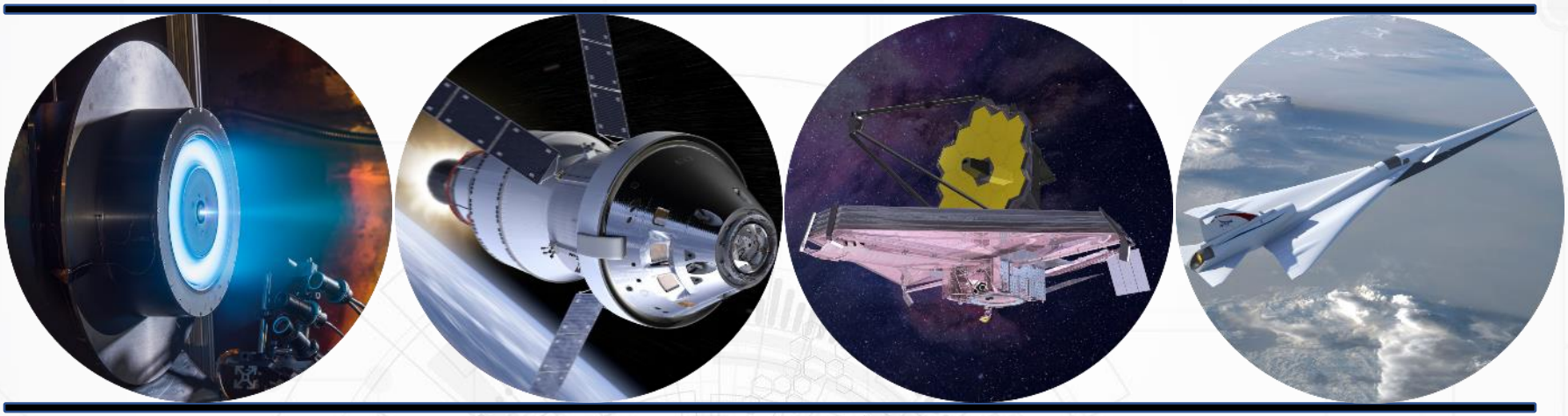
Office of The Chief Technologist

National Aeronautics and Space Administration



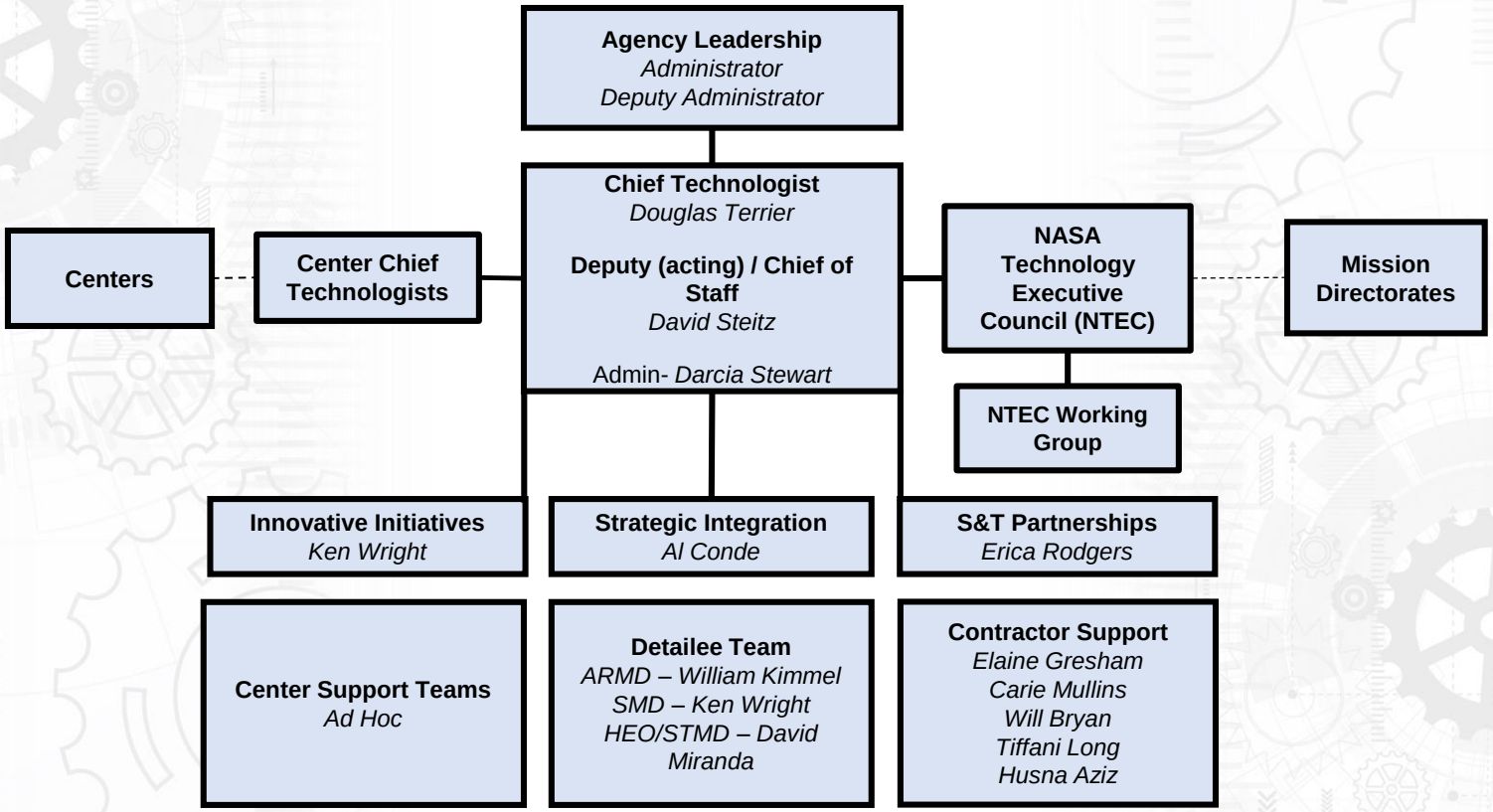
Strategic Technology Investment

Al Conde(OCT)

March 27, 2019

Office of The Chief Technologist

National Aeronautics and Space Administration



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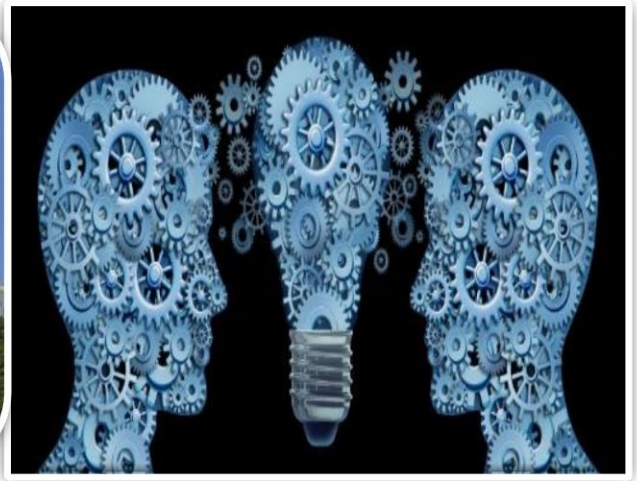


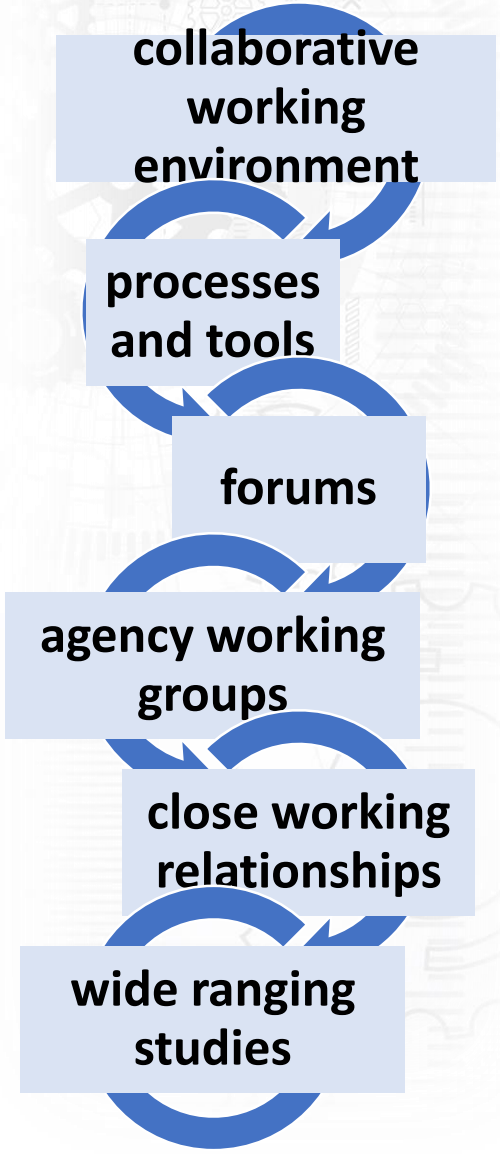
Top Advisor
Strategy

Advocate
Technology

Champion
Innovation

Strategic Integration

National Aeronautics and Space Administration



To engage all agency stakeholders to create a optimal technology portfolio.

To inform investment decisions based on agency needs, priorities and provide insight on effectiveness and ROI.

To foster discussion and decision-making.

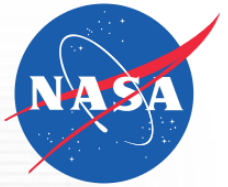
To disseminate information, resolve crosscutting issues and develop policy recommendations relevant to the technology domain.

To inform advisory role of the administrator.

To inform agency decision makers across the agency.

Space Policy Directive - 1

National Aeronautics and Space Administration

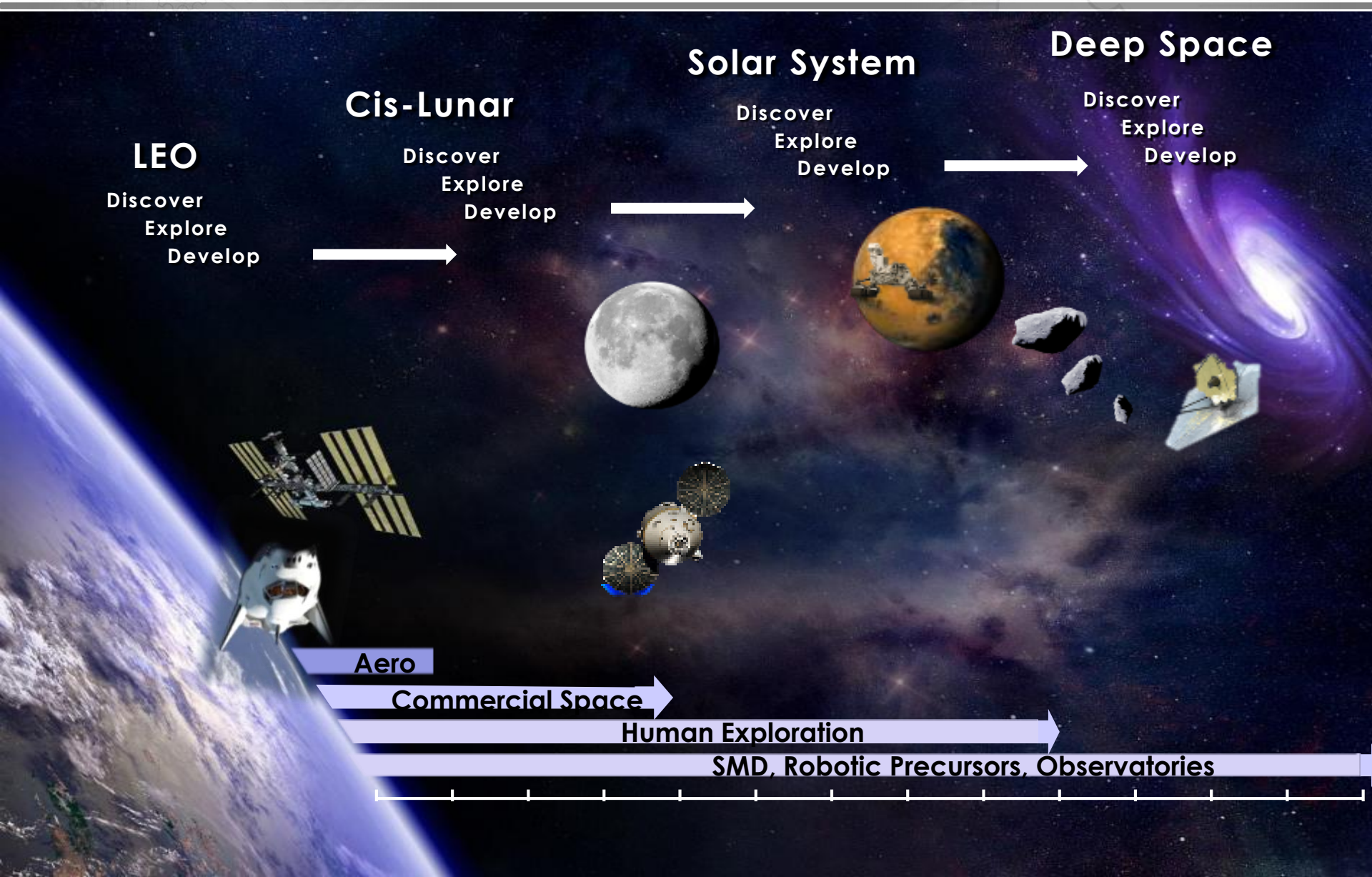


Reinvigorating America's Human Exploration Program

- NASA shall "**lead** an **innovative and sustainable** program of exploration with commercial and international partners to enable **human expansion** across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for **long-term** exploration and utilization, followed by human missions to Mars and other destinations."

NASA Exploration

National Aeronautics and Space Administration



Technology Programs (FY17)

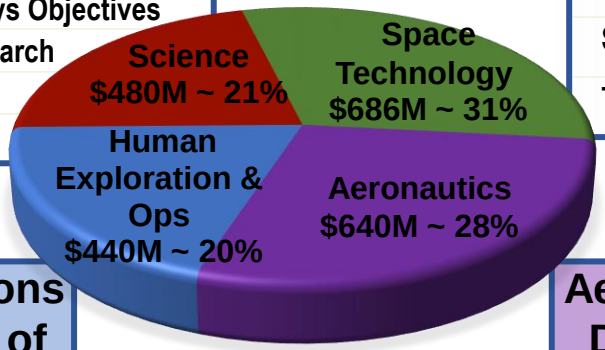
National Aeronautics and Space Administration

Science Mission Directorate – (~$480M of $5.6B ~9%)

- Advanced Component Technology
- Advanced Information Systems Technology
- Astrophysics Research and Analysis
- Europa Technology
- Heliophysics - Tech and Instrument Development for Science
- In-Space Validation of Earth Science Technologies
- Instrument Incubator
- Maturation of Instruments for Solar System Exploration
- Nancy Grace Roman Technology Fellowships
- Planetary Instrument Concepts for Adv of Solar Sys Objectives
- Planetary Science and Tech Through Analog Research
- Strategic Astrophysics Technology
- + Mission-Directed Technology

Space Technology Mission Directorate – ($686M or 100%)

- Centennial Challenges
- Center Innovation Fund
- Flight Opportunities
- Game Changing Development
- NASA Innovative Advanced Concepts
- SBIR/STTR
- Small Spacecraft Technology
- Space Tech Research Grants
- Technology Demonstration Missions



Human Exploration and Operations Mission Directorate – (~ $440M of $9B or ~5%)

- Advanced Exploration Systems
- Space Life and Physical Sciences Research and Applications
  - - Human Research Program
  - - Life and Physical Sciences
- Space Communications and Navigation

Aeronautics Research Mission Directorate – ($640 or 100%)

- Advanced Air Vehicles
- Airspace Operations and Safety
- Integrated Aviation Systems
- Transformative Aeronautics Concepts

JULY 2015

National Aeronautics and Space Administration

NASA TECHNOLOGY ROADMAPS
TECHNOLOGY AREA BREAKDOWN STRUCTURE

2015

TA 1 LAUNCH PROPULSION SYSTEMS

1.1 SOLID ROCKET PROPULSION SYSTEMS
- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies
- Integrated Solid Motor Systems
- Liner and Insulation

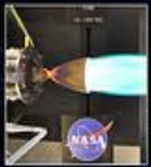
1.2 LIQUID ROCKET PROPULSION SYSTEMS
- LH2/LOX Based
- RP/LOX Based
- CH4/LOX Based
- Detonation Wave Engines - Closed Cycle
- Propellants
- Fundamental Liquid Propulsion Technologies

1.3 AIR BREATHING PROPULSION SYSTEMS
- Turbine Based Combined Cycle
- Rocket Based Combined Cycle
- Detonation Wave Engines - Open Cycle
- Turbine Based Jet Engines
- Ramjet and Scramjet Engines
- Deeply Cooled Air Cycles
- Air Collection and Enrichment Systems
- Fundamental Air Breathing Propulsion Technologies

1.4 ANCILLARY PROPULSION SYSTEMS
- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management and Sensors
- Pyro and Separation Systems
- Fundamental Ancillary Propulsion Technologies

1.5 UNCONVENTIONAL AND OTHER PROPULSION SYSTEMS
- Ground Launch Assist
- Air Launch and Drop Systems
- Space Tether Assist
- Beamed Energy and Energy Addition
- Nuclear
- High Energy Density Materials and Propellants

1.6 BALLOON LAUNCH SYSTEMS
- Super-Pressure Balloon
- Materials
- Pointing Systems
- Telemetry Systems
- Balloon Trajectory Control
- Power Systems
- Mechanical Systems: Launch Systems
- Mechanical Systems: Parachute
- Mechanical Systems: Floatation



TA 2 IN-SPACE PROPULSION TECHNOLOGIES

2.1 CHEMICAL PROPULSION · **2.2 NON-CHEMICAL PROPULSION** · **2.3 ADVANCED (TRL<3) PROPULSION TECHNOLOGIES** · **2.4 SUPPORTING TECHNOLOGIES**

TA 3 SPACE POWER AND ENERGY STORAGE

3.1 POWER GENERATION · **3.2 ENERGY STORAGE** · **3.3 POWER MANAGEMENT AND DISTRIBUTION** · **3.4 CROSS CUTTING TECHNOLOGY**

TA 4 ROBOTICS AND AUTONOMOUS SYSTEMS

4.1 SENSING AND PERCEPTION · **4.2 MOBILITY** · **4.3 MANIPULATION** · **4.4 HUMAN-SYSTEM INTERACTION** · **4.5 SYSTEM-LEVEL AUTONOMY** · **4.6 AUTONOMOUS RENDEZVOUS AND DOCKING** · **4.7 SYSTEMS ENGINEERING**

TA 5 COMMUNICATIONS, NAVIGATION, AND ORBITAL DEBRIS TRACKING AND CHARACTERIZATION SYSTEMS

5.1 OPTICAL COMMUNICATIONS AND NAVIGATION · **5.2 RADIO FREQUENCY COMMUNICATIONS** · **5.3 INTERNETWORKING** · **5.4 POSITION, NAVIGATION, AND TIMING** · **5.5 INTEGRATED TECHNOLOGIES** · **5.6 REVOLUTIONARY CONCEPTS** · **5.7 ORBITAL DEBRIS TRACKING AND CHARACTERIZATION**

TA 6 HUMAN HEALTH, LIFE SUPPORT, AND HABITATION SYSTEMS

6.1 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS AND HABITATION SYSTEMS · **6.2 EXTRAVEHICULAR ACTIVITY SYSTEMS** · **6.3 HUMAN HEALTH AND PERFORMANCE** · **6.4 ENVIRONMENTAL MONITORING, SAFETY, AND EMERGENCY RESPONSE** · **6.5 RADIATION**

TA 7 HUMAN EXPLORATION DESTINATION SYSTEMS

7.1 IN-SITU RESOURCE UTILIZATION · **7.2 SUSTAINABILITY AND SUPPORTABILITY** · **7.3 HUMAN MOBILITY SYSTEMS** · **7.4 HABITAT SYSTEMS** · **7.5 MISSION OPERATIONS AND SAFETY** · **7.6 CROSS-CUTTING SYSTEMS**

TA 8 SCIENCE INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS

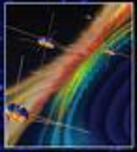
8.1 REMOTE SENSING INSTRUMENTS AND SENSORS · **8.2 OBSERVATORIES** · **8.3 IN-SITU INSTRUMENTS AND SENSORS**

TA 9 ENTRY, DESCENT, AND LANDING SYSTEMS

9.1 AEROASSIST AND ATMOSPHERIC ENTRY · **9.2 DESCENT AND TARGETING** · **9.3 LANDING** · **9.4 VEHICLE SYSTEMS**

TA 10 NANOTECHNOLOGY

10.1 ENGINEERED MATERIALS AND STRUCTURES · **10.2 ENERGY STORAGE, POWER GENERATION, AND POWER DISTRIBUTION** · **10.3 PROPULSION** · **10.4 SENSORS, ELECTRONICS, AND DEVICES**



TA 11 MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING

11.1 COMPUTING · **11.2 MODELING** · **11.3 SIMULATION** · **11.4 INFORMATION PROCESSING**

TA 12 MATERIALS, STRUCTURES, MECHANICAL SYSTEMS AND MANUFACTURING

12.1 MATERIALS · **12.2 STRUCTURES** · **12.3 MECHANICAL SYSTEMS** · **12.4 MANUFACTURING** · **12.5 CROSS-CUTTING**

TA 13 GROUND AND LAUNCH SYSTEMS

13.1 OPERATIONAL LIFE CYCLE · **13.2 ENVIRONMENTAL PROTECTION AND GREEN TECHNOLOGIES** · **13.3 RELIABILITY AND MAINTAINABILITY** · **13.4 MISSION SUCCESS**

TA 14 THERMAL MANAGEMENT SYSTEMS

14.1 CRYOGENIC SYSTEMS · **14.2 THERMAL CONTROL SYSTEMS** · **14.3 THERMAL PROTECTION SYSTEMS**

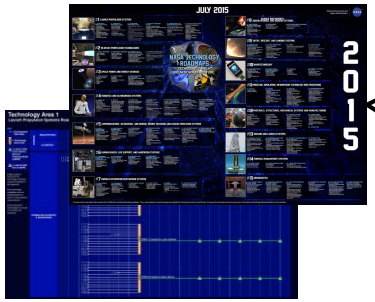
TA 15 AERONAUTICS

15.1 SAFE, EFFICIENT GROWTH IN GLOBAL AVIATION · **15.2 INNOVATION IN COMMERCIAL SUPERSONIC AIRCRAFT** · **15.3 ULTRA-EFFICIENT COMMERCIAL VEHICLES** · **15.4 TRANSITION TO LOW-CARBON PROPULSION** · **15.5 REAL-TIME SYSTEM-WIDE SAFETY ASSURANCE** · **15.6 ENABLE ASSURED MACHINE AUTONOMY FOR AVIATION**

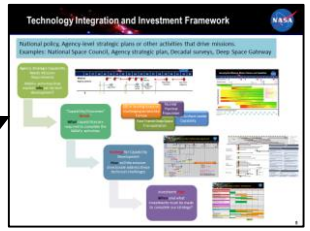
Background

2012 Space Technology Roadmaps & Technology Area Breakdown Structure

2015 NASA Technology Roadmaps & Technology Area Breakdown Structure



MD Strategic Technology Development Frameworks



2020 NASA Technology Taxonomy

The 2020 update of the taxonomy is a refinement of the 2015 edition to make it more discipline based and to realign like technologies (Example: TX01 Propulsion includes both space and atmospheric systems)

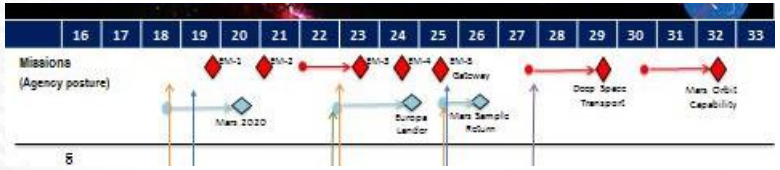
Strategic Integration Framework

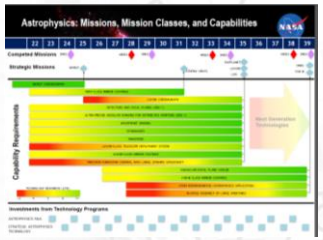
National Aeronautics and Space Administration

National policy, agency-level strategic plans or other activities that drive missions.

Examples: National Space Council, agency strategic plan, decadal surveys, Exploration Mission

Mission/ Outcomes "Why"





Technical Challenges "What"

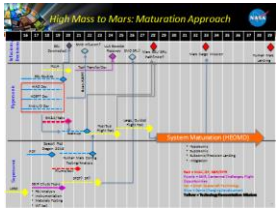
100 m landing footprint, challenging terrains like Europa

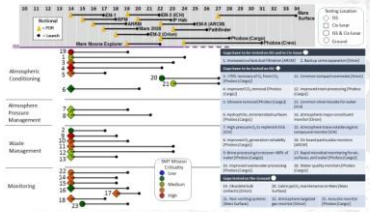
Nuclear Thermal Propulsion

Fast Transit Deep Space Transportation

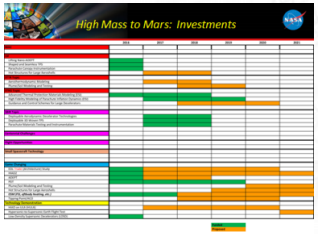
~20 MT to Surface Lander Capability

Strategy for Development "How"





Technology Investment "When"



Framework End-State

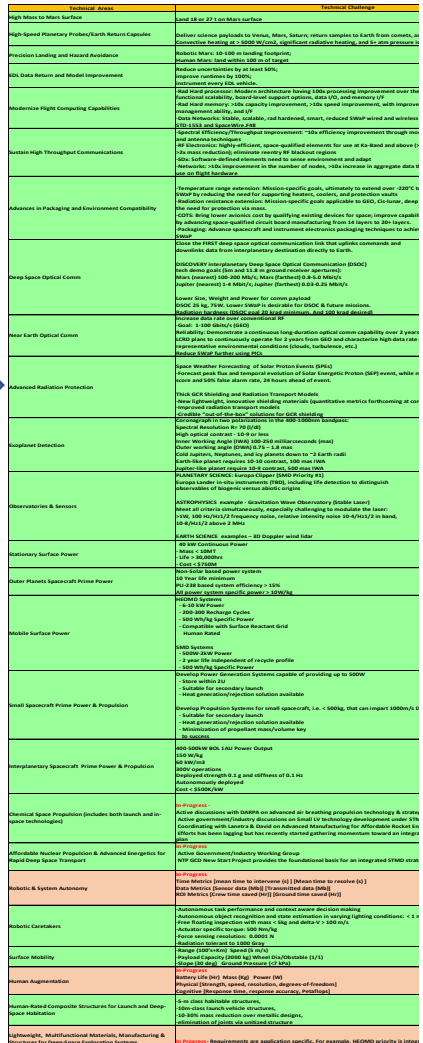
Step 1
NASA Strategic Goals

~25

- Efficient, safe Air Transportation
- Innovation in Commercial Supersonic Aircraft
- Ultra-Efficient Subsonic Transports
- Safe, Quiet and Affordable Vertical Lift Air Vehicles
- In-Time System-Wide Safety Assurance
- Assured Autonomy for Aviation Transformation
- How is the global Earth system changing?
- Understanding what drives the constant change we observe on our sun?
- Expand Capabilities Through Robotic Exploration and Discovery
- Enable Humans to Live and Work in Space and on Planetary Surfaces
- Increase Access to Planetary Surfaces
- Enable Safe and Efficient Transportation Into and Through Space
- Long-duration crewed missions beyond low Earth orbit
- Conduct Human Exploration in Deep Space, Including to the Surface of the Moon

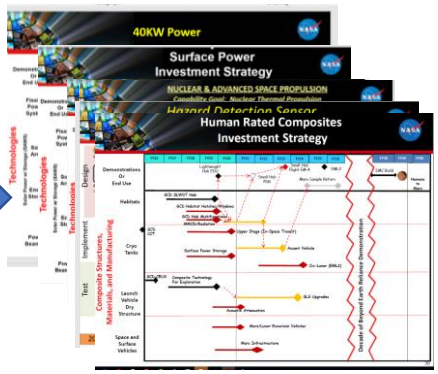
- Etc.

Step 2
Identify Strategic Technical Challenges
~150



Technical Areas	Technical Challenge
High Mass to Mars Surface	Land 18 or 27 t on Mars surface
High-Speed Planetary Probes/Earth Return Capsules	Deliver science payloads to Venus, Mars, Saturn; return samples to Earth from comets, a Convective heating at > 5000 W/cm2, significant radiative heating, and 5+ atm pressure i
Precision Landing and Hazard Avoidance	Robotic Mars: 10-100 m landing footprint; Human Mars: land within 100 m of target
EDL Data Return and Model Improvement	Reduce uncertainties by at least 50%; improve runtimes by 100%; instrument every EDL vehicle.
Modernize Flight Computing Capabilities	-Rad Hard processor: Modern architecture having 100x processing improvement over the functional scalability, board-level support options, data I/O, and memory I/F -Rad Hard memory: >10x capacity improvement, >10x speed improvement, with improve management ability, and I/F -Data Networks: Stable, scalable, rad hardened, smart, reduced SWaP wired and wireless STD-1553 and SpaceWire /1G
Sustain High Throughput Communications	-Spectral Efficiency/Throughput improvement: ~10x efficiency improvement through mo and antenna techniques -RF Electronics: highly-efficient, space-qualified elements for use at Ka-Band and above (>3 -3x mass reduction); eliminate reentry RF blackout regions -SDs: Software-defined elements need to sense environment and adapt -Networks: >10x improvement in the number of nodes, >10x increase in aggregate data t use on flight hardware
Advances in Packaging and Environment Compatibility	-Temperature range extension: Mission-specific goals, ultimately to extend over -220°C t SWaP by reducing the need for supporting heaters, coolers, and protection vaults -Radiation resistance extension: Mission-specific goals applicable to GEO, Cis-lunar, deep the need for protection via mass. -COTS: Bring lower avionics cost by qualifying existing devices for space; improve capabil by advancing space-qualified circuit board manufacturing from 14 layers to 20+ layers. -Packaging: Advance spacecraft and instrument electronics packaging techniques to achie SWaP
Deep Space Optical Comm	Close the FIRST deep space optical communication link that uplinks commands and downlinks data from interplanetary destination directly to Earth. DISCOVERY Interplanetary Deep Space Optical Communication (DSOC) Inch demo goals (lm and 11.8 m ground receiver apertures): Mars (nearest) 100-200 MB/s; Mars (farthest) 0.8-5.0 MBit/s Jupiter (nearest) 1-4 MBit/s; Jupiter (farthest) 0.03-0.25 MBit/s Lower Size, Weight and Power for comm payload DSOC 25 kg, 75W. Lower SWaP is desirable for DSOC & future missions. Radiation hardness DSOC cual 10 krad minimum. And 100 krad desired
Near Earth Optical Comm	Increase data rate over conventional RF -Goal: 1-100 Gbits/s (GEO) Reliability: Demonstrate a continuous long-duration optical comm capability over 2 years LCRD plans to continuously operate for 2 years from GEO and characterize high data rate representative environmental conditions (clouds, turbulence, etc.) Reduce SWaP further using PICs
Advanced Radiation Protection	Space Weather Forecasting of Solar Proton Events (SPEs) -Forecast peak flux and temporal evolution of Solar Energetic Proton (SEP) event, while a score and 60% false alarm rate, 24 hours ahead of event. Thick GCR Shielding and Radiation Transport Models -New lightweight, innovative shielding materials (quantitative metrics forthcoming at co -Validated radiation transport models -Credible "out-of-the-box" solutions for GCR shielding
Exoplanet Detection	Coronograph in two polarizations in the 400-1000nm bandpass: Spectral Resolution R> 70 (UV) High optical contrast - 10-9 or less Inner Working Angle (IWA): 100-250 milliarcseconds (mas) Outer working angle (OWA) 0.75 – 1.8 mas Cold Jupiters, Neptunes, and icy planets down to ~2 Earth radii Earth-like planet requires 10-10 contrast, 100 mas IWA Jupiter-like planet require 10-9 contrast, 100 mas IWA
Observatories & Sensors	PLANETARY SCIENCE: Europa Clipper (SMD Priority #1) Europa Lander in-situ instruments (TBD), including life detection to distinguish observables of biogenic versus abiotic origins ASTROPHYSICS example - Gravitation Wave Observatory (Stable Laser) Meet all criteria simultaneously, especially challenging to modulate the laser: ~1W, 100 Hz/Hz1/2 frequency noise, relative intensity noise 10-4/Hz1/2 in band, 10-6/Hz1/2 above 2 MHz EARTH SCIENCE examples – 3D Doppler wind lidar
Stationary Surface Power	- 40 kW Continuous Power - Mass < 10MT - Life > 30,000hrs - Cost < $750M
Outer Planets Spacecraft Prime Power	Non-Solar based power system 10 Year life minimum Pu-238 based system efficiency > 15% All power system specific power > 10W/kg
Mobile Surface Power	HEOMD Systems - 5-10 kW Power - 200-300 Recharge Cycles - 500 Wh/kg Specific Power - Compatible with Surface Reactant Grid - Human Rated SMD Systems - 500W-2kW Power - 2 year life independent of recycle profile - 500 Wh/kg Specific Power
Small Spacecraft Prime Power & Propulsion	Develop Power Generation Systems capable of providing up to 500W - Store within 2U - Suitable for secondary launch - Heat generation/rejection solution available Develop Propulsion Systems for small spacecraft, i.e. < 500kg, that can impart 1000m/s
Interplanetary Spacecraft Prime Power & Propulsion	400-500kW BOL 1AU Power Output 150 W/kg 50 kW/m3 300V operations Deployed strength 0.1 g and stiffness of 0.1 Hz Autonomously deployed Cost < $500K/kW
Chemical Space Propulsion (includes both launch and in-space technologies)	In Progress - Active discussions with DARPA on advanced air breathing propulsion technology & strate Active government/industry discussions on Small LV technology development under STN Coordinating with Lanetra & David on Advanced Manufacturing for Affordable Rocket En Efforts has been lagging but has recently started gathering momentum toward an integra plan
Affordable Nuclear Propulsion & Advanced Energetics for NPP GCD New Start Project provides the foundational basis for an integrated STMD strat	In Progress - Active Government/Industry Working Group
Robotic & System Autonomy	In Progress Time Metrics [mean time to intervene (s)] [Mean time to resolve (s)] Data Metrics [Sensor data (Mb)] [Transmitted data (Mb)] ROI Metrics [Crew time saved (Hr)] [Ground time saved (Hr)]
Robotic Caretakers	-Autonomous task performance and context aware decision making -Autonomous object recognition and state estimation in varying lighting conditions: < 1 c -Free floating inspection with mass < 5kg and delta-V > 100 m/s -Actuator specific torque: 500 Nm/kg -Force sensing resolution: 0.0001 N -Radiation tolerant to 1000 Gray
Surface Mobility	-Range (100's+Km) Speed (5 m/s) -Payload Capacity (2000 kg) Wheel Dia/Obstable (1/1) -Slope (30 deg) Ground Pressure (<7 kPa)
Human Augmentation	In Progress Battery Life (hr) Mass (Kg) Power (W) Physical [Strength, speed, resolution, degrees-of-freedom] Cognitive [Response time, response accuracy, Petaflops]
Human-Rated Composite Structures for Launch and Deep-Space Habitation	-5-m class habitable structures, -10m-class launch vehicle structures, -10-30% mass reduction over metallic designs, -elimination of joints via unitized structure
Lightweight, Multifunctional Materials, Manufacturing &	In Progress- Requirements are application specific. For example, HEOMD priority is inte

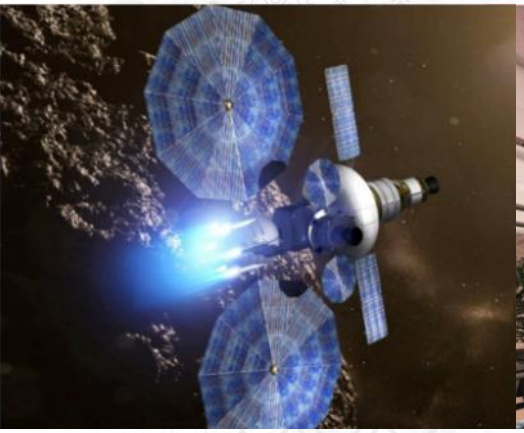
Step 3
Develop Investment Strategies
~150



Step 4
Technology Investments
~1500

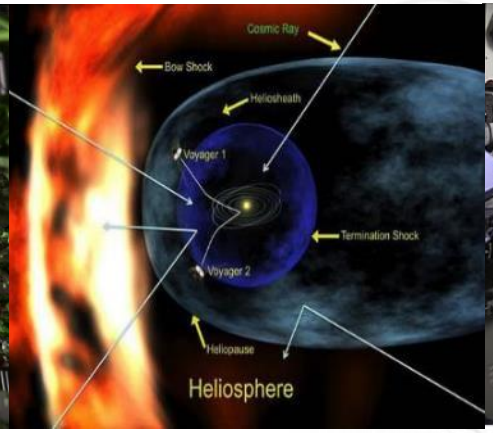
Solving Technology Challenges

National Aeronautics and Space Administration



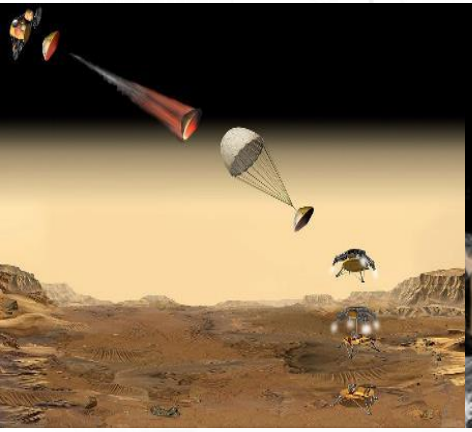
Advanced Propulsion Power

Closed Loop Life Support

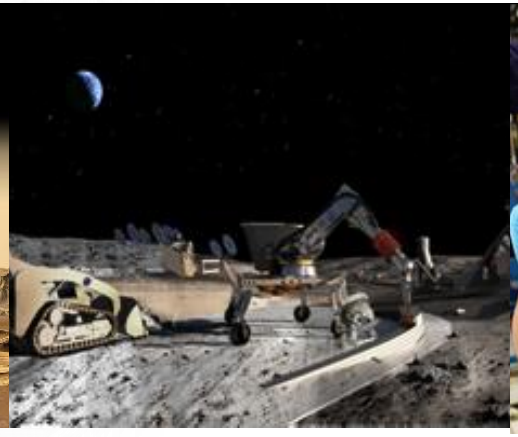


Radiation Protection

Human System Research



Entry, Descent, Landing



In-situ Resource Utilization

Additive Manufacturing

Autonomy Robotics

Commercial Space Industry

National Aeronautics and
Space Administration


NASA
EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION