, worked out that other planets, and space itself, would be a better venue for an expanding technological species, offering more energy and raw materials and risking less pollution of our home planet.





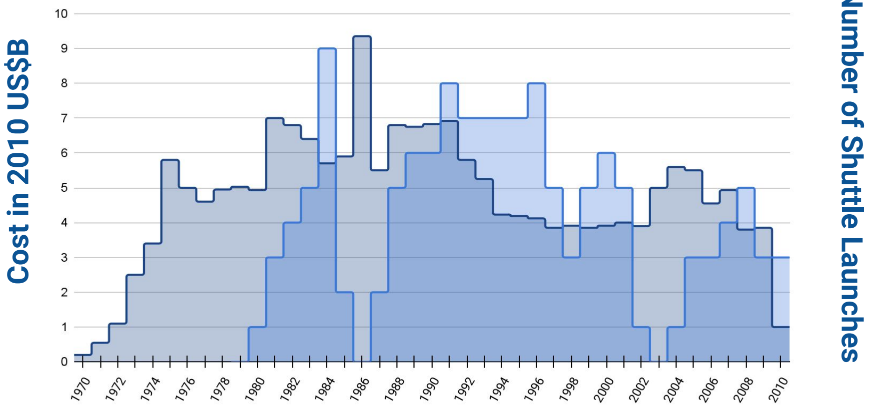


Cost of Access to Orbit has Made Settlement Dreams Impractical

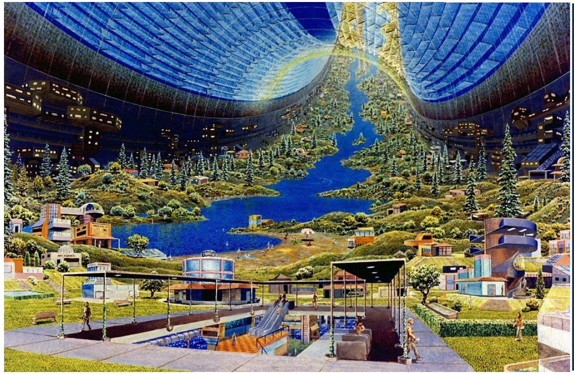
1974 Gerard K. O'Neill authored a paper called "Colonisation of Space", in which he described ways to build space settlements in the Earth-Moon Lagrange points if humans could bring lots of payload to space frequently. Inspired by him, the **L-5 Society was** formed and hoped that the Space Shuttle would enable "L-5 by '95," a **settlement at Earth-Moon** L-5 Lagrange point.

But Shuttle failed in its promise of frequent flights at low cost. The intended **24 missions per year** NASA predicted were not possible. The prices would go up and flight rates down, and even at that flight frequency, tragedies occurred.

Cost and Number of Shuttle Launches Timeline



Although all the dreams, humanity had to face the reality that the Shuttle would not open space. In 2021, all we have is a seven-person space station in low-Earth orbit, though prospects for the future are brighter.



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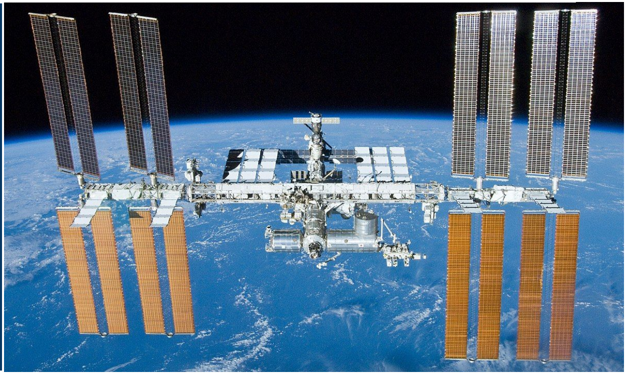
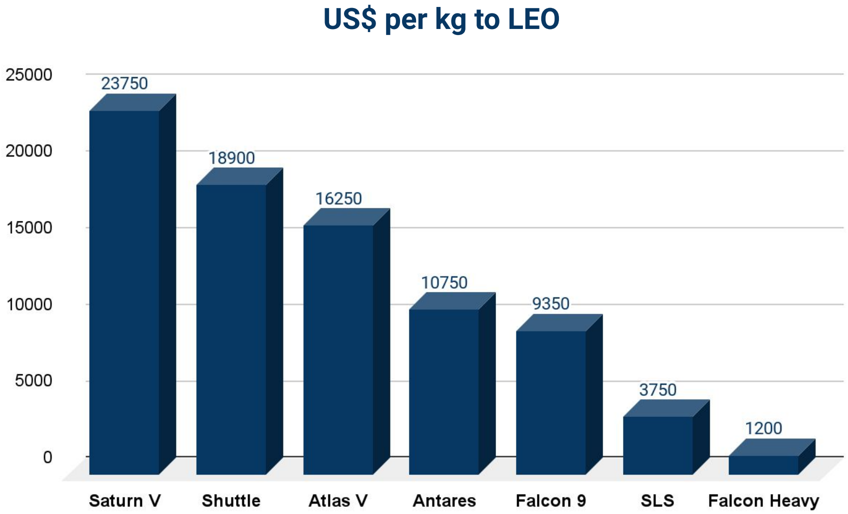


Cost of Access is Finally About to Plummet

SpaceX, with its SuperHeavy, plans on **delivering 100 tons to LEO** at the cost of tens of dollars per pound four times each day. Four flights a day would be **~300,000 tons per year** in orbit, at a cost on the order of **$10B**. That is the equivalent of launching **200 ISS's every year**. If that occurs, the space industry will develop much more rapidly than previously imagined.

This kind of capability will allow a space logistics and transportation industry will emerge, with the potential of a "pipeline," or transcontinental railroad" to and from orbit, for construction material, air, water, and people. In addition, it may make it possible to deliver almost anything anywhere within **30-40 minutes using these cheap** reusable space vehicles.

Source: SpaceX



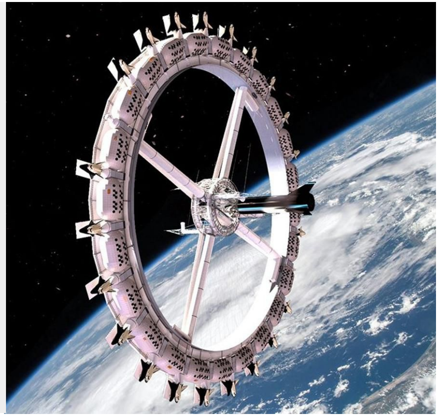
Technologies Coming Together Enable Large-Scale Human Habitation

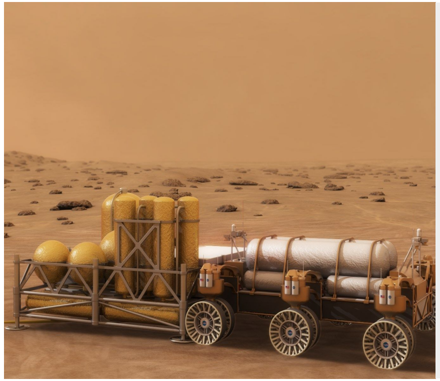
As the cost of access to orbit decreases every day, more and more technologies will be sent into space, spurring innovation and rapid progress. With modern space construction methods, in-situ **resource utilisation, and robotics**, the O'Neillian vision may be on the brink of fruition.

Robotics
Archinaut is a solution by **Made in Space,** a subsidiary company of **Redwire** designed for in-space construction needs using robotics and 3D printing. It is potentially capable of fabricating complex space-optimized structures and repairing previously launched satellites.

Space Construction

The **Orbital Assembly** company is planning human orbital habitats with artificial gravity. They have already scheduled the first rotating prototypes with various scientific payloads for 2023.





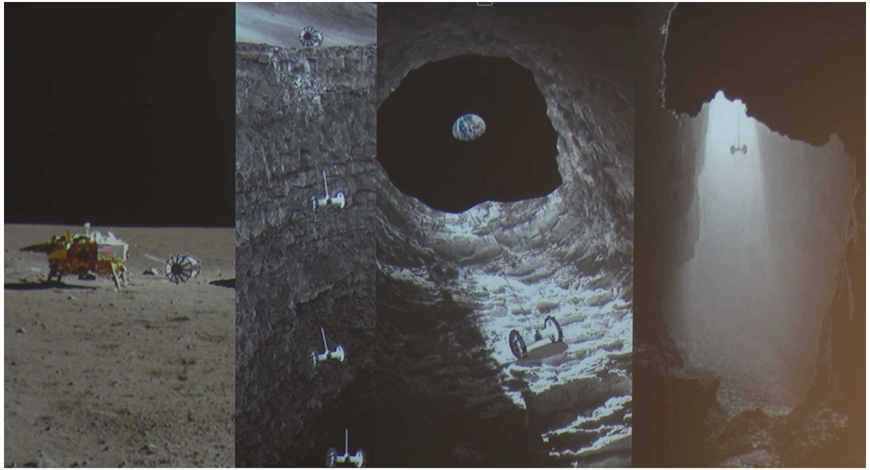
ISRU

Skyhaven Systems were awarded a contract with NASA to develop a hydrogen and methane separation unit for Martian processing. The **Sabatier** reactor produces methane and water.

Source: Made in Space

Many Want to Live on Other Planets

Lunar lava tubes are lava tubes on the Moon formed during the eruption of **basaltic lava flows**. When the surface of a lava flow cools, it hardens, and the lava can channel beneath the surface in a tube-shaped passage.



Artists rendering of the Axel rover descending into a lunar lava tube skylight as part of the Moon Diver mission. The Axel rover has power, communication, and support provided by a surface lander or vehicle. Credit: Kerber et al., 2018, video presentation.

Lunar lava tubes may potentially serve as enclosures for human habitats. Tunnels larger than **300 metres (980 ft)** in diameter may exist, lying under **40 metres (130 ft)** or more of basalt, with a stable temperature of **−20 °C (−4 °F)**. These natural tunnels protect from impacts from cosmic radiation, solar radiation, meteorites, micrometeorites, and ejecta. They are insulated from the extreme temperature variations on the lunar surface and could provide a stable environment for inhabitants.

Lunar lava tubes are typically found along the boundaries between lunar mares and highland regions. This would give ready **access to**:

Elevated regions for communications

Basaltic plains for landing sites and regolith harvesting

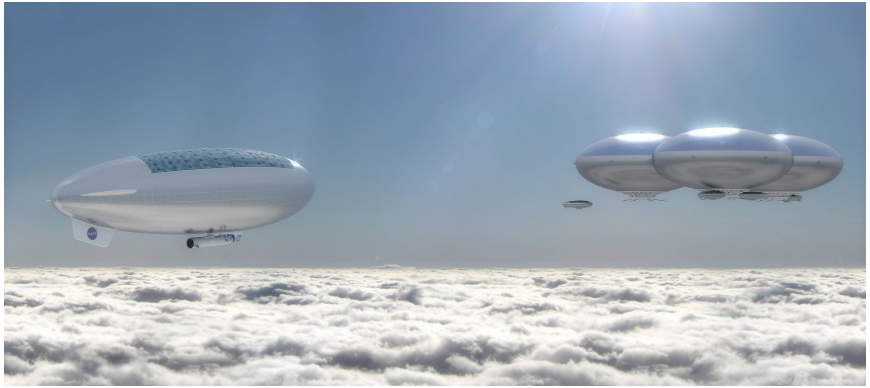
Underground mineral resources

Source: Daily Advent

How Humans Can Live on Venus?

Difficulties of Venus settlement

The temperature at the equator averages around 450 °C (723 K; 842 °F)	The atmospheric pressure on the surface is ninety times greater than on Earth.
Water, in any form, is almost entirely absent from Venus.	The visible clouds are composed of corrosive sulfuric acid and sulfur dioxide vapor.



Artist's rendering of a crewed floating outpost on Venus of NASA's High Altitude Venus Operational Concept (HAVOC).

Sources: NASA

At least as early as 1971, Soviet scientists had suggested that rather than attempting to settle Venus' hostile surface, humans might try to **settle in the Venusian atmosphere**. Geoffrey A. Landis of NASA's Glenn Research Center has summarized the perceived difficulties in **Venus settlement** as being driven by the assumption that a colony would need to be based on the surface of a planet:

However, viewed differently, the problem with Venus is merely that the ground level is too far below the one-atmosphere level. At the cloud-top level, Venus could be a paradise planet, whose atmosphere could be mined.

Issues of Gestation in Partial Gravity

The data is partly taken from SpaceTech Analytics and SpaceBorn United “DeepTech Engineering the Pathway to Giving Birth on Mars”.

A family frolics on the surface of Mars in an illustration.
Illustration by Robert Murray / Mars Society

Lack of food

Pregnancy during long term space flights such as Mars One is dangerous because it could put the entire crew in danger. Resources such as air, food, and medical supplies will be limited and carefully gauged to keep the crew members alive. An unexpected addition to the crew could put these carefully managed resource and risk calculations out of balance.

The health of mother and crew

Pregnancy on the mission would also pose a greater risk to the mother. Although one or two of the astronauts will receive comprehensive medical training and medical equipment to treat anticipated illnesses or injuries will be available, the crew will likely not be prepared to assist with birth complications or provide care for a newborn.

Sex in space

Human sex drive has persisted when humans are isolated in a small group for an extended time. At this time, NASA’s policy forbids sex in space, and there have been no confirmed instances of it happening, but the long trip to Mars and starting a settlement would almost unavoidably result in sex.

Failed Attempts and Plans for Space Settlement

Mars One

Country	The Netherlands
Crew Capacity	4 (first group)
Status	Looking for investment

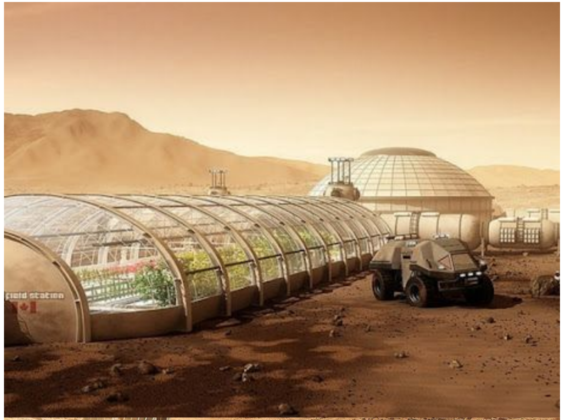
Mars One was a private project led by Bas Lansdorp that envisioned a flight to Mars with the subsequent establishment of a settlement on its surface and broadcasting everything that happened on television.

SpaceX Mars Program

Country	The USA
Crew Capacity	≤ 100
Status	Planned/Happening (Planned-90%, Happening 9.9%)

Elon Musk, CEO of Tesla and SpaceX, said SpaceX plans to land Starship spaceships on Mars well before 2030. Landing the ship is not a problem, he said. The main problem is the creation of a self-sufficient Mars Base Alpha.

Many Technologies Must Still be Developed



Today, the number of space technologies is growing exponentially, but there are still many things needed. The habitat question is still an issue. We would require construction technologies for pressured living modules, oxygen generators, water recyclers and other things needed for healthy space settlers. Modern life-support technologies need to be greatly advanced to mostly close the cycle. Payload delivery is still costly, so we would need to build structures using materials present on the spot, and additive manufacturing. We don’t have enough insight on growing food in either space or other planets, even though such technologies work on ISS. Finally, as mentioned, we lack an understanding of gestation in partial gravity that is vital to such communities.

Sources: NASA

Conclusions

September 2021

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Key Financial Takeaways

Over the past decades, space has attracted many participants, with New Space and non-space companies entering various industry development chains. The number of private space-related companies is prevalent in the United States, while Asian and European regions accelerate the activity.

North America is the leading region by SpaceTech companies, with more than 6600 companies in the area. It is followed by Europe & Central Asia with 2681 companies and East Asia & Pacific with 1131 companies. **The US is firmly in the lead regarding the number of SpaceTech companies (52.1%). The UK ranks second (5.7%), while Canada, China, Germany, and India follow** (4.9%, 4.5%, 3.8%, and 3.6%, respectively).

Showing stable growth, the global SpaceTech economy was valued at **$4T in 2020 and is expected to grow to $10T by 2030**. According to the most conservative estimates, **it accounts for 0.5% of the global GDP.** This will dramatically impact the annual growth in the global SpaceTech market, primarily because of the growth of the development of Satellite Technologies, the Space Exploration sector, and advances in AI, IT, FinTech, and other digital technologies.

Our Top 20 Core Publicly Traded Companies by Capitalization in 2021 include Korea Aerospace Industries, IHI Corporation, AT&T Inc., Honeywell International Inc., and The Boeing Company sharing the first five places whose **cumulative capitalization is estimated to be more than $4T. The most recent SpaceTech companies that have achieved IPOs include: Redwire (09/08/2021), Rocket Lab (08/25/2021), and Virgin Orbit (08/23/2021)**

The SpaceTech industry is experiencing rapid growth and gaining momentum among entities that were not space-related initially, but have expanded into the sector. We include the **top 20 verge SpaceTech companies** that have recently started to contribute to the industry or are positioning to establish themselves in the booming industry. These include **Amazon** with the project "Kuiper", **Jacobs** and its Space Exploration Challenges, **Intel** with the first AI technology enablers to supply its VPU in a "satellite-as-a-service" space mission, and **Garmin's** GPS systems.

Key Takeaways

SpaceTech Analytics has analyzed almost **twenty thousand entities** and concluded that the capitalization of the whole industry is highly underestimated. Thus, we have developed a unique methodology that includes three key categories: Core companies, Verge companies, and Space-Applied Businesses. This approach allowed us to analyze not only hardware companies that are directly developing solutions for the space industry - "**Core Companies**".

We developed the separate category of "**Verge space companies**" for those businesses that are only partly involved in SpaceTech, simultaneously with their main activities, but have a great potential in the market to become full-fledged Core companies. For multiple layers of companies that have not yet entered the space industry but are already using those technologies or solutions that are closely related to the SpaceTech sector, we have created the "**Space-Applied Businesses**" category. The methodology may contain some inaccuracies due to manual entry, so not all SpaceTech companies were necessarily included in the database.

Today's active development of technologies enabling the efficient return of payload back to Earth will spur manufacturing in space, with its unique properties of weightlessness and cheap vacuum. Currently, the cost of getting mass back from space is too high, but that is changing. This is resulting in **increased interest from companies who formerly couldn't see a business case.** Together space assembly and refuelling can generate completely new transportation means better suited for space settlement tasks. They could be much larger while carrying less propellent and more payload.

Space law formally began in January 1967 with the Outer Space Treaty and is still in the stage of development. The Committee on the Peaceful Uses of Outer Space (COPUOS), formed in 1959, gathers multiple times per year. **Commercial spaceflight in the United States was legalized in 1984 with the Commercial Space Launch Act, while similar processes were also going on in Europe and USSR.** Some concerns about space legislation turned out to be justified, some not. There is still a significant controversy in the space law community, especially around the Moon Agreement, accepted in 1979.

Historically, rockets were expended, and the first stages crashed downrange. The early American spaceports were put on coasts. The first Soviet Union spaceport for orbital and human launches - the Baikonur Cosmodrome in southern Kazakhstan, started as a Soviet military rocket range in 1955. Established in 1958, Jiuquan Satellite Launch Center in China's earliest launch site with state-of-the-art satellite launch facilities. Overall, **most spaceports are located in these three countries: the USA, Russian Federation and China.**

Key Takeaways

Regardless of the ultimate destination, a launch system is necessary to get payloads or people into space. However, high launch costs have been the most significant limiting factor to expanded space exploration and utilization. **The average cost to launch a kilogram** of payload into LEO on the space shuttle **remained constant at over $50,000**. Now, **the cost per kilogram is less than $3000 on a SpaceX Falcon 9 rocket**.

Small satellites are actively expanding in the SpaceTech market. Small satellites are very light and may mass as little as 30 kg. unfortunately, it is not generally affordable and reasonable to launch one small satellite. However, **launching dozen or hundreds of satellites reduces costs significantly.** This is making launches more accessible. **On January 24th 2021, SpaceX set a record and launched 143 satellites on a single rocket for $57M** on a Falcon 9.

Today, commercial **space transportation are the primary means of delivery to Earth orbit.** Soon, this will include **commercial in-space transportation systems and their support infrastructure.** There are commercial in-space transportation companies now. Today, one can book payload delivery to the Moon on expendable commercial lunar landers with **Astrobotic for $1.2 million per kilogram**. In addition, **Momentus is offering expendable space-tug services in Earth orbit for small payloads.**

Along with the commercialization of space transportation, private human space flights and space tourism sectors are gaining popularity, and becoming more accessible. This raises the issue of keeping humans' healthy during space flights using novel approaches in Space Medicine. These include pre-flight training, telemedicine, fundamental research in molecular medicine in the space flight environment. Long-duration spaceflight needs to be investigated more thoroughly. The main challenges of weightlessness and space radiation include **muscle loss, bone loss, renal dysfunction, cardiovascular system, immune system, different neurological disorders and behavioural health**.

In the last century, the size of the fairing of a **rocket determined the maximum dimensions of a satellite**. As long as this remained the case, space **hardware was limited in size to what would fit in the rocket.** This started to change when the International Space Station began to be assembled over two decades ago. It could not have been launched as a single piece for reasons discussed in the Economics of Space section. Once we start constructing facilities in space, there will be no limit to how large they can be.

Key Takeaways (Final)

Satellite servicing was considered from the early days of the space era, as any machine needs some assistance. It is usually understood as servicing of a satellite by robotic spacecraft or by human astronauts. Nevertheless, nobody did it until 1984. **In the 20th century, the space industry was driven by the government,** so **satellite servicing had to become a government-funded effort**. Earth's orbit is now becoming a teeming place full of non-operational satellites and debris. Moreover, **according to NASA, on average, one hundred tons of junk falls out of orbit annually, creating a hazard not just in space, but on Earth**.

The use of *in situ* resources is in space exploration and settlement, and it is **defined as the collection, processing, storage and use of materials encountered in space.** As a result, the need to deliver them from Earth disappears. **ISRU includes commercial applications, robotic planetary exploration, human exploration, and the establishment of outposts.** The key players in this field are diverse in the ways to utilize the resources and include such companies as **Made in Space, Orbit Fab, Neumann Space, Altius** and many more.

In addition to the almost unlimited potential of ISRU, space solar power provides a fantastic opportunity for **sustainable energy recovery using Space Solar Power (SSP) technology**. This concept was invented in **1968 by Dr Peter Glaser** at Arthur D. Little, who proposed building large satellites in geostationary orbit to collect solar power and beam it to Earth via microwaves. Today, SSP is actively developed at the **California Institute of Technology**, which raised a cumulative **$117,5 million** for this purpose, primarily by the private investment of Donald Bren. The Japanese and Chinese are interested as well.

ISRU technologies need to be greatly advanced. Payload delivery is still costly, so we would need to build structures using materials present on the spot and additive manufacturing. And finally, we lack an understanding of gestation in partial gravity that is vital to such space communities. Cumulatively, **it raises the serious question of human deep space habitation.**

Today's era of commercial space flights and habitable Low-Earth Orbit predisposes accelerating the pace and necessity of experiments and related data concerning living and procreating in gravity environments. **Terraforming** of the last ones **may be required to create a safe environment for next generations** (e.g. artificial magnetosphere to provide an atmosphere providing radiation protection and oxygen).

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CONTACT US

www.spacetech.global
info@spacetech.global

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www.dkv.global
info@dkv.global