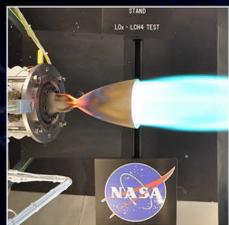


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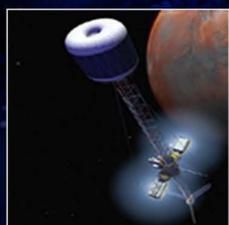
TA1 LAUNCH PROPULSION SYSTEMS

- 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**
 - L₂/LOX Based
 - RZ/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



TA2 IN-SPACE PROPULSION TECHNOLOGIES

- 2.1 CHEMICAL PROPULSION**
 - Liquid Storable
 - Liquid Cryogenic
 - Gels
 - Solids
 - Hybrid
 - Cold Gas/Warm Gas
 - Micropropulsion
- 2.2 NON-CHEMICAL PROPULSION**
 - Electric Propulsion
 - Solar and Drag Sail Propulsion
 - Thermal Propulsion
 - Tether Propulsion
- 2.3 ADVANCED (TRL<3) PROPULSION TECHNOLOGIES**
 - Beamed Energy Propulsion
 - Electric Sail Propulsion
 - Fusion Propulsion
 - High-Energy-Density Materials
 - Antimatter Propulsion
 - Advanced Fission
 - Breakthrough Propulsion
- 2.4 SUPPORTING TECHNOLOGIES**
 - Engine Health Monitoring and Safety
 - Propellant Storage and Transfer Technologies
 - Fusion Propulsion
 - Heat Rejection
 - Power



TA3 SPACE POWER AND ENERGY STORAGE

- 3.1 POWER GENERATION**
 - Energy Harvesting
 - Chemical
 - Solar
 - Radioisotope
 - Fission
 - Fusion
- 3.2 ENERGY STORAGE**
 - Batteries
 - Flywheels
 - Regenerative Fuel Cells
 - Capacitors
- 3.3 POWER MANAGEMENT AND DISTRIBUTION**
 - Fault Detection, Isolation, and Recovery
 - Management and Control
 - Distribution and Transmission
 - Wireless Power Transmission
 - Conversion and Regulation
- 3.4 CROSS CUTTING TECHNOLOGY**
 - Analytical Tools
 - Fault Detection Impact
 - Multi-Functional Structures
 - Alternative Fuels



TA4 ROBOTICS AND AUTONOMOUS SYSTEMS

- 4.1 SENSING AND PERCEPTION**
 - 3D Sensing
 - State Estimation
 - Onboard Mapping
 - Object, Event, and Activity Recognition
 - Force and Tactile Sensing
 - Onboard Science Data Analysis
- 4.2 MOBILITY**
 - Extreme-Terrain Mobility
 - Below-Surface Mobility
 - Above-Surface Mobility
 - Small-Body and Microgravity Mobility
 - Surface Mobility
 - Robot Navigation
 - Collaborative Mobility
 - Mobility Components
- 4.3 MANIPULATION**
 - Manipulator Components
 - Dexterous Manipulation
 - Modeling of Contact Dynamics
 - Mobile Manipulation
 - Collaborative Manipulation
 - Sample Acquisition and Handling
 - Grappling
- 4.4 HUMAN SYSTEM INTERACTION**
 - Multi-Modal Interaction
 - Supervisory Control
 - Proximate Interaction
 - Intent Recognition and Reaction
 - Distributed Collaboration and Coordination
 - Common and Standard Human-System Interfaces
 - Safety, Trust and Interfacing of Robotic and Human Proximity Operations
 - Remote Interaction
- 4.5 SYSTEM-LEVEL AUTONOMY**
 - System Health Management
 - Activity Planning, Scheduling, and Execution
 - Autonomous Guidance and Control
 - Multi-Agent Coordination
 - Adjustable Autonomy
 - Terrain Relative Navigation
 - Path and Motion Planning with Uncertainty
 - Automated Data Analysis for Decision Making
- 4.6 AUTONOMOUS RENDEZVOUS AND DOCKING**
 - Relative Navigation Sensors
 - GN&C Algorithms
 - Docking and Capture Mechanisms and Interfaces
 - Mission and System Managers for Autonomy and Automation
- 4.7 SYSTEMS ENGINEERING**
 - Modularity, Commonality, and Interfaces
 - Verification and Validation of Complex Adaptive Systems
 - Robot Modeling and Simulation
 - Robot Software
 - Safety and Trust



TA5 COMMUNICATIONS, NAVIGATION, AND ORBITAL DEBRIS TRACKING AND CHARACTERIZATION SYSTEMS

- 5.1 OPTICAL COMMUNICATIONS AND NAVIGATION**
 - Detector Development
 - Large Apertures
 - Propagation
 - Acquisition and Tracking
 - Atmospheric Mitigation
 - Optical Tracking
 - Integrated Photonics
- 5.2 RADIO FREQUENCY COMMUNICATIONS**
 - Spectrum-Efficient Technologies
 - Power-Efficient Technologies
 - Lasers
 - Earth Launch and Re-Entry Communications
 - Antennas
- 5.3 INTERNETWORKING**
 - Disruption-Tolerant Networking
 - Adaptive Network Topology
 - Information Assurance
 - Integrated Network Management
- 5.4 POSITION, NAVIGATION, AND TIMING**
 - Timekeeping and Time Distribution
 - Onboard Auto Navigation and Maneuver
 - Sensors and Vision Processing Systems
 - Relative and Proximity Navigation
 - Auto Precision Formation Flying
 - Autonomous Approach and Landing
- 5.5 INTEGRATED TECHNOLOGIES**
 - Radio Systems
 - Ultra Wideband
 - Cognitive Networks
 - Science from the Communications System
 - Hybrid Optical Communications and Navigation Sensors
 - Superconducting Quantum Interference Filter Microwave Amplifier
 - Reconfigurable Large Apertures
- 5.6 REVOLUTIONARY CONCEPTS AND CHARACTERIZATION**
 - X-Ray Navigation
 - X-Ray Communications
 - Neutrino-Based Navigation and Tracking
 - Quantum Key Distribution
 - Quantum Communications
 - Superconducting Quantum Interference Filter Microwave Amplifier
 - Reconfigurable Large Apertures
- 5.7 ORBITAL DEBRIS TRACKING AND CHARACTERIZATION**
 - Tracking Technologies
 - Characterization Technologies



TA6 HUMAN HEALTH, LIFE SUPPORT, AND HABITATION SYSTEMS

- 6.1 ENVIRONMENTAL MONITORING AND LIFE SUPPORT SYSTEMS AND HABITATION SYSTEMS**
 - Air Revitalization and Management
 - Waste Management
 - Habitation
- 6.2 EXTRAVEHICULAR ACTIVITY SYSTEMS**
 - Pressure Garment
 - Portable Life Support System
 - Power, Avionics, and Software
- 6.3 HUMAN HEALTH AND PERFORMANCE**
 - Medical Diagnosis and Prognosis
 - Long-Duration Health
 - Behavioral Health
 - Human Factors
- 6.4 ENVIRONMENTAL MONITORING, SAFETY, AND EMERGENCY RESPONSE**
 - Sensors: Air, Water, Microbial, and Acoustic
 - Fire Detection, Suppression, and Recovery
 - Protective Clothing and Breathing
 - Remediation
- 6.5 RADIATION**
 - Risk Assessment Modeling
 - Radiation Mitigation and Biological Countermeasures
 - Protection Systems
 - Space Weather Prediction
 - Monitoring Technology



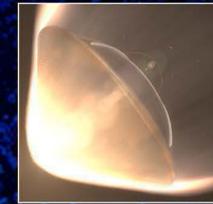
TA7 HUMAN EXPLORATION DESTINATION SYSTEMS

- 7.1 IN-SITU RESOURCE UTILIZATION**
 - Destination Reconnaissance, Prospecting, and Mapping
 - Resource Acquisition, Processing and Production
 - Manufacturing Products and Infrastructure Emplacement
- 7.2 SUSTAINABILITY AND SUPPORTABILITY**
 - Autonomous Logistics Management
 - Maintenance Systems
 - Repair Systems
 - Food Production, Processing, and Preservation
- 7.3 HUMAN MOBILITY SYSTEMS**
 - EVA Mobility
 - Surface Mobility
 - Off-Surface Mobility
- 7.4 HABITAT SYSTEMS**
 - Integrated Habitat Systems
 - Habitat Evolution
 - "Smart" Habitats
 - Artificial Gravity
- 7.5 MISSION OPERATIONS AND SAFETY**
 - Crew Training
 - Planetary Protection
 - Integrated Flight Operations Systems
 - Integrated Risk Assessment Tools
- 7.6 CROSS-CUTTING SYSTEMS**
 - Particulate Contamination Prevention and Mitigation
 - Construction and Assembly



TA8 SCIENCE INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS

- 8.1 REMOTE SENSING INSTRUMENTS AND SENSORS**
 - Detectors and Focal Planes
 - Electronics
 - Optical Components
 - Microwave, Millimeter-, and Submillimeter- Waves
 - Lasers
 - Cryogenic / Thermal
- 8.2 OBSERVATORIES**
 - Mirror Systems
 - Structures and Antennas
 - Distributed Aperture
- 8.3 IN-SITU INSTRUMENTS AND SENSORS**
 - Field and Particle Detectors
 - Fields and Waves
 - In-Situ (other)



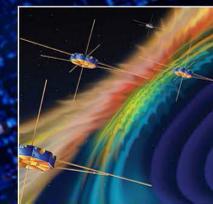
TA9 ENTRY, DESCENT, AND LANDING SYSTEMS

- 9.1 AERODISSIST AND ATMOSPHERIC ENTRY**
 - Thermal Protection Systems for Rigid Decelerators
 - Thermal Protection Systems for Deployable Decelerators
 - Rigid Hypersonic Decelerators
 - Deployable Hypersonic Decelerators
 - Instrumentation and Health Monitoring
 - Entry Modeling and Simulation
- 9.2 DESCENT AND TARGETING**
 - Attached Deployable Decelerators
 - Trailing Deployable Decelerators
 - Supersonic Retropropulsion
 - GN&C Sensors
 - Descent Modeling and Simulation
 - Large Divert Guidance
 - Terrain-Relative Sensing and Characterization
 - Autonomous Targeting
- 9.3 LANDING**
 - Propulsion and Touchdown Systems
 - Egress and Deployment Systems
 - Propulsion Systems
 - Large Body GN&C
 - Small Body Systems
 - Landing Modeling and Simulation
- 9.4 VEHICLE SYSTEMS**
 - Architecture Analysis
 - Separation Systems
 - System Integration and Analysis
 - Atmosphere and Surface Characterization
 - Modeling and Simulation
 - Instrumentation and Health Monitoring
 - GN&C Sensors and Systems



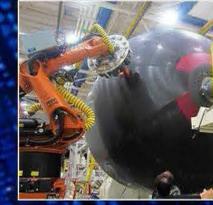
TA10 NANOTECHNOLOGY

- 10.1 ENGINEERED MATERIALS AND STRUCTURES**
 - Lightweight Structures
 - Damage-Tolerant Systems
 - Coatings
 - Adhesives
 - Thermal Protection and Control
- 10.2 ENERGY STORAGE, POWER GENERATION, AND POWER DISTRIBUTION**
 - Energy Storage
 - Power Generation
 - Power Distribution
- 10.3 PROPULSION**
 - Propellants
 - Propulsion Components
 - In-Space Propulsion
- 10.4 SENSORS, ELECTRONICS, AND ACTUATORS**
 - Sensors and Actuators
 - Nanoelectronics
 - Miniature Instruments and Instrument Components



TA11 MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING

- 11.1 COMPUTING**
 - Flight Computing
 - Ground Computing
- 11.2 MODELING**
 - Software Modeling and Model Checking
 - Integrated Hardware and Software Modeling
 - Human-System Performance Modeling
 - Science Modeling
 - Frameworks, Languages, Tools, and Standards
 - Analysis Tools for Mission Design
- 11.3 SIMULATION**
 - Distributed Simulation
 - Integrated System Lifecycle Simulation
 - Simulation-Based Systems Engineering
 - Simulation-Based Training and Decision Support Systems
 - Exascale Simulation
 - Uncertainty Quantification and Nondeterministic Simulation Methods
 - Multiscale, Multiphysics, and Multifidelity Simulation
 - Verification and Validation
- 11.4 INFORMATION PROCESSING**
 - Science, Engineering, and Mission Data Lifecycle
 - Intelligent Data Understanding
 - Semantic Technologies
 - Collaborative Science and Engineering
 - Advanced Mission Systems
 - Cyber Infrastructure
 - Human-System Integration
 - Cyber Security



TA12 MATERIALS, STRUCTURES, MECHANICAL SYSTEMS AND MANUFACTURING

- 12.1 MATERIALS**
 - Lightweight Structural Materials
 - Computationally-Designed Materials
 - Reliability and Sustainment
 - Flexible Material Systems
 - Materials for Extreme Environments
 - Special Materials
- 12.2 STRUCTURES**
 - Lightweight Concepts
 - Design and Certification Methods
 - Reliability and Sustainment
 - Test Tools and Methods
 - Innovative, Multifunctional Concepts
 - Loads and Environments
- 12.3 MECHANICAL SYSTEMS**
 - Deployables, Docking, and Interfaces
 - Mechanism Life Extension Systems
 - Electro-Mechanical, Mechanical, and Micromechanisms
 - Design and Analysis Tools and Methods
 - Reliability, Life Assessment, and Health Monitoring
 - Certification Methods
- 12.4 MANUFACTURING**
 - Manufacturing Processes
 - Intelligent Integrated Manufacturing and Cyber Physical Systems
 - Electronics and Optics Manufacturing Process
 - Sustainable Manufacturing
 - Nondestructive Evaluation and Sensors
- 12.5 CROSS-CUTTING**



TA13 GROUND AND LAUNCH SYSTEMS

- 13.1 OPERATIONAL LIFE-CYCLE AND GREEN TECHNOLOGIES**
 - On-Site Production, Storage, Distribution, and Conservation of Fluids
 - Automated Alignment, Coupling, Assembly, and Transportation Systems
 - Autonomous Command and Control for Integrated Vehicle and Ground Systems
 - Logistics
- 13.2 ENVIRONMENTAL PROTECTION AND GREEN TECHNOLOGIES**
 - Corrosion Prevention, Detection, and Mitigation
 - Environmental Remediation and Site Restoration
 - Preservation of Natural Ecosystems
 - Alternate Energy Prototypes
 - Curatorial Facilities, Planetary Protection, and Clean Rooms
- 13.3 RELIABILITY AND MAINTAINABILITY**
 - Launch Infrastructure
 - Environment-Hardened Materials and Structures
 - On-Site Inspection and Anomaly Detection and Identification
 - Fault Isolation and Diagnostics
 - Prognostics
 - Repair, Mitigation, and Recovery Technologies
 - Communications, Networking, Timing, and Telemetry
 - Decision-Making Tools
- 13.4 MISSION SUCCESS**
 - Range Tracking, Surveillance, and Flight Safety Technologies
 - Landing and Recovery Systems and Components
 - Weather Prediction and Mitigation
 - Robotics and Telerobotics
 - Safety Systems



TA14 THERMAL MANAGEMENT SYSTEMS

- 14.1 CRYOGENIC SYSTEMS**
 - Passive Thermal Control
 - Active Thermal Control
 - Integration and Modeling
- 14.2 THERMAL CONTROL SYSTEMS**
 - Heat Acquisition
 - Heat Transport
 - Heat Rejection and Energy Storage
- 14.3 THERMAL PROTECTION SYSTEMS**
 - Ascent/Entry TPS
 - TPS Modeling and Simulation
 - TPS Sensors and Measurement Systems



TA15 AERONAUTICS

- 15.1 SAFE EFFICIENT, GROWTH IN GLOBAL AVIATION**
 - Improved Efficiency and Hazard Reduction within NextGen Operational Domains
 - System-Wide Safety, Predictability, and Reliability through Full NextGen Functionality
- 15.2 INNOVATION IN COMMERCIAL SUPERSONIC AIRCRAFT**
 - Supersonic Overland Certification Standard Based on Acceptable Sonic Boom Noise
 - Introduction of Affordable, Low-Boom, Low-Noise, and Low-Emission Supersonic Transports
- 15.3 ULTRA-EFFICIENT COMMERCIAL VEHICLES**
 - Achieve Community Goals for Improved Vertical Lift Vehicle Efficiency and Environmental Performance in 2025
 - Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance in 2035
 - Achieve Community Goals for Improved Vehicle Efficiency and Environmental Performance Beyond 2035
- 15.4 TRANSITION TO LOW-CARBON PROPULSION**
 - Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems
 - Initial Introduction of Alternative Propulsion Systems
- 15.5 REAL-TIME SYSTEM-WIDE SAFETY ASSURANCE**
 - Introduction of Advanced Safety Assurance Tools
 - An Integrated Safety Assurance System Enabling Continuous System-Wide Safety Monitoring
 - Automated Safety Assurance Integrated with Real-Time Operations Enabling a Self-Protecting Aviation System
- 15.6 ENABLE ASSURED MACHINE AUTONOMY FOR AVIATION**
 - Initial Autonomy Applications
 - Ability to Fully Certify and Trust Autonomous Systems for NAS Operations

The areas noted in gray above reflect sections of the TABS with no identified technology candidates. This is either because no new technologies were identified for development within the next 20 years, or because the technologies which were previously in this section are now being addressed elsewhere in the roadmaps.