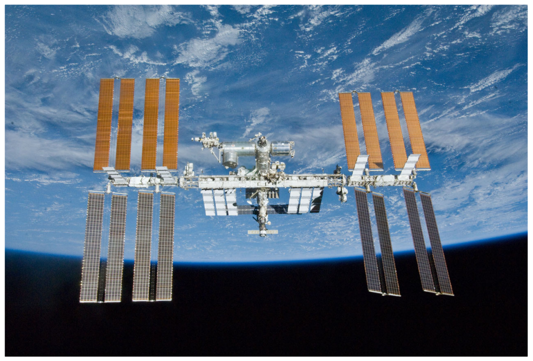
EXPLORE SPACE TECH
TECHNOLOGY DRIVES EXPLORATION

EXPLORE: Advanced Manufacturing
NASA Space Technology Mission Directorate

STMD welcomes feedback on this presentation. Please visit https://techport.nasa.gov/framework/feedback if you have any questions or comments regarding this presentation.

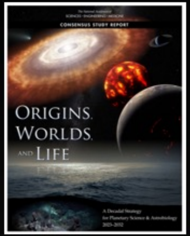
How We Explore… NASA Manufacturing



Inclusive Strategic Technology Planning

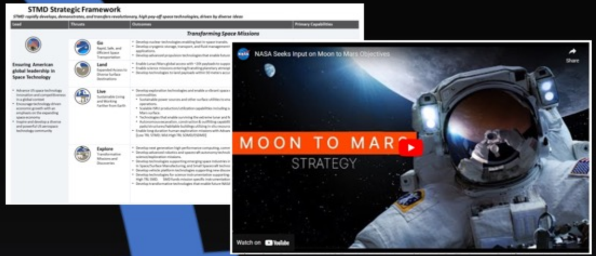
Strategic Technology Architecture Roundtable (STAR) Process

In order to achieve the NASA Strategic Objective led by the Space Technology Mission Directorate, the STAR process was implemented to bring together the various inputs from stakeholders to produce a set of gaps that can be closed through STMD investments.



Draws directly on Artemis architectures and Science Mission Directorate Decadal to identify technology gaps.

STMD Strategic Framework describes the STMD investment priority strategy. Strategic Technology Framework aligned to Agency Moon to Mars Strategy along with Agency Strategic Capability Leads (SCLs) and Principal Technologists (PTs).



STAR

Industry Partners' participation is obtained through Requests for Information (RFIs) to validate envisioned futures, the current state of the art and the gaps between those two.

STAR process inclusive of Center Chief Technologists, ESDMD and SMD Representation.

Maps to OTPS Taxonomy.

STARPORT – STMD and ESDMD Gap database + Envisioned Future Priorities → PPBE Process

STARPort is the database of all Capability Area gaps for both STMD and ESDMD. Envisioned Future Priorities (EFPs) are written by SCL/PTs to show the future state envisioned and suggested path forward to inform Planning, Programming, Budgeting, and Execution (PPBE) process.

Strategic Technology Framework

STMD rapidly develops, demonstrates, and transfers revolutionary, high pay-off space technologies, driven by diverse ideas

Lead	Thrusts	Outcomes	Primary Capabilities
Ensuring American global leadership in Space Technology • Advance US space technology innovation and competitiveness in a global context • Encourage technology driven economic growth with an emphasis on the expanding space economy • Inspire and develop a diverse and powerful US aerospace technology community * represents contributing crosscutting technologies	**Go** Rapid, Safe, and Efficient Space Transportation	• Develop nuclear technologies enabling fast in-space transits. • Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications. • Develop advanced propulsion technologies that enable future science/exploration missions.	• Nuclear Systems* • Cryogenic Fluid Management* • Advanced Propulsion*
	Land Expanded Access to Diverse Surface Destinations	• Enable Lunar/Mars global access with ~20t payloads to support human missions. • Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. • Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.	• Entry, Descent, Landing, & Precision Landing*

	Live
	Sustainable Living and Working Farther from Earth
		• Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities
		  • Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.
		  • Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.
		  • Technologies that enable surviving the extreme lunar and Mars environments.
		  • Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.
		• Enable long duration human exploration missions with Advanced Habitation System technologies. [Low TRL STMD; Mid-High TRL SOMD/ESDMD]
			• Advanced Power*
			• In-Situ Resource Utilization*
			• Advanced Thermal*
			• Advanced Materials, Structures, & Construction*
			• Advanced Habitation Systems*

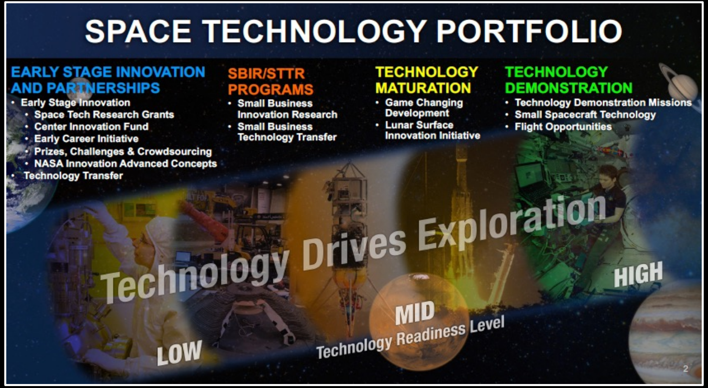
	Explore Transformative Missions and Discoveries	• Develop next generation high performance computing, communications, and navigation. • Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions. • Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. • Develop vehicle platform technologies supporting new discoveries. • Develop technologies for science instrumentation supporting new discoveries. [Low TRL STMD/Mid-High TRL SMD. SMD funds mission specific instrumentation (TRL 1-9)] • Develop transformative technologies that enable future NASA or commercial missions and discoveries	• Advanced Avionics Systems • Advanced Communications & Navigation • Advanced Robotics • Autonomous Systems • Satellite Servicing & Assembly* • Advanced Manufacturing • Small Spacecraft* • Rendezvous, Proximity Operations & Capture • Sensor & Instrumentation

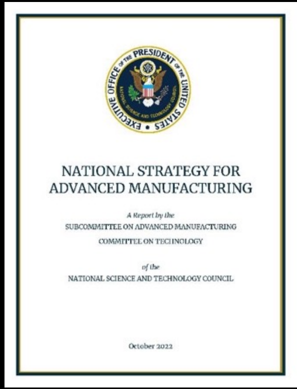
EXPLORE: Develop technologies supporting emerging space industries

Advanced Manufacturing technologies make NASA's missions more capable and affordable by bringing together industry, academia, and government

Plan to close gaps and achieve outcomes

- Integrated plan across Mission Directorates and Centers; Across TRLs (e.g., leverage STRG), programs and projects pipeline; Industry/Academia alignment
- Increase collaboration and public private partnerships. Leverage National Strategic Plans: Office of Science and Technology Policy Subcommittee on Advanced Manufacturing; In-Space Servicing, Assembly, and Manufacturing; Materials Genome Initiative; National Nanotechnology Initiative; others
- Outcome based - Innovative advanced manufacturing technologies targeted at commercial drivers for performance, affordability, and sustainability. "Bridge the Valley of Death"

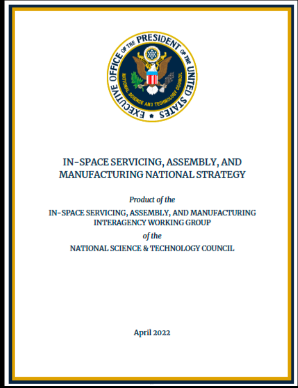




NATIONAL STRATEGY FOR ADVANCED MANUFACTURING

A Report by the
SUBCOMMITTEE ON ADVANCED MANUFACTURING
COMMITTEE ON TECHNOLOGY
of the
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

October 2022



IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING NATIONAL STRATEGY

Product of the
IN-SPACE SERVICING, ASSEMBLY, AND MANUFACTURING INTERAGENCY WORKING GROUP
of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

April 2022

Moon to Mars Strategy

Objective-based Approach – Architect from the Right - Stick with the Plan

LI-4L: Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-8L: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.

RT-5: Maintainability and Reuse: when practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.

PPS-2LM: Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.

AS-6LM: Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.

TH-4LM: Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.

OP-11LM: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.

OP-12LM: Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.

EXPLORE: Develop technologies supporting emerging space industries

Priorities - Targeted advanced manufacturing outcomes aligned with space industry trends that will shape the course of research and development over many years

In-Space Manufacturing and Space Infrastructure

> 50% Mass reduction, > 99% 3D printer readiness. A catalyst for space infrastructure and economic opportunities

1

3D Printing / Additive Manufacturing

>50% Cost reduction, 12 months instead of five years,
Parts reduction >100 to 1

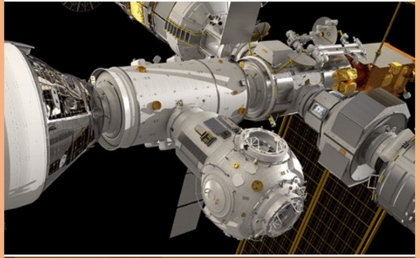
2

Digital Transformation Digital Twins and Artificial Intelligence

>50% of physical resources replaced with virtual
More intelligent and more accurate predictions and capabilities

3

Lightweight Composite Spacecraft



30% - 50% More payload, equipment, and experiments

4

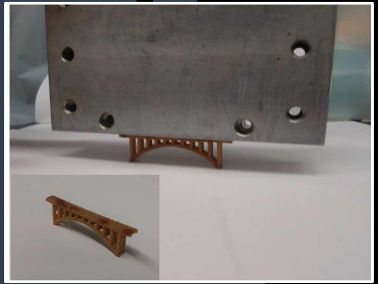
1 In Space Manufacturing and Space Infrastructure

Motivation/State of the Art

- Aligned with STMD Strategic Framework and Moon to Mars Objectives
- The Post-ISS Plan: Commercial demand for in-space manufacturing
- The current logistics model is unsustainable for long duration space missions
- 3D Printer GCD tech demo on-board ISS in 2014
- 20 years of ISS microgravity materials science research (SMD BPS)
- STMD GCD ISM project (FabLab prototype testing)
- ISS commercial In Space Production Applications (InSPA)
- ISS National Lab/CASIS In-orbit materials/manufacturing
- NASA OSAM-1 and OSAM-2

Next Steps, Future Focus Areas and Investments

- Announcement of Collaboration Opportunity & Partnership Proposals to Advance Tipping Point Technologies
- On-demand manufacturing of metals, electronic components, recycling, and reuse
- ISRU-derived materials for feedstocks (e.g., Al, Si) for lunar surface manufacturing
- Certification is a top challenge - Physics-based models to predict processing and material properties
- ISAM - welding in space, recycling and reuse, large scale additive manufacturing
- Maximize use of ISS for demonstration



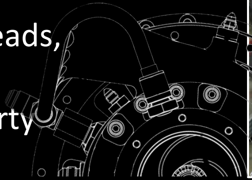
2 3D Printing/Additive Manufacturing

Motivation/State of the Art

- Administration Launch of AM Forward Initiative
- Revolutionary design flexibility and dramatic reductions in cost/schedule
- Ideal applications for complex components (e.g., liquid rocket engines)
- Large-scale additive technologies are just being demonstrated
- Available materials are limited and not optimized for AM
- Entirely empirical certification approaches
- Variability is the achilles heel

Next Steps, Future Focus Areas and Investments

- Accelerate certification (STRI, computational tools, MGI, ICME, digital twin)
- Early Stage Innovations topic 4 - Functionally Graded Materials
- Materials for extreme environments (e.g., refractories for nuclear)
- New processes (e.g., additive friction stir, directed energy)
- Large scale freeform applications
- NDE/Inspection, In situ monitoring, and closed-loop control
- Technologies for non-propulsion structures (e.g., common bulkheads, tanks, domes, optical structures etc.)
- Advance modeling and simulation for optimal parameters, property predictions, and material designs



Extensive National Collaborations - Industry Driven Focus

3

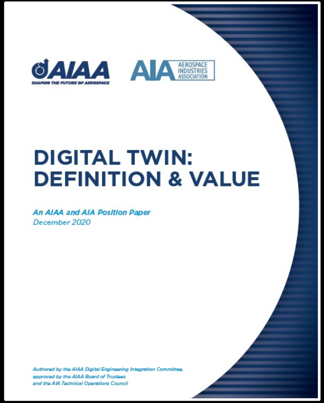
Manufacturing Digital Transformation Digital Twins and Artificial Intelligence

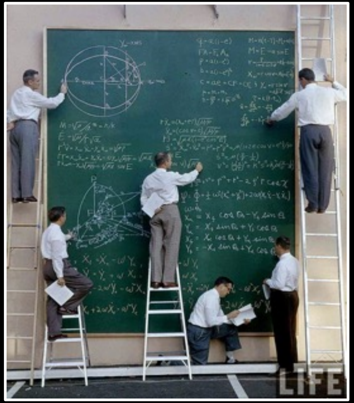
Motivation/State of the Art

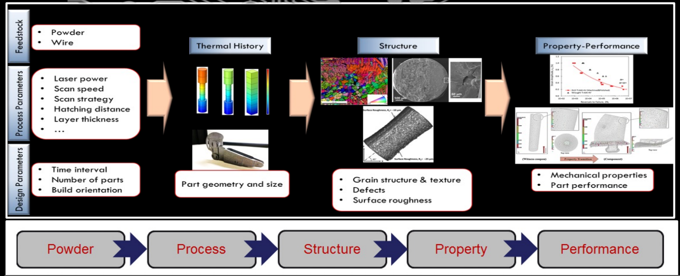
- Complexity of aerospace systems has significantly outpaced conventional development approaches – Inflection point!
- Global competition to achieve economic leadership through the development and application digital transformation
- Industry 4.0 EU strategic initiative - digital transformations in design, manufacture, and operations
- Air Force B-21 and F-16 “digital twins”
- Limited physics-based computational materials, design and manufacturing capabilities in use today (e.g., ICME, MGI initiatives)

Next Steps, Future Focus Areas and Investments

- Interdisciplinary modeling across the building block levels of “R&D to certification” (major agency/industry problem)
- Digital twin physics-based modeling and simulation of predictive relationships between processing parameters, material microstructure, material properties, and hardware performance
- Artificial intelligence, machine learning, and digital twin technologies for manufacturing processes







Modeling Process-Structure-Property Relationships for Additive Manufacturing

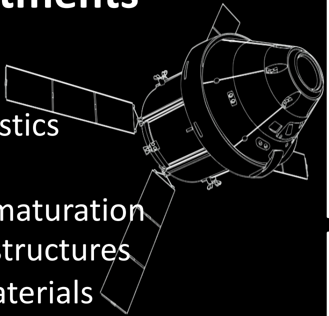
4 Lightweight Composite Spacecraft

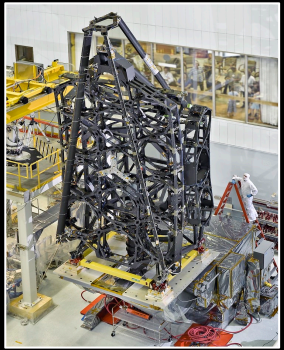
Motivation/State of the Art

- Decadal Survey (Astro2020) - “Composite Material Process Development and Optimization”
- Immediate 30% weight savings and 25% cost savings compared to SOA
- Aluminum is most widely used in space vehicle structures
- Composites usage in space applications lags aviation and military
- Thermoplastic composites development is rapidly advancing
- Thermoset composites are de facto baseline and mechanical fastening is still primarily used (joints are the achilles heel)

Next Steps, Future Focus Areas and Investments

- Dimensional stability - Topic 3 ECF22
- Thermoplastic composites for space applications
- Adhesive bonding thermosets and welding thermoplastics
- Tailorable properties offer new design possibilities
- Digital/model-based discovery, characterization, and maturation
- High temperature and cryo-temperature materials & structures
- New materials and space environmental effects on materials
- Accelerated analytical certification and failure mode approaches





Recent Space Tech Advanced Manufacturing Solicitations/Selections

SBIR and STTR Phase I and Phase II	>30 awards across ISM, AM, Digital, Composites
SBIR IGNITE	2 Topics - Point-of-use Recycling for Optimized Space-Age Logistics, Commercial Development of Active Debris Remediation
NASA Space Technology Graduate Research Opportunities	~8 awards TA12 Materials, Structures, Mechanical Systems, and Manufacturing
2022 Early Career Faculty (ECF)	2 universities - Tailorable Composite Dimensionally Stable Structures
2022 Early-Stage Innovation (ESI)	5 Universities - Functionally Graded Materials, Manufacturing for High-Temperature Radiators
Space Technology Research Institute	Accelerating Additive Manufacturing Certification with Model-Based Tools
Flight Opportunities Tech Flights	Cislunar/Lunar Surface and In-Space Infrastructure & Capabilities
Tipping Point and Announcement of Collaboration Opportunity (ACO)	Cislunar/Lunar Surface and In-Space Infrastructure & Capabilities
Breakthrough, Innovative and Game-Changing (BIG) Idea Challenge	Lunar Forge - extracting metal from lunar minerals to creating structures and tools

(*representative activities, not a comprehensive list)

Summary

- Advanced manufacturing technologies are critical to NASA, the Nation's aerospace industry, and almost every sector of the U.S. economy
- White House Critical Emerging Technology List - Advanced Manufacturing (Additive Manufacturing), Space Technologies and Systems (In-Space servicing, assembly, and manufacturing), Advanced Engineering Materials (Materials Genome)
- An integrated/focused plan of investment strategies across the full TRL pipeline and across Mission Directorates
  - Linked to Agency strategies/missions, commercial strategies, and other national needs
  - Deep understanding of SOA, key challenges, and emerging innovations
  - Bridge the "valley of death" for translational technologies from research to infusion
- Better collaboration between government, industry, and academia will accelerate realization of innovative technologies

Acronyms

- ARMD: Aeronautics Research Mission Directorate
- BPS: Biological and Physical Sciences
- GCD: Game Changing Development
- ICME: Integrated Computational Materials Engineering
- InSPA: In-Space Production Applications
- ISAM: In-space Servicing, Assembly, and Manufacturing
- ISRU: In-Situ Resource Utilization
- MGI: Materials Genome Initiative
- NASA: National Aeronautics and Space Administration
- OCT: Office of the Chief Technologist
- OOA: Out Of Autoclave
- R&D: Research and Development
- SMD: Science Mission Directorate
- SOA: State of the Art
- STAR: Strategic Technology Architecture Roundtable
- STMD: Space Technology Mission Directorate
- STRG: Space Technology Research Grants
- TIM: Technical Interchange Meeting
- TRL: Technology Readiness Level