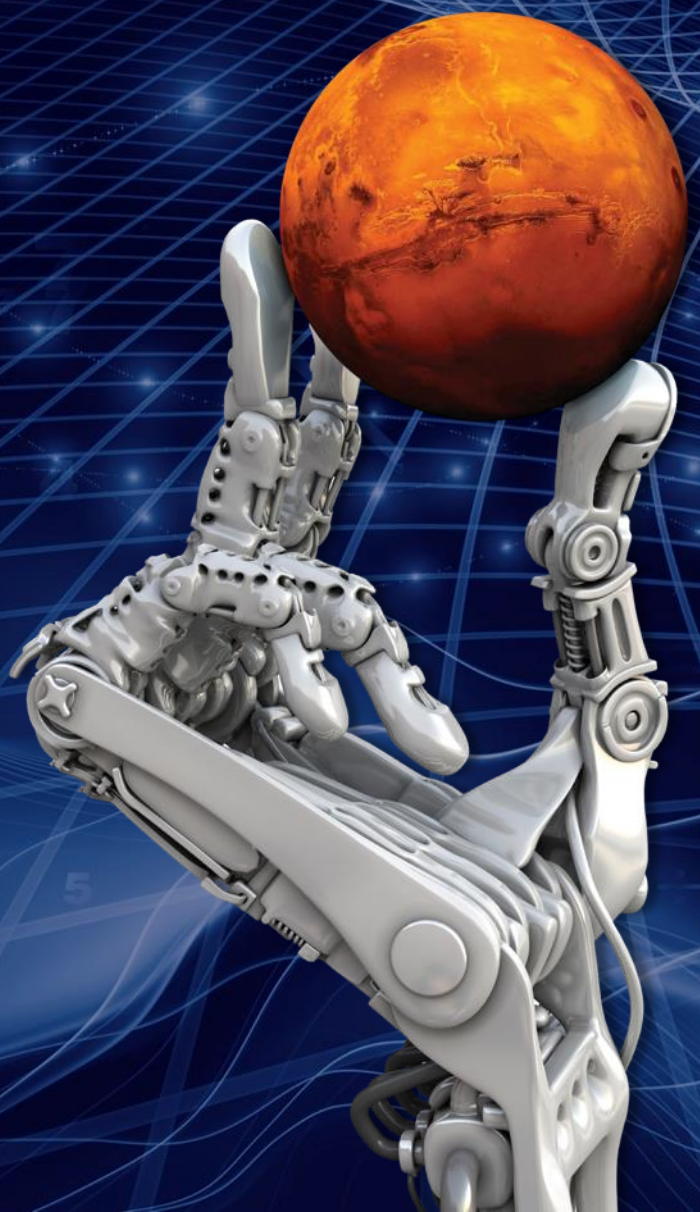
National Aeronautics and Space Administration



Update on OCT Activities

NAC TI&E

David W. Miller
NASA Chief Technologist

Nov 10, 2015

Outline

- **Agency Integration/Architecture**
- **Space S&T Partnership Forum**
- **OCT Updates**
- **Emerging Commercial Space**

Agency Integration/Architecture – Nov-2015

David Miller and Ellen Stofan

#JOURNEYTOMARS

Elements of the Journey to Mars

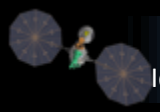
2010 — Now — 2020 — Transition Decade — 2030

LEGEND

- Exploration
- Cross-Cutting (Exploration/Technology/Science)
- Science

First Human Mars Missions

Human LEO Transition & Cis-Lunar Habitat
Long duration human health & habitation build-up including validation for Mars transit distances



Mars Robotic Precursors
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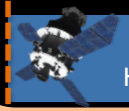


Asteroid Redirect Mission
Human operations in deep space

Orion
Enabling Crew Operations in Deep Space

Space Launch System
Traveling beyond low Earth orbit

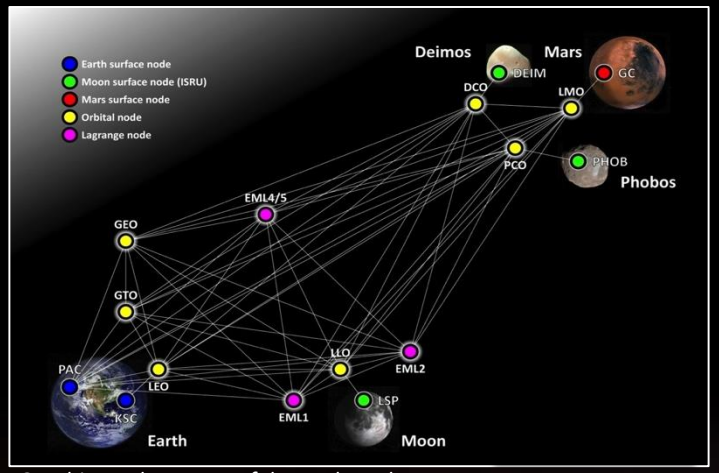
Commercial Cargo and Crew
US companies provide affordable access to low earth orbit

International Space Station
Mastering Long duration stays in space

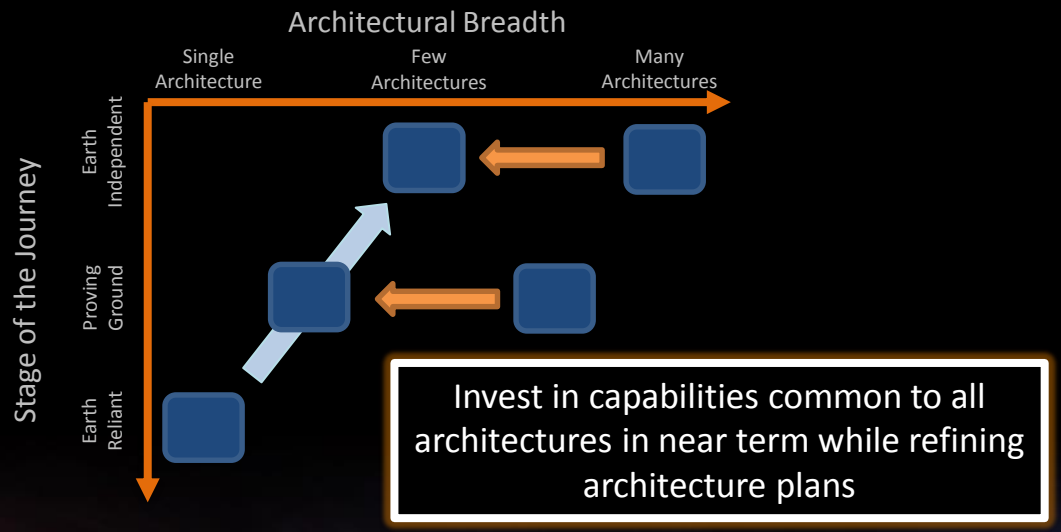
Mars Exploration Program
MRO, Curiosity, MAVEN, InSight, Mars 2020. Observing Mars and Exploring the Surface

#JOURNEYTOMARS

Resilient Architectures for Mars Exploration



Graphic used courtesy of de Weck et al



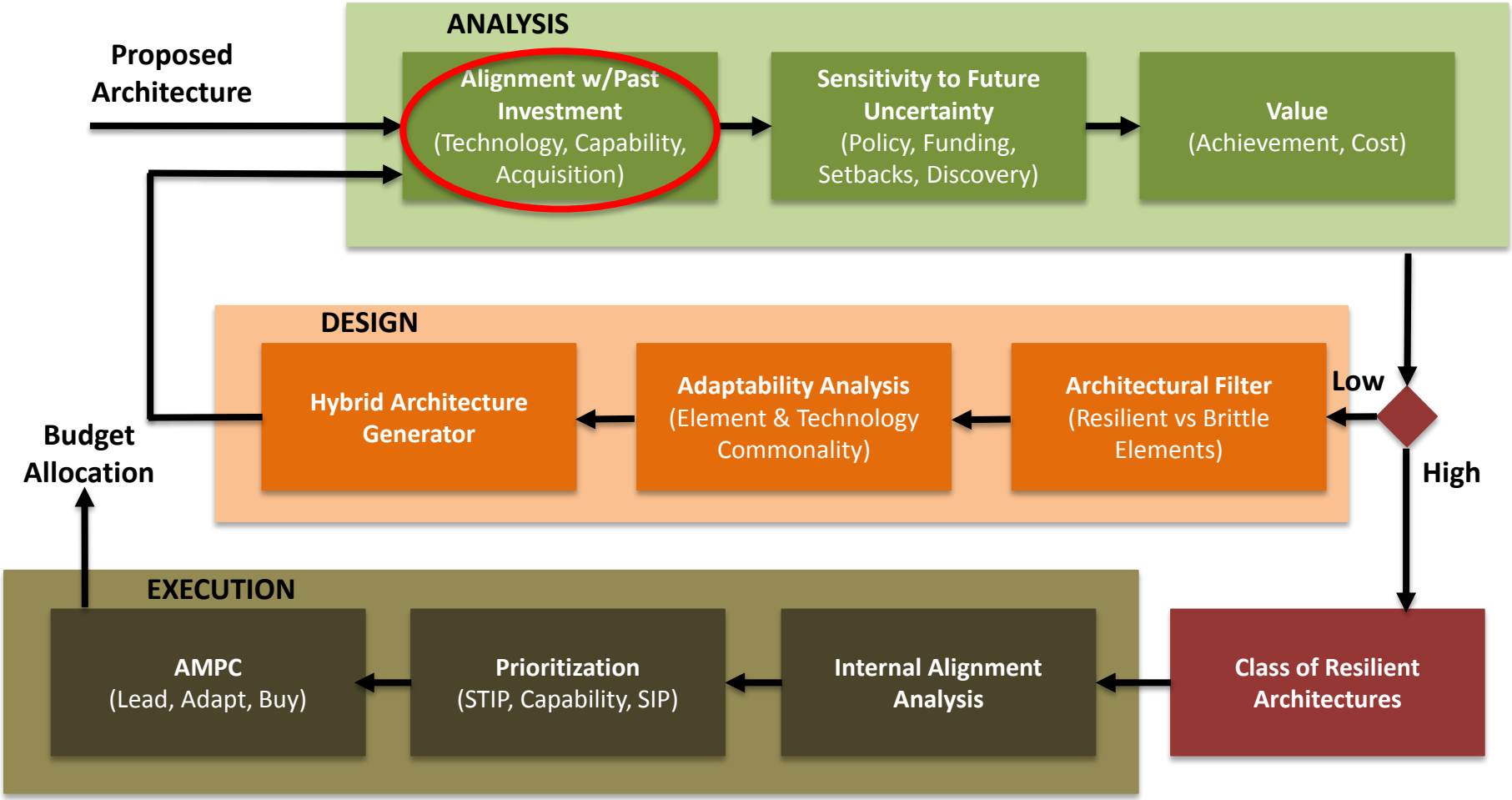
- There are many different architectures and implementation approaches that can be employed on the Journey to Mars
- The first step of each Journey to Mars architecture is the same – develop/validate common required Mars mission capabilities in the 2020s
- The NASA Mission Directorates are collaborating to define a resilient class of architectures for the Journey to Mars in the 2030s
- Concurrently, they will define missions for the 2020s that reduce the risk for this resilient class of architectures

#JOURNEYTOMARS

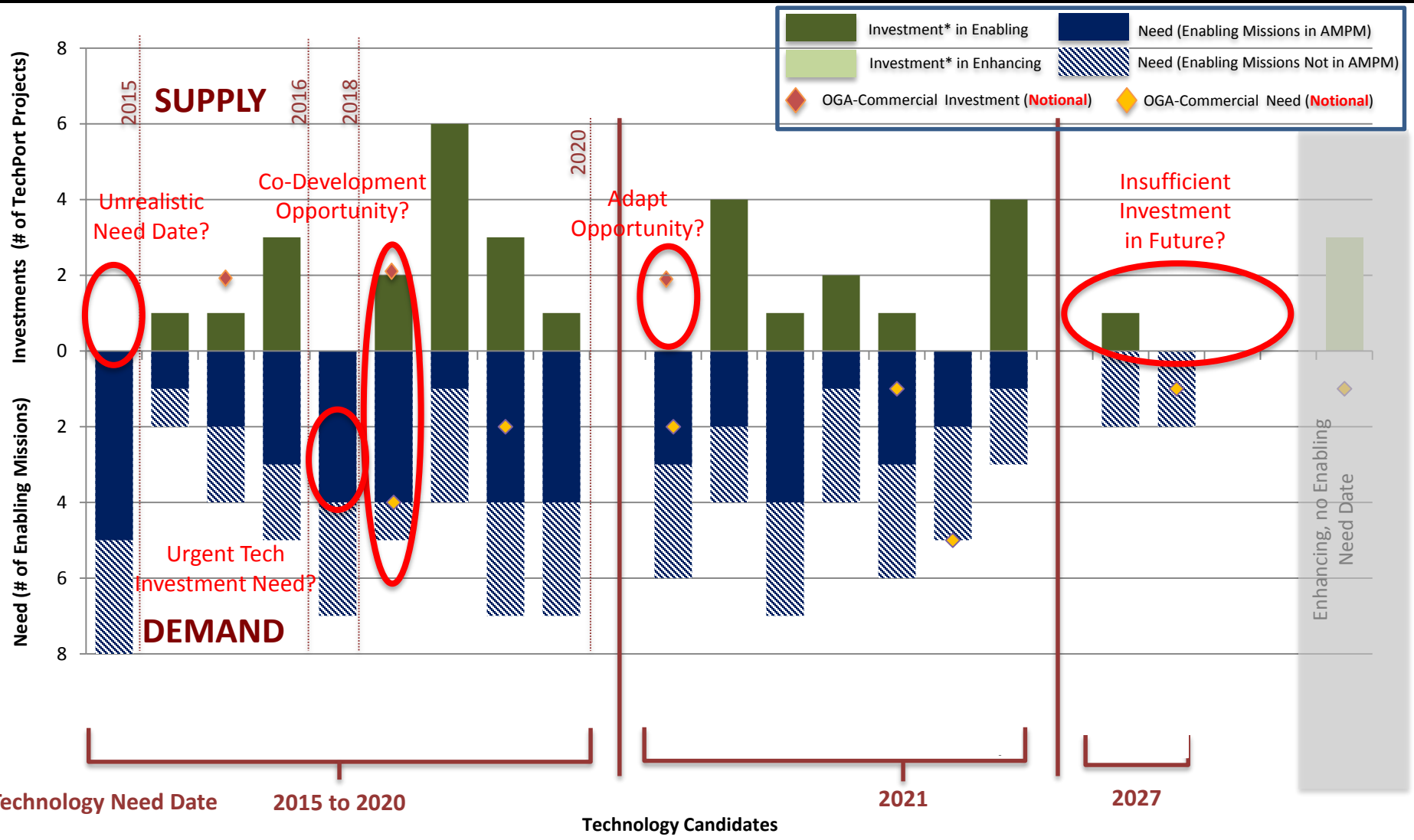
AI/Architecture : Resilient Architecture

National Aeronautics and Space Administration

- OBJECTIVE: To identify a resilient class of architectures, by evaluating sensitivity to future uncertainty, while assessing alignment with past investments



J2M Campaign Need vs Technology Supply



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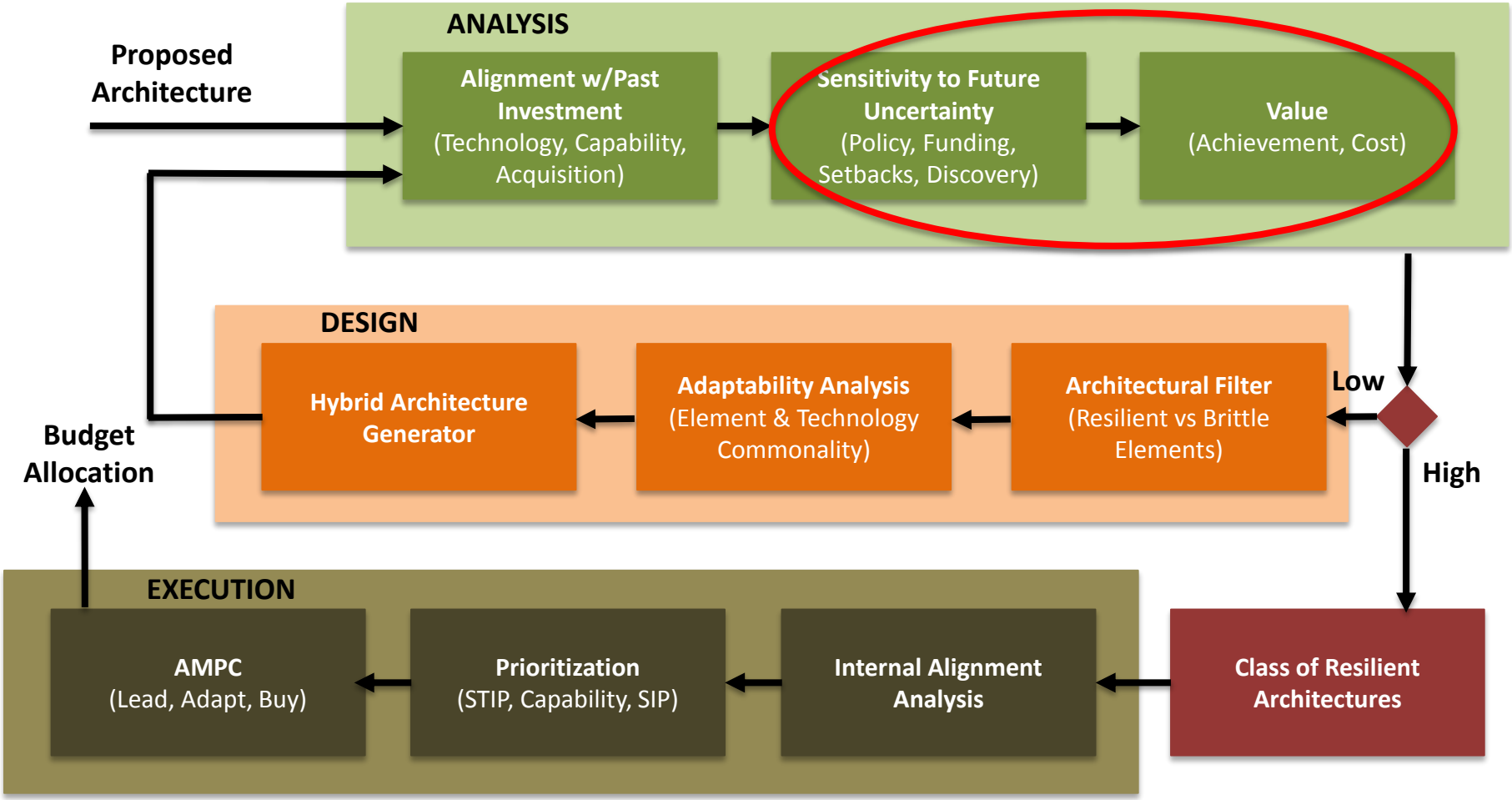
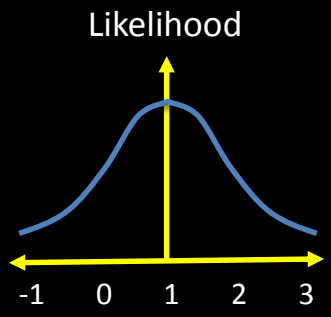
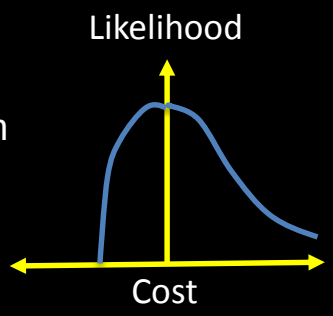


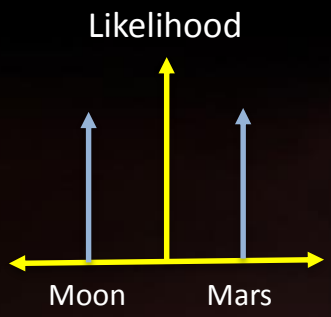
Architectural Value



Resiliency is being robust, or adaptable, to change

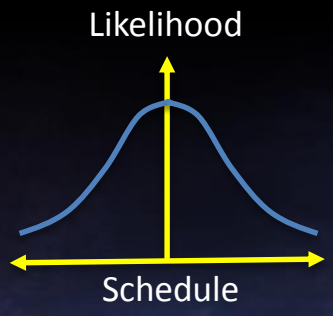
- J2M will span decades while changes occur yearly
- Narrow to set of architectures between which exploration can cost-effectively switch as conditions change

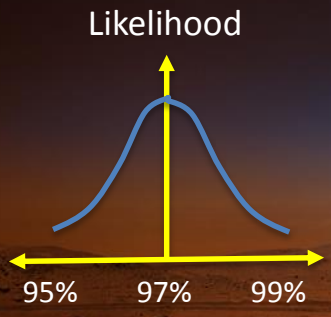




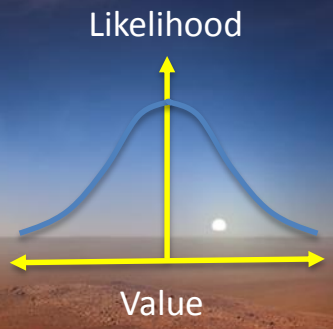
Candidate Architectures

NRC Pathways
Evolvable Mars Campaign
DRA-5
Inspiration Mars
Mars One
Mars Society
Modular Mars Architecture
Space-X Red Dragon
Explore Mars
Mars Cycler





Proactively planning for change is always better than simply reacting to change as it occurs



#JOURNEYTOMARS

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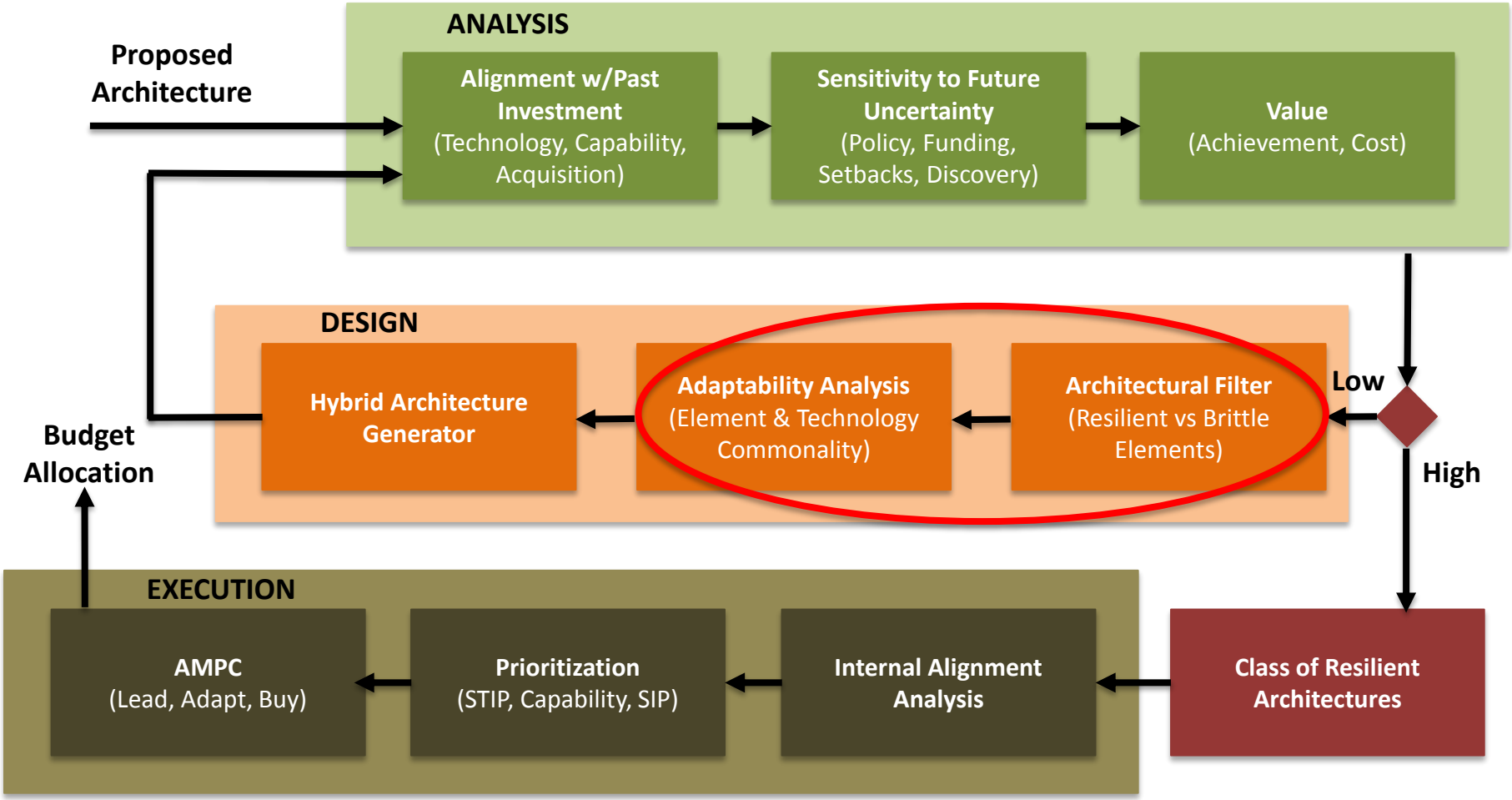

Cross Architecture Analysis

	Launch			Earth Aggregation			Predeploy to Mars			In-Space Crew Propulsion					In-Space Cargo Propulsion					Mars Parking Orbit			Crew Capture at Mars	Propulsion Stage Capture at Mars		Lander Capture at Mars				Mars EDL				Mars Ascent		Earth Return	
	Heavy Lift	120-280 day Launch Centers	30-60 day Launch Centers	LEO	HEO	Cis-Lunar	Crew Return Propulsion Stages	Landers	Crew Return Logistics	ZBO NCPS	ZBO LOx-Methane	Hybrid Storable/SEP	Storable	Modified EUS	ZBO NCPS	SEP	Hybrid Storable/SEP	Storable	Modified EUS	1 Sol	5 Sol	HMO	Propulsive	SEP	Not Applicable	Propulsive	Aerocapture - Dual-Use Launch Shroud	Aerocapture - Dual-Use HIAD	Aerocapture - Dual-Use Aeroshell	Dual-Use Launch Shroud, LOx-Methane SSRP	Dual-Use HIAD, LOx-Methane SSRP	HIAD, LOx-Methane SSRP	Dual-Use Heat Shield, Storable Chemical SSRP	LOx-Methane Ascent, ISRU O2	Storable Chemical Ascent, Rendezvous with Boost Stage in LMO	Propulsive Capture into LDHEO, Rendezvous w/ Orion (11 km/sec entry)	Direct Entry, Orion with Crew to Mars (12 km/sec entry)
DRA 5.0	✓		✓	✓				✓		✓					✓					✓			✓		✓		✓			✓				✓			✓
EMC - Split	✓	✓				✓	✓	✓			✓					✓				✓			✓	✓				✓			✓			✓		✓	
EMC - Hybrid	✓	✓				✓		✓				✓					✓				✓		✓		✓	✓						✓			✓		
JPL (Short Stay)	✓	✓			✓		✓	✓	✓				✓	✓		✓			✓			✓	✓	✓					✓				✓			✓	✓

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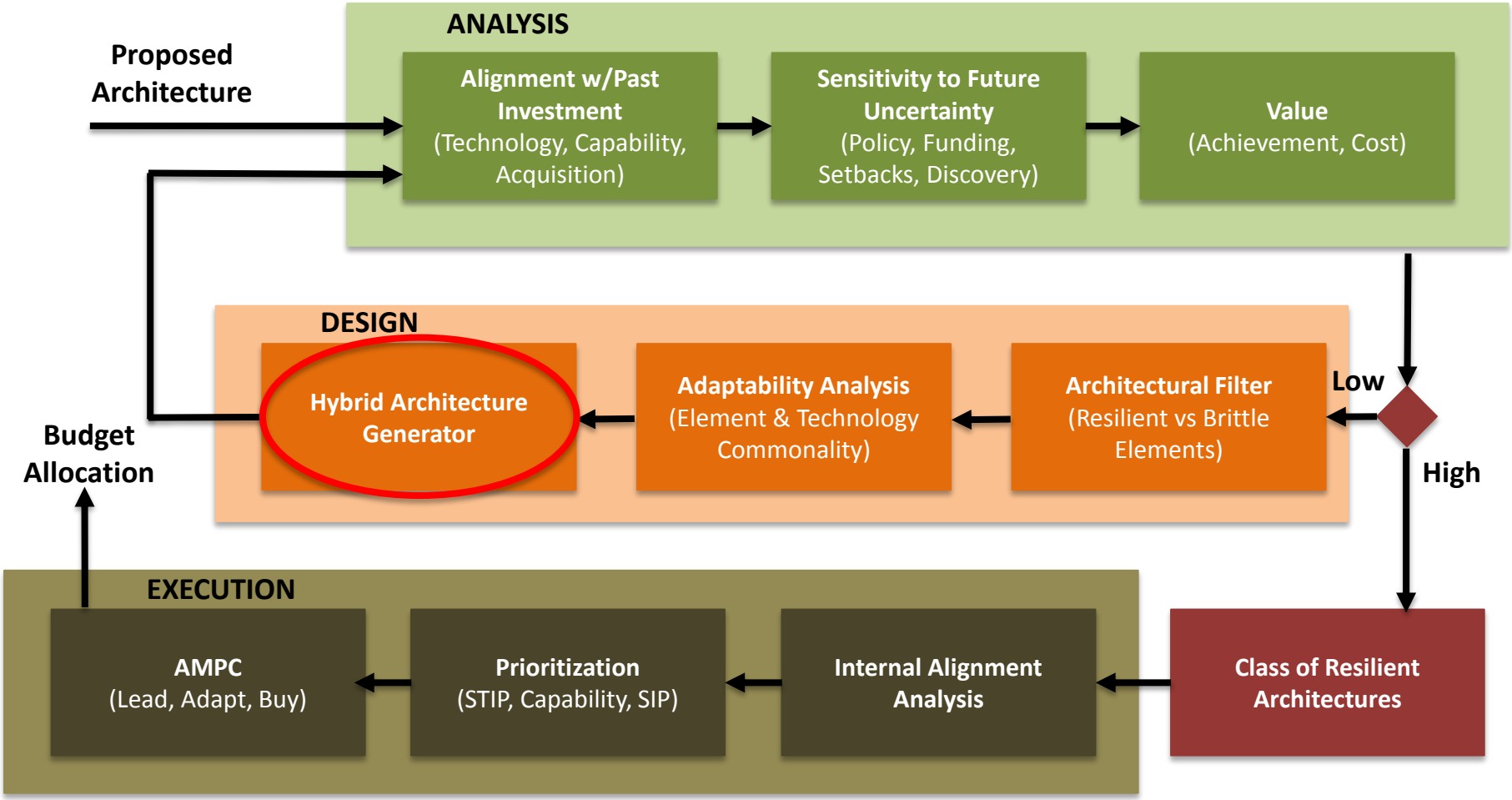


Modularity: Mars Lander Trade - Sizing

Aeroentry Configuration	Supersonic Decelerator	Ascent Stage ISRU	Ascent Crew Size & Destination Orbit		Payload to Surface
Rigid Mid-L/D	Supersonic Retropropulsion	None	1	LMO	1 t
Inflatable	Supersonic Inflatable	Oxidizer Only	2	Mid Orbit	…
Rigid Deployable	Supersonic Parachute	Oxidizer + Fuel	4	1-Sol	3 – 4 t
…	…	…	6+	5-Sol	18 t
					27 t
					40 t

Increased No. of Landers & Complexity

Drives Lander Payload

Current Robotic State-of-the-Art

Potential Human Minimum Ascent Stage

- One crew to LMO
- No pressure vessel
- Full LOX/CH_4 ISRU

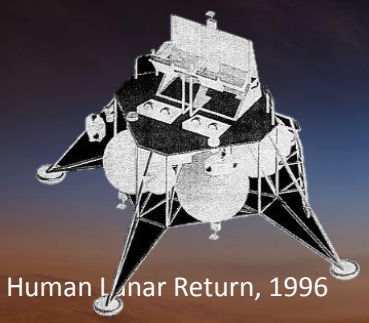
Other Potential Trades:

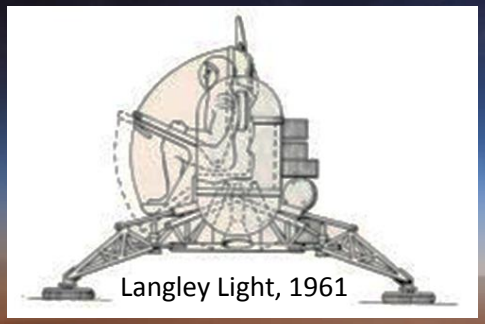
Reusability: None, Partial (engines, tanks, etc.), Full
Propellant Selection

Other Orbit Considerations:

Phasing for departure
Inclination targeting
In-space transportation

Similar to minimal, single stage lunar vehicles:


Human Lunar Return, 1996


Langley Light, 1961


Langley Lightest, 1961

Trades | Identified Options | Notional Implementation | Potential Minimum Ascent Stage | … Other Options

#JOURNEYTOMARS

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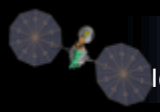

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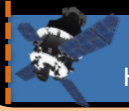

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International Space Station
Mastering Long duration stays in space

Mars Exploration Program
MRO, Curiosity, MAVEN, InSight, Mars 2020. Observing Mars and Exploring the Surface

#JOURNEYTOMARS

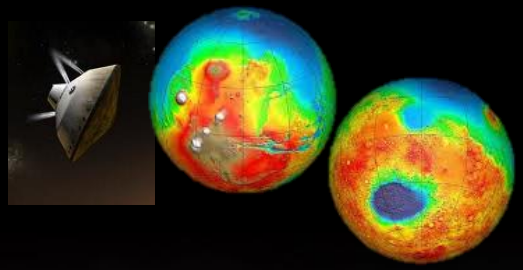
What We've Learned and Still Need to Learn at Mars in the 2020's

Orbital environment and operations

Learned:
- Deep space navigation
- Orbit transfer near low-gravity bodies
- Gravity assist
- Aero-braking
- Gravitational potential
- Mars' moons characteristics
- ISRU potential

To Learn:
- Return flight from Mars to Earth
- Autonomous Rendezvous & Docking
- ISRU feasibility
- Resource characterization of Mars moons
- High-power SEP

Capture, EDL & Ascent at Mars



Learned:
- Spatial/temporal temperature variability
- Density and composition variability
- Storm structure, duration and intensity
- 1 mT Payload
- ~10 km Accuracy

To Learn:
- Ascent from Mars
- Large mass EDL
- Precision EDL
- Aero-capture
- Site topography and roughness
- Long-term atmospheric variability

Surface Operations at Mars

Learned:
- Water once flowed and was stable
- Global topography: elevation and boulder distributions
- Remnant magnetic field
- Dust impacts on Solar Power / Mechanisms
- Radiation dose
- Global resource distribution
- Relay strategies, operations cadence

To Learn:
- Landing site resource survey
- Dust effects on human health, suits & seals
- Rad/ECLSS in Mars in environment
- Power sufficient for ISRU
- Surface Navigation

A collaborative Mars precursor initiative will address the capabilities we need to validate and questions we need to answer in the 2020's

#JOURNEYTOMARS

Addressing High Priority Technology and Knowledge Gaps For Human Exploration of Mars

Mars Vicinity & Orbit	Global Temperatures	Global Aerosols	Global Winds	Orbital Particles	Optical Comm	In Space Prop. / SEP
Short-Stay Human Surface Mission	Local Dust Climatology	Weather at Sites	EDL (site) Winds	EDL Density Profiles	Extant Life (biohazards)	Special Regions
	Surface Dust*	Dust Effects on ISRU*	Regolith Properties*	Regolith Pore Space	Surface EDL Hazards*	Regolith Composition*
	Site Certification	Traction Cohesion	Charged Particles	Hazardous Chemicals*	Soluble Ion Distributions	Fine Dust Hazard*
Human Mission to Phobos or Deimos	Near-Surface Composition	Near-Surface Resources	Gravity Field	Regolith Properties	Near-Sfc. Temp.	
Sustained Human Surface Mission	High-Res Mineralogy	Sub-Surface Ice Site Maps	Water Extraction	Water Access (drill)	Resource Extraction	End-to-End ISRU Design

Mission Legend (Color)

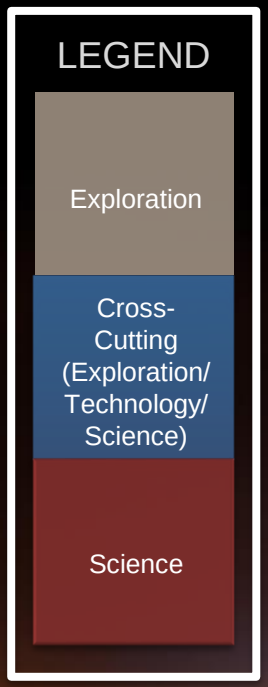
Addressed by Missions thru 2020
(assumes samples to be returned at later date)*

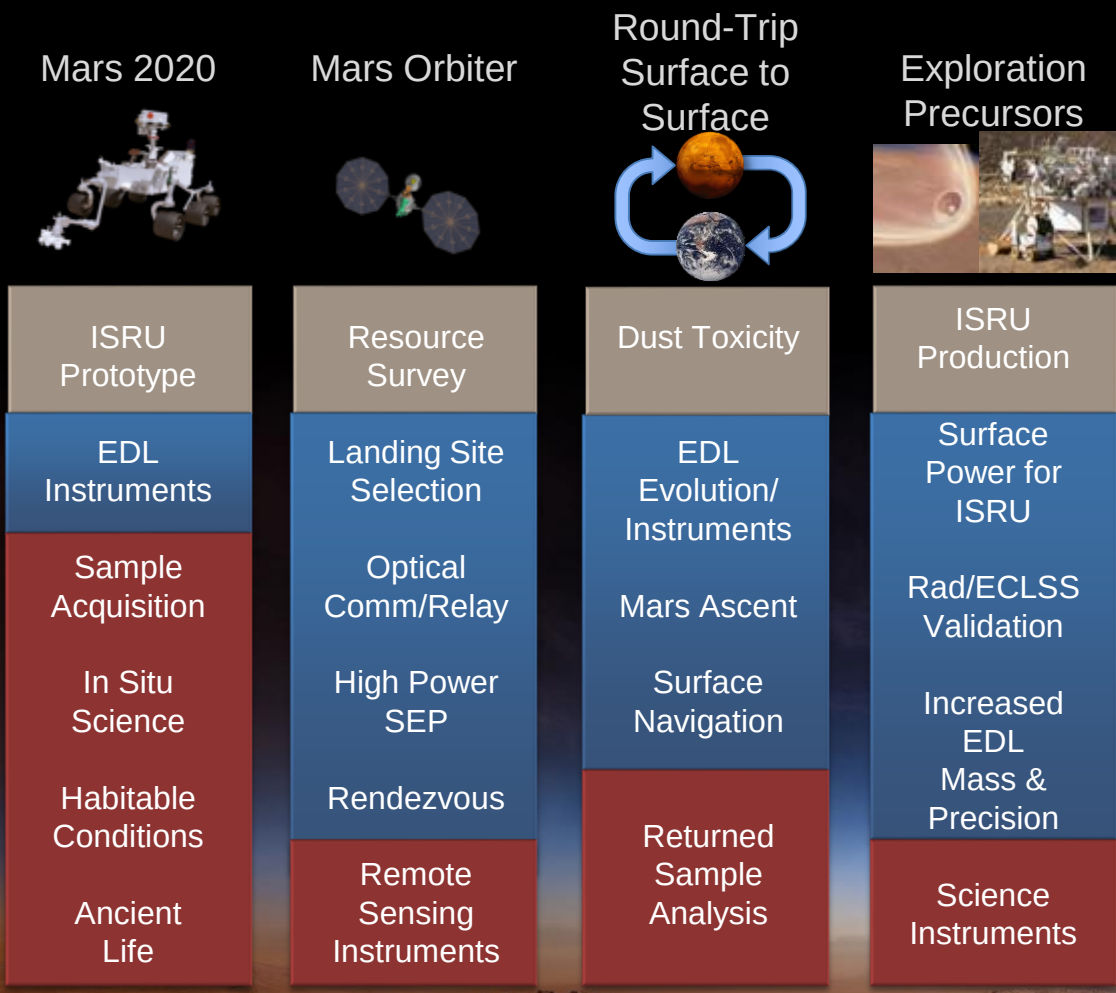
Addressed by Future Orbiters

Addressed by Future Landers

#JOURNEYTOMARS

Conceptual Integrated Campaign for Mars in the 2020's

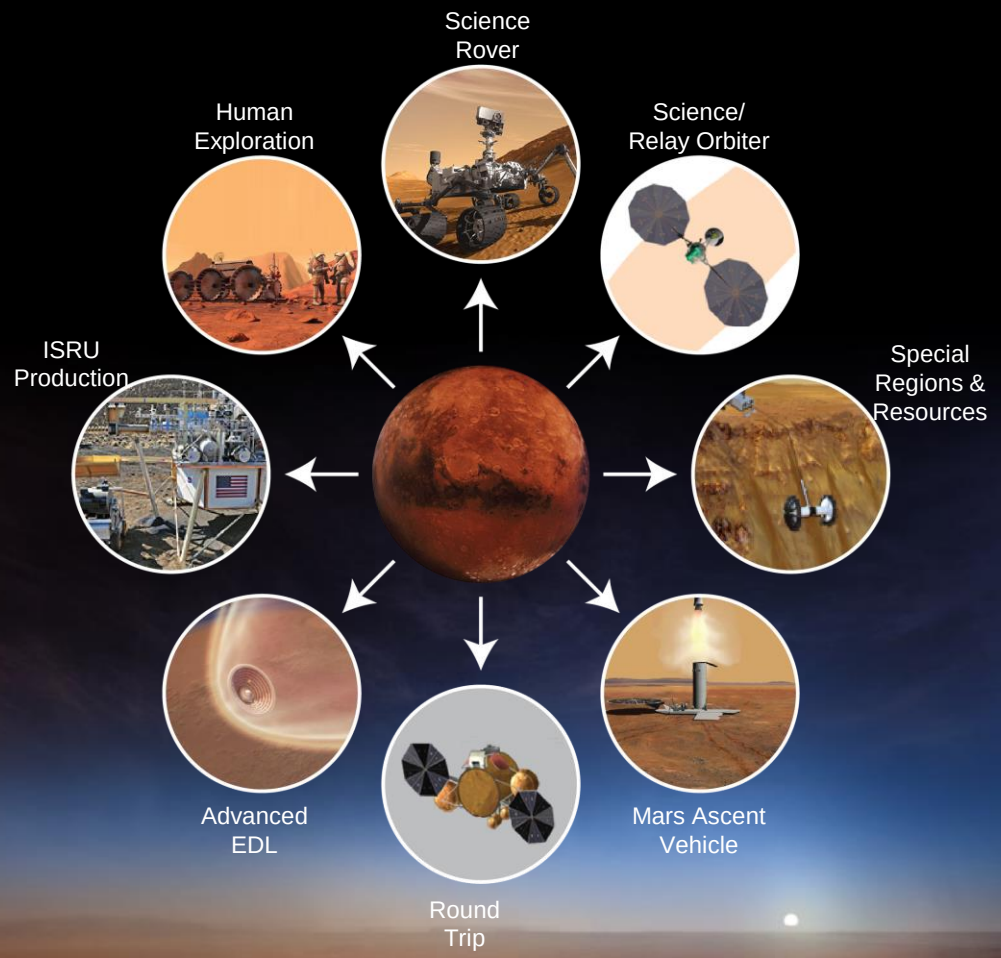




#JOURNEYTOMARS

Integrated Vision for a Mars Robotic Precursor Initiative

- **Exploration:**
  - Address key issues to build confidence in round-trip missions to/from Mars
  - Identify and characterize concentrated resources for potential ISRU exploitation
- **Science:**
  - Leverage expertise built through five decades of robotic Mars exploration
  - Build upon recent science discoveries
  - Continue to support decadal priorities
- **Technology:**
  - Leverage technology investments
  - Mission Infusion opportunities
  - Enable end-to-end Earth/Mars missions
- **Infrastructure:**
  - Sustain and improve Mars telecommunications and surface reconnaissance infrastructure



The 2020's will be a "**transition decade**" that leads to Humans to Mars in the 2030's

#JOURNEYTOM

S&T PARTNERSHIP FORUM

Chart 1 from Summit

S&T Partnership Forum

Purpose:

- Strategic forum of Agencies to identify synergistic efforts/technologies where efficiencies can be made to address pervasive needs
- Identify “Hot” Topics for technology discussion at future AF/NASA/NRO Summits
- Tackle difficult problems and coordinate joint messages for Hill and White House—Be proactive through Agency Legislative Affairs
- Develop and baseline process in unclassified level and then review applicability to classified level

Mechanisms for collaboration:

- Personnel exchange (e.g., AFRL-NASA)
- Cooperative research and development agreements (CRADAs)
- Technical Interchange Meetings (TIMs) (e.g., Next TPS TIM Sept)
- Joint working group

Participants

- NASA
- NRO
- AFSPC, ST
- AFRL, CZ, RQ & RV
- DARPA (TT0)
- NOAA
- OSD

Chart 2 from Summit

Near Term Goals:

- **Actively working to crosswalk NASA-AF-NRO roadmaps to identify opportunities for synergy and collaboration in technology investments**
  - Example initial focus areas under discussion: robotics, radiation hardened electronics, infrared focal planes, solar electric propulsion, carbon phenolic, cyber-security in embedded systems, disaggregated satellite systems, and cold atomic clocks.
  - Join efforts on non-destructive evaluation of new carbon phenolic technology (3-D weave and more)
- **Propose new national technology initiative(s)**
  - Each year, OSTP, OSD, and NASA create new S&T priorities and initiatives
  - Proactively influence the creation of these priorities and initiatives by proposing pervasive technology development efforts that are mutually beneficial and of high interest
  - Use the technology roadmap crosswalk effort to inform this process
- **Provide technology based recommendations to help inform US Policy on Orbital Debris Removal (ODR)**

Long Term Goals:

Example - Develop a joint roadmap that focuses on mutually beneficial long term goal(s).

- Proposed Goal: Develop a joint roadmap that focuses on technologies that reduce launch cost by at least 25% in 10 years.

Recent Activity

At July Summit

NASA Administrator requested that the S&T Partnership Forum:

- Provide annual updates on technology-related topics, and
- Within six months, provide three options for a long-term strategic technology goal.

November 2, 2015 NASA hosted S&T Partnership Forum Meeting to discuss potential long-term strategic goals that:

- Include a problem statement
- Address problem that impacts all (or most) S&T Partnership organizations
- Include a solution that enables Agencies to leverage existing work to solve the problem (or begin to solve the problem).

➢ 16 Goals were presented by Agencies and organizations and hybrid concepts were developed.

➢ Future telecoms and meetings will be held to refine the list of opportunities for collaboration and goals.

Participating Organizations In Goal Development Meeting

- NASA
- Office of the Assistant Secretary of Defense for Research & Engineering
- Air Force Space Command
- Air Force Office of Deputy Assistant Secretary (Science, Technology & Engineering)
- Air Force Research Laboratory (AFRL) Space Vehicles Directorate
- Army Space and Missile Defense Command
- DARPA Tactical Technology Office
- National Oceanic and Atmospheric Administration (NOAA) NESDIS
- National Reconnaissance Office (NRO) Advanced Systems & Technology Directorate
- NRO Systems Engineering

OTHER OCT ACTIVITIES

2015 NASA Technology Roadmap

National Aeronautics and Space Administration

Technology Roadmap Completed July 2015

Considers
- Updates in Science Decadal surveys
- Human Exploration capability work
- Advancements in technology

Includes:
- State-of-art
- Capability needs
- Performance goals

Expanded Scope:
- ✓Aeronautics technology
- ✓Autonomous systems
- ✓Avionics
- ✓Information technology
- ✓Orbital debris
- ✓Radiation
- ✓Space weather

2015 Technology Roadmaps Facts:

340 people contributed (authored content)
This included input from all NASA Centers, organizations, industry and government. Others provided edits during Center and HQ reviews.

The 2015 NASA Technology Roadmaps are comprised of:
- 16 sections
- 15 technology areas
- 2,100 pages
- 1,278 technology candidates

Since the 2012 Roadmaps were released, the 2015 Roadmaps have been expanded to include:
44 new level 3 Space Technology Areas that will be evaluated by the NRC.

Technology Areas: 1, 4, 5, 7, 9, 11, 13, and 14

Other Government Agencies Provided Input

National Aeronautics and Space Administration

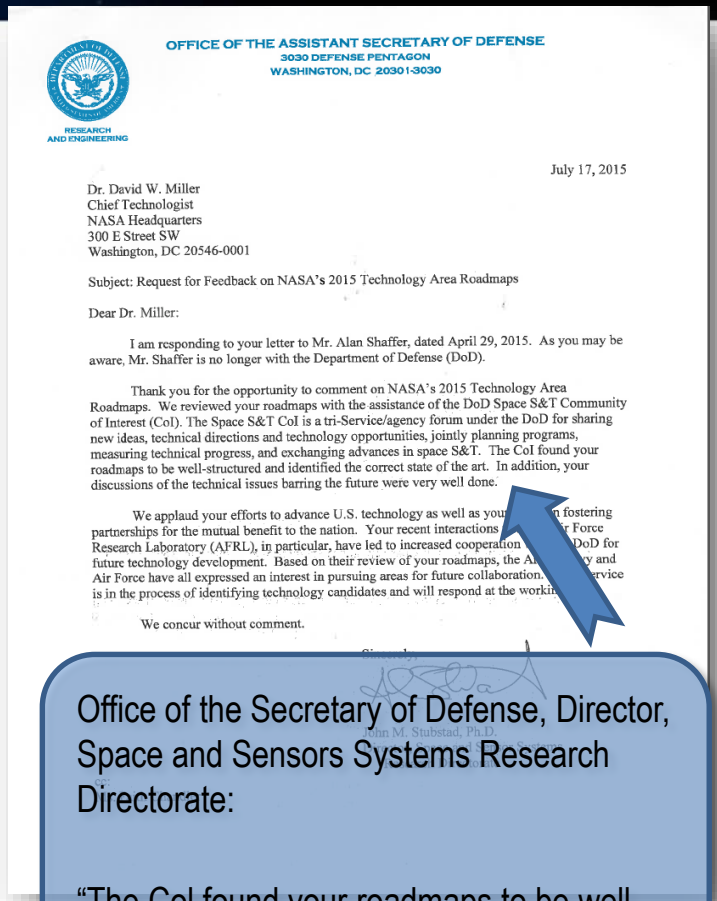
Examples of participants:

July 2014 review of draft:

- Department of Defense
  - US Army Development and Engineering Center
  - Air Force Research Laboratory (AFRL)
  - Office of the Secretary of Defense/Acquisition, Technology & Logistics
  - Air Force Space and Missile Test Branch
- U.S. Department of Energy
- Department of Transportation, Federal Railway Administration
- National Oceanic and Atmospheric Administration (NOAA)

May 2015 review:

- AFRL
- Defense Advanced Research Projects Agency (DARPA)
- Missile Defense Agency (MDA)
- Department of Transportation, Federal Aviation Administration (FAA)
- NOAA
- 4 International Space Agencies



OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3030 DEFENSE PENTAGON
WASHINGTON, DC 20301-3030

RESEARCH AND ENGINEERING

July 17, 2015

Dr. David W. Miller
Chief Technologist
NASA Headquarters
300 E Street SW
Washington, DC 20546-0001

Subject: Request for Feedback on NASA's 2015 Technology Area Roadmaps

Dear Dr. Miller:

I am responding to your letter to Mr. Alan Shaffer, dated April 29, 2015. As you may be aware, Mr. Shaffer is no longer with the Department of Defense (DoD).

Thank you for the opportunity to comment on NASA's 2015 Technology Area Roadmaps. We reviewed your roadmaps with the assistance of the DoD Space S&T Community of Interest (CoI). The Space S&T CoI is a tri-Service/agency forum under the DoD for sharing new ideas, technical directions and technology opportunities, jointly planning programs, measuring technical progress, and exchanging advances in space S&T. The CoI found your roadmaps to be well-structured and identified the correct state of the art. In addition, your discussions of the technical issues barring the future were very well done.

We applaud your efforts to advance U.S. technology as well as your [illegible] in fostering partnerships for the mutual benefit to the nation. Your recent interactions [illegible] Air Force Research Laboratory (AFRL), in particular, have led to increased cooperation [illegible] DoD for future technology development. Based on their review of your roadmaps, the Air [illegible] and Air Force have all expressed an interest in pursuing areas for future collaboration. [illegible] Service is in the process of identifying technology candidates and will respond at the workin[illegible]

We concur without comment.

Sincerely,

John M. Stubstad, Ph.D.

Office of the Secretary of Defense, Director, Space and Sensors Systems Research Directorate:

"The CoI found your roadmaps to be well-structured and identified the correct state of the art. In addition, your discussions of the technical issues barring the future were very well done"

2015 Draft Technology Roadmap Completed External Review

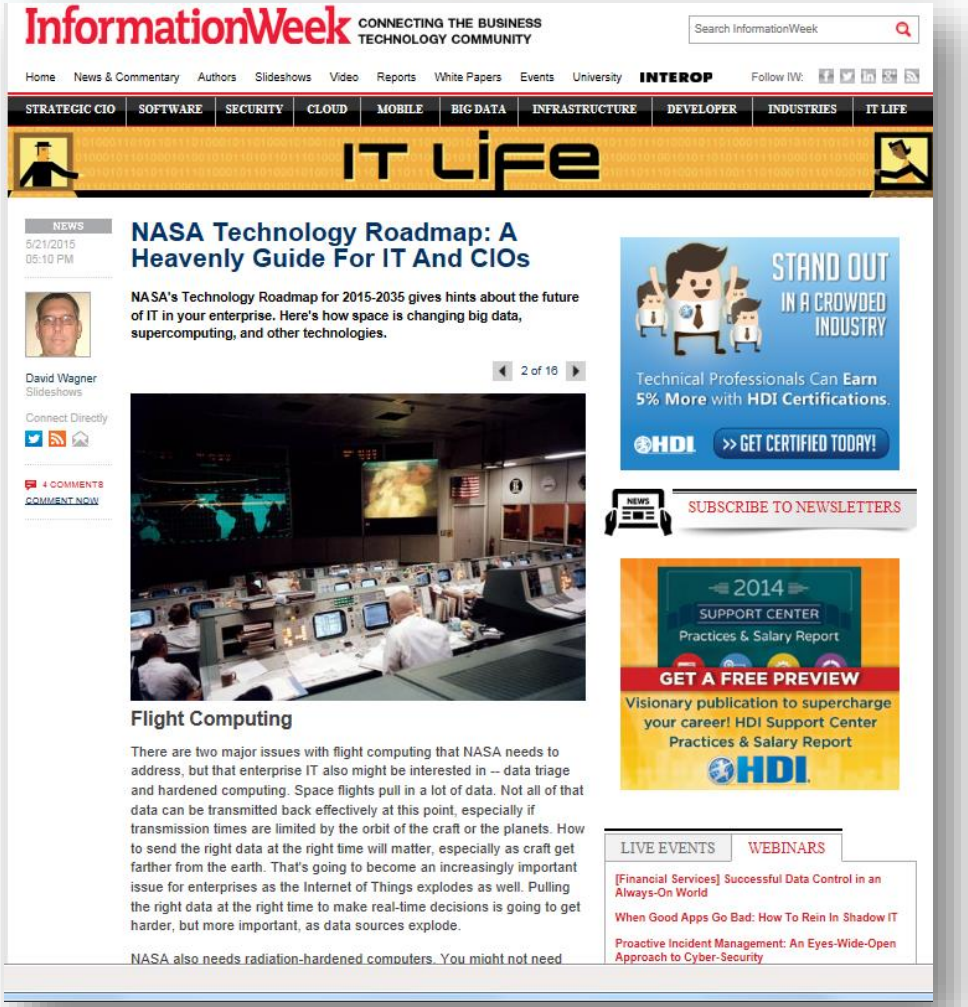
National Aeronautics and Space Administration

2015 draft Technology Roadmaps Released to the Public on May 11, 2015

- Press Release
- Federal Register
- FedBiz Ops
- Request for Information
- Multiple news stories followed

77 Letters Sent by NASA Announcing Release and Requesting Input:

- Other Government Agencies
- Commercial Industry Associations
- Academic Institutions
- International Partners



Roadmap Next Steps

National Aeronautics and Space Administration

Roadmaps Updated With Public Comments – Roadmaps Completed and Final Posted July 2015

National Research Council Status

- Statement of Work (SOW) was Approved by NASA Technology Executive Council (NTEC) – Focus of SOW to prioritize new technologies in 2015 Technology Roadmaps
- **NRC Contract Awarded on 05-27-2015**

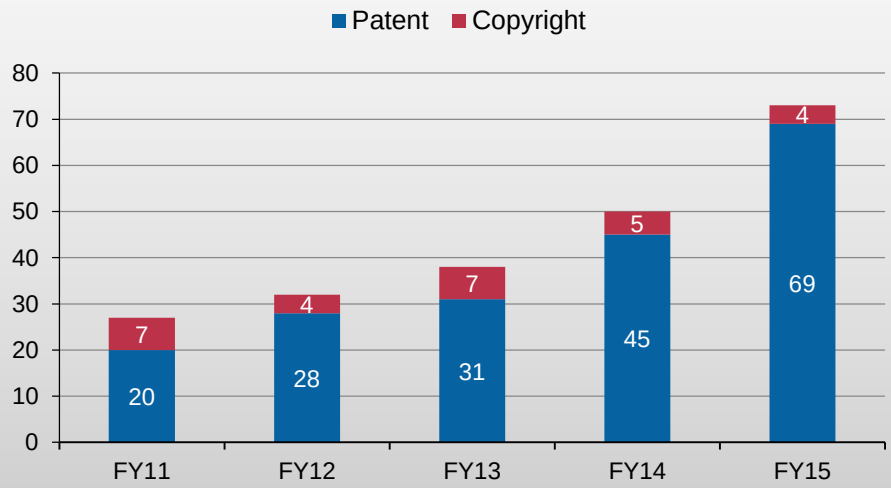
- Schedule
  - 8/10/2015 Committee membership approved
  - 9/28/2015 First Meeting, Washington, D.C.
  - 11/12/2015 Second Meeting, Washington, D.C.
  - TBD Third Meeting, location TBD
  - TBD Fourth Meeting, location TBD
  - 4/1/2016 Development of Consensus Draft
  - 5/1/2016 Report Sent to External Review
  - 7/15/2016 Report Review Complete
  - 8/1/2016 Report Delivered to Sponsor (Prepub)
  - 10/1/2016 Report Delivered to Sponsor (Published copies)

Note: NASA Updates the Strategic Technology Investment Plan (STIP) every 2 years. We are currently updating the STIP. We will be using 2015 new technology candidates and 2013 NRC priorities for FY2016 STIP. The STIP in FY2018 will include NRC's 2016 recommendations.

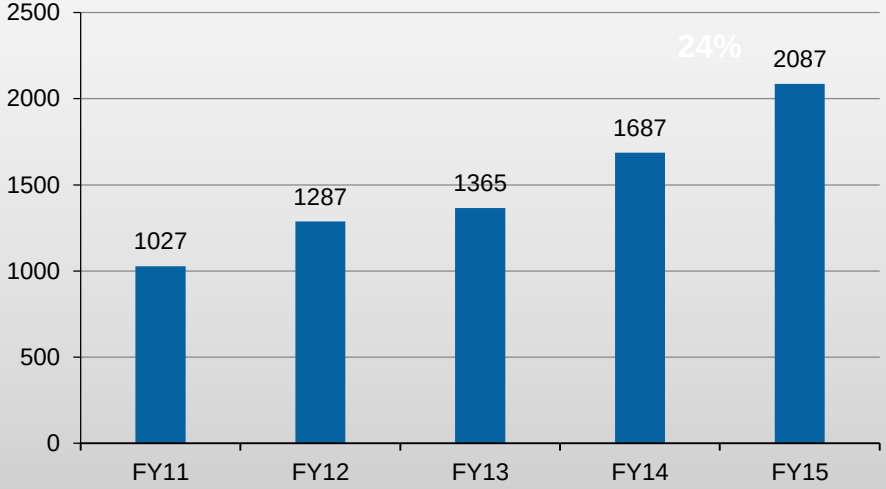
FY 2015 Agency Metrics Highlights

TECHNOLOGY TRANSFER PROGRAM

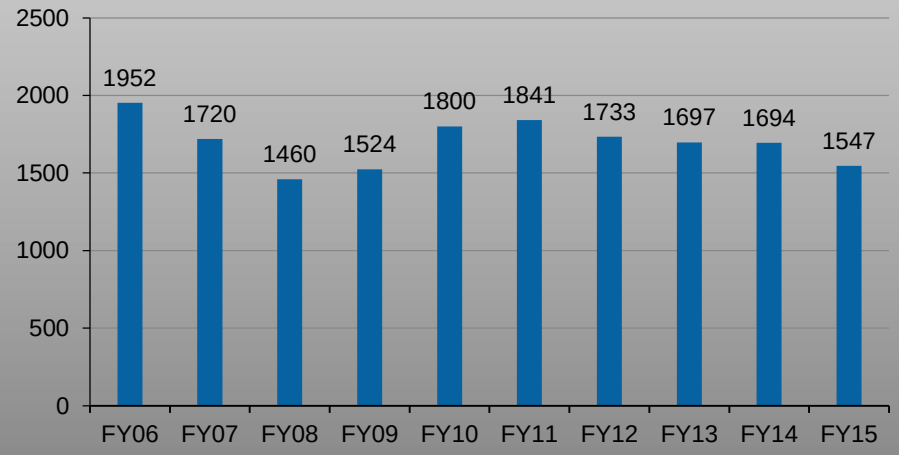
New Licenses Executed (Total)



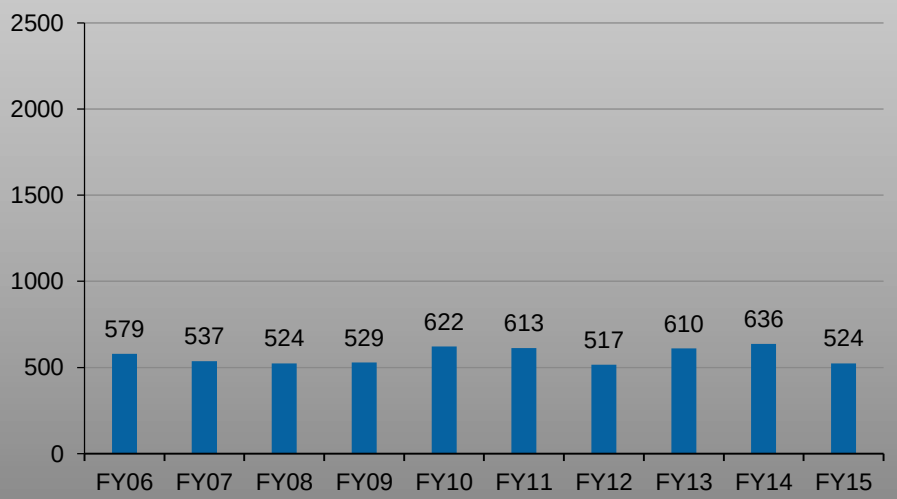
New Software Usage Agreements (Total)



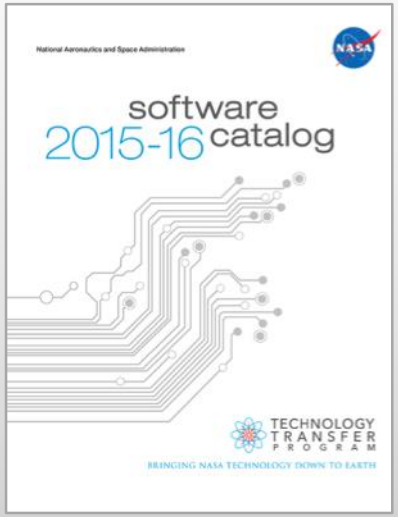
New Technology Reports Disclosed (All Types)



NTRs with C/S Inventorship Trend

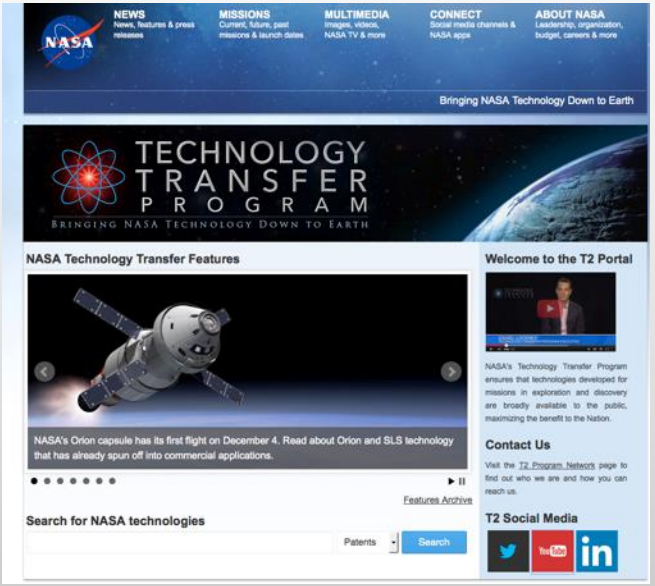


T2 Program Products



Software Solutions

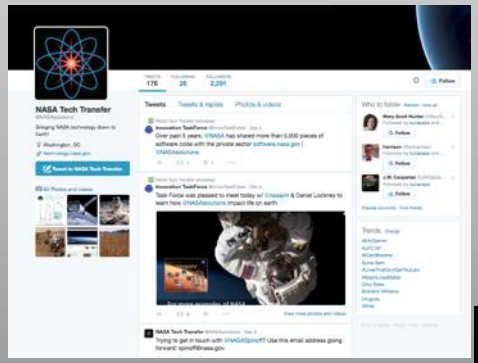
Technology Solutions Fact Sheets



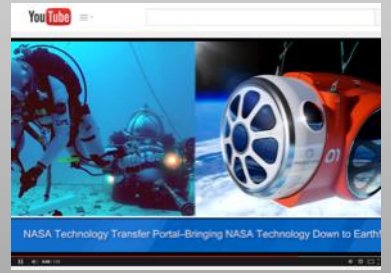
T2P Portal

Spinoff

Tech Briefs



Social Media



NASA Technology Transfer University

TECHNOLOGY TRANSFER PROGRAM

T2U teaches business students about NASA's technology portfolio, allowing them to work with agency technology and inventors to discover new uses for the innovations in commercial applications.

- The students benefit from the interaction with real inventors, real technologies, and all-around real-world experience.
- Student teams may form start-up companies, licensing NASA-patented technologies
- NASA teaches thousands of potential entrepreneurs about the availability of taxpayer-funded technologies across the federal government

Startup NASA

TECHNOLOGY TRANSFER PROGRAM

By offering a license with no up-front costs for commercial use of our patented technologies, we're letting companies hold onto their cash while securing the intellectual property needed to carve out competitive market space.

- **These technologies have been vetted for technical and commercial viability by NASA and external sources.**
- **Patents are maintained and protected by the US Government.**
- **NASA technical personnel and facilities can be available to lend additional support.**

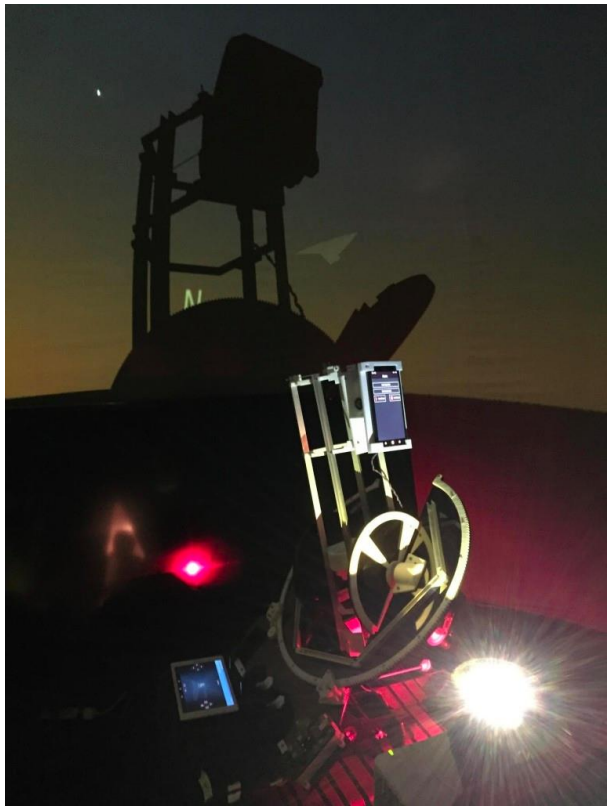
Prizes, Challenges and Crowdsourcing

NASA SOLVE Highlights

- **Center of Excellence for Collaborative Innovation (CoECI)**
  - Completed the NASA Open Innovation Services procurement, awarding 10 contracts to crowdsourcing based companies with a variety of domain expertise expanding the capabilities of the NASA Tournament Lab
    - 8 task orders competitively awarded and challenges launched including In-Situ regolith challenge, Orion Bio-Inspired Exercise Device, AGC Video.
  - Received “Greatest Impact to Government Mission” award at the GSA Five Years of Excellence in Prizes and Challenges Event
- **Centennial Challenges**
  - Awarded three teams a total of $40,000 in the first stage of the 3-D Printed Habitat Challenge Design Competition at 2015 New York Maker Faire
  - Registration opened for 2015 Sample Return Robot Challenge
  - CubeQuest Challenge received Most Ground Breaking award at GSA Event
- **Future Engineers**
  - 3D Printing Space Container Challenge junior winner Ryan Beam's toured the Space Shuttle Endeavour with Astronaut Leland Melvin and SpaceX. All finalists will be attending Space Camp.
  - 3D Printing challenges received Best Student Challenge at GSA Event.
  - Also received 2015 ASAE Summit Award

Asteroid Grand Challenge FY16 Update

- **Successful Expert and Citizen Assessment of Science and Technology (ECAST) final report released**
- **Two winning proposals selected from the Citizen science Asteroid Data, Education, and Tools (CADET) grant call**
- **Ultrascope, an open hardware automated robotic observatory, was highlighted at NYC Wired conference capturing live images of Jovian moons from a township in South Africa- this is the first step to an 18 inch observatory for asteroid follow-up**



Highlighted OCT Activity

EMERGING COMMERCIAL SPACE

DR. ALEX MACDONALD

Emerging Space Office

National Aeronautics and Space Administration

- Emerging Space Office (ESO) was formed in recognition of the rising importance of private-sector individuals and organizations that invest their own time and money in space activities. This emerging space community is increasingly a major force in American space developments.

- NASA's ESO investigates, monitors, and provides analytical support to the Office of the Chief Technologist and other NASA organizations on the state of this rapidly growing sector to assist in NASA's legislated responsibility to seek and encourage, to the maximum extent possible, the fullest commercial use of space.

- Level I Program Executive at HQ, Level II Program managed at ARC

Emerging Space November-2015

National Aeronautics and Space Administration

- ESO approach to realizing its mission is three fold:
  - Monitoring and evaluation function (HQ)
  - Special Reports and Investigations (HQ and ARC)
  - Economic Research for Space Development NRA (ARC)

- Monitoring and Evaluation Function:
  - Recent Due Diligence and Advisory:
    - Lunar CATALYST Support
    - Collaborations for Commercial Space Capabilities (CCSC) BAA Support
    - NEXTSTEP BAA Support
    - 'Tipping Point' and Emerging Space Technologies Support
    - Strategy Implementation Support

- Special Reports and Investigations
  - Emerging Space Report (2014)
  - Public-Private Partnerships for Space Capability Development (2014)
  - Microgravity Imperative (2014-2015)
  - LEO Commercialization Economic Study Team (forthcoming 2015)
  - Strategic Geography of the Solar System and Beyond (In work)

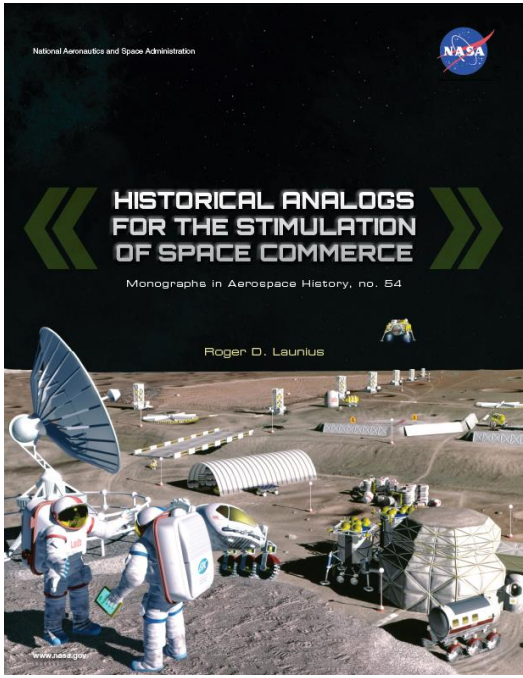
Emerging Space November-2015

National Aeronautics and Space Administration

- Pre-NRA External Studies
  - Economic History of Climbing Everest (McCurdy)
  - Historical Analogs for Space Commerce (Launius)
  - Leadership Perspective on History of COTS Program (Lambright)

- 2014 Economic Research for Space Development NRA (ARC)
  - "An Integrated Economic Model for ISRU in support of a Mars Colony" JPL and UNSW
  - "Anchoring and Black Swans: Reconsidering Risk Aversion and the Future of Commercial Space" Resources for the Future
  - "Start Up Space" Tauri Group
  - "Economic Assessment and Systems Analysis of an Evolvable Lunar Architecture" NexGen LLC
  - "Seeds of Discovery: An Economic History of Innovation with the National Aeronautics and Space Administration" Smithsonian and American University
  - "Narrative Projections for Commercial Space Futures" Arizona State University

- 2015 NRA received 35 proposals, selections due soon. 1 year of 5 year NRA.



Emerging Space November-2015

National Aeronautics and Space Administration

- **NRA on Economic Research for Space Development - NNA15ZBP0001N**
- Estimated $400-500k available for 2015 NRA. $50/6 months or $100k/year proposals encouraged
- Three High-Level Subject Categories:
  - A. Historical Economic Studies
  - B. Economics, Systems Analysis, and Projections, in orbital and deep space development; lunar development, asteroid development, and Mars development
  - C. Current and Near-Term Trends, Analyses and Concepts for accelerating U.S. space development
- Five Areas of Interest Identified for 2015
  - Sociological and economic research into the socioeconomic environment for American entrepreneurship in areas of space exploration and development,
  - Logistics for in-space propellant production and supply within architectures for space exploration and development,
  - Econometric analysis of the impact of space activities and R&D in the context of regional development and clusters,
  - Empirical demand-side assessments of the relative size of potential revenue sources for commercial LEO space stations,
  - Methods for developing profitable manufacturing and production applications in microgravity.
- Evaluation Criteria: 1) Relevance to NASA/ESO's Objectives and 2) Intrinsic Merit

Emerging Space November-2015

National Aeronautics and Space Administration

- Other Program Results:
  - Increased focus within CASIS/ISSPO on microgravity applications identified in Microgravity Imperative report
  - Spacecraft Nation - 50 spacecraft from 50 states
    - Status: 30 of 50 launched, manifested or in queue

July 31, 2014

CubeSat Launch Initiative: 50 CubeSats from 50 States in 5 Years

» View the Announcement of CubeSat Launch Initiative Synopsis
» Download the full text (2.3 MB PDF)

As part of the White House Maker Initiative, NASA is seeking to leverage the growing community of space-enthusiasts to contribute to NASA's space exploration goals. NASA is broadening the CubeSat Launch Initiative to promote a spacecraft nation and develop innovative technology partnerships among NASA, U.S. industry and educational institutions to build upon an existing successful initiative and expand it to include launching 50 small satellites from 50 states within five years. The initiative will enable the acceleration of flight-qualified technology that will increase our

This map of the United States shows states with selected (blue), manifested (yellow), and launched (green) CubeSats through

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Questions?
TECHNOLOGY DRIVES EXPLORATION

BACK-UPS

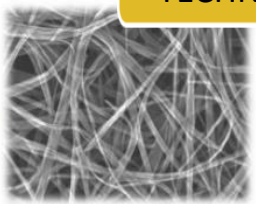
NASA Technology Roadmap
Technology Area 10 - Example

National Aeronautics and Space Administration

Technology Candidate Snapshot

TA 10.1: Engineered Materials and Structures

While the ultimate goal of developing continuous, single-wall carbon nanotube (CNT) fibers has yet to be realized, considerable effort has been devoted to high-volume manufacturing of CNT materials. These materials are now commercially available in large sheets and continuous fiber formats suitable for the evaluation of their utility in aerospace applications. The electrical conductivity of these commercially available CNT sheets has proven to be effective for electrostatic charge dissipation and electromagnetic interference shielding, as demonstrated on the Juno satellite launched in 2011. These materials have also been tested for data cables and are in development by commercial entities for lightweight wiring. Their use in such applications is far more mature than those in structural applications where the bulk tensile strength and modulus of these carbon nanotube assemblages are significantly lower than predicted values measured on the nanoscale.



State of the art for lightweight structures, purified carbon nanotubes.

TECHNOLOGY

CAPABILITY

REFERENCE MISSIONS

2015 NASA Technology Roadmaps
TA 10: Nanotechnology
DRAFT

10.1 Engineered Materials and Structures
10.1.1 Lightweight Structures

10.1.1.3 Nanomanufacturing Method for Multifunctional Structures

TECHNOLOGY

Technology Description: Provides a net shape fabrication method to produce topologically-optimized lightweight multifunctional structures with inherently integrated sensors.

Technology Challenge: Metallic parts need means of inspection quality assurance in applications beyond non-load bearing secondary structures. Plastic components can only be fabricated from non-aerospace-grade material systems.

Technology State of the Art: Three-dimenstional (3D) printing of homopolymeric materials for consumer use is rapidly growing. However, 3D printing of aerospace-grade components using nanomaterials is in its infancy.

Parameter, Value:
Nanocomposite feedstock are now commercially available. This technology is more advanced in the area of 3D printed electronics, which uses ink containing nanomaterials.

TRL: 3

Technology Performance Goal: Advanced manufacturing/processes/materials to reduce recurring hardware production cost while maintaining highly reliable aerospace systems is essential for meeting affordability and sustainability requirements. Develop manufacturing method to take advantage of lightweight multifunctional materials in topologically optimized structural designs. In-space manufacturing.

Parameter, Value:
Integrated functions for CubeSat with mass range 1-20 kg. Demonstrated performance of manufactured components in relevant applications.

TRL: 6

Technology Development Dependent Upon Basic Research or Other Technology Candidate: None

CAPABILITY

Needed Capability: Ultralightweight structural components.

Capability Description: Enables lighter weight components for aircraft and spacecraft to reduce launch and flight costs.

Capability State of the Art: 3D printing only available for homogeneous polymers, metals mostly powder technology. Plastic disposable parts can be made for terrestrial applications. Metallic parts have been produced and used in secondary parts for aircraft. 3D printing demonstrated in microgravity on the International Space Station (ISS).

Parameter, Value:
Homogeneous material systems with non-optimal mechanical properties. No nano enabled functions integrated.

Capability Performance Goal: Manufacturing methods and component evaluation under realistic aerospace environments required.

Parameter, Value:
Integrated functions for CubeSat with mass range 1-20 kg. Demonstrated performance of manufactured components in relevant applications.

Technology Needed for the Following NASA Mission Class and Design Reference Mission	Enabling or Enhancing	Mission Class Date	Launch Date	Technology Need Date	Minimum Time to Mature Technology
Exploring Other Worlds: DRM 6 Crewed to NEA	Enhancing	2027	2027	2021	6 years
Exploring Other Worlds: DRM 7 Crewed to Lunar Surface	Enhancing	2027	2027	2021	6 years
Exploring Other Worlds: DRM 8 Crewed to Mars Moons	Enabling	2027	2027	2021	6 years
Planetary Exploration: DRM 8a Crewed Mars Orbital	Enabling	2033	--	2027	8 years
Planetary Exploration: DRM 9 Crewed Mars Surface Mission (DRA 5.0)	Enabling	2033	--	2027	10 years
Planetary Exploration: DRM 9a Crewed Mars Surface Mission (Minimal)	Enabling	2033	--	2027	10 years

Office of the Chief Technologist Responsibilities

- **Provides the strategy, leadership, and coordination that guides NASA's technology and innovation activities**
  - Develops and implements NASA technology policies, roadmaps, and Strategic Technology Investment Plan (STIP).
  - Coordinates technology needs across the NASA Mission Directorates
- **Documents, Tracks, and Analyzes NASA's technology investments**
  - Develops and Operates the TechPort Database, which provides capability to share information about NASA's technology investments within the Agency and to the public
- **Coordinates with other Government agencies and the emerging commercial space sector to maximize benefit to the Nation**
- **Provides Agency-level leadership and coordination of the use of prizes and competitions to spur innovation**
  - Pilot new approaches to technology innovation and track their success
- **Leads technology transfer and technology commercialization activities across the agency**

Technology Roadmaps

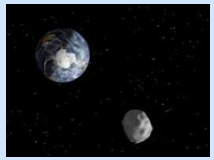
Strategic Technology Investment Plan

Technology partnerships

TechPort

Develop & operate the TechPort database

Tech Transfer, Partnerships and Commercialization Activities



Prizes, Competitions and Grand Challenge

Download the SSTIP at: http://www.nasa.gov/offices/oct/home/sstip.html

OCT Division Functions

Innovation Office

- Technology Transfer - supports an office at each of the field centers, as well as a full intellectual property management tool, the NASA Technology Transfer System (NTTS), and the Spinoff Program Office.
- Prizes and Challenges - keeps NASA at the cutting edge of new business practices, while supporting realistic pilots to enable implementation at scale. The function currently drives two major sets of innovation activities within NASA:
    1. Drive the appropriate use of prizes, challenges and crowdsourcing (open innovation) as additional, unique tools within NASA and the aerospace industry
    2. Facilitate, catalyze, and lead the implementation of special technology initiatives and strategic concepts, including Grand Challenges and Launch
- Emerging Space - provides economic intelligence on the emerging commercial space ecosystem. Advises NASA HQ on the economics of space development and commercial space

Strategic Integration

- Roadmaps – A set of documents that consider a wide range of needed technologies and development pathways for the next 20 years. The roadmaps focus on "applied research" and "development" activities.
- Strategic Technology Investment Plan (STIP)– An actionable plan that lays out the strategy for developing the technologies essential to the pursuit of NASA"s mission and achievement of National goals. This plan provides the prioritization and guiding principles of investment for the technologies identified in the roadmaps.
- Technology Coordination-Coordinates technology needs across the NASA Mission Directorates and communicates with other Government agencies to identify opportunities for technology collaboration
- TechPort – Web-based software system that serves as NASA's integrated authoritative technology data source

Technology Definitions

National Aeronautics and Space Administration

NASA Technology Definition:

A solution that arises from applying the disciplines of engineering science to synthesize a device, process, or subsystem to enable a specific capability.

Government-Wide Office of Management and Budget Circular No. A-11 **Conduct of Research and Development****	
Basic Research	Systematic study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. Basic research, however, may include activities with broad applications in mind.
Applied Research	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
Development	Is directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.

Technology Included

OMB Analytical Perspectives, Budget of the United States Government, Fiscal Year 2016
NASA Technology Actuals For Applied Research and Development ~ 9B in 2015
(This includes mission-specific technology and development and supporting infrastructure).

Technology Portfolio Management

National Aeronautics and Space Administration

Roadmaps – A set of documents that consider a wide range of **needed technologies** and development pathways for the next 20 years. The roadmaps focus on "applied research" and "development" activities.

http://www.nasa.gov/offices/oct/home/roadmaps

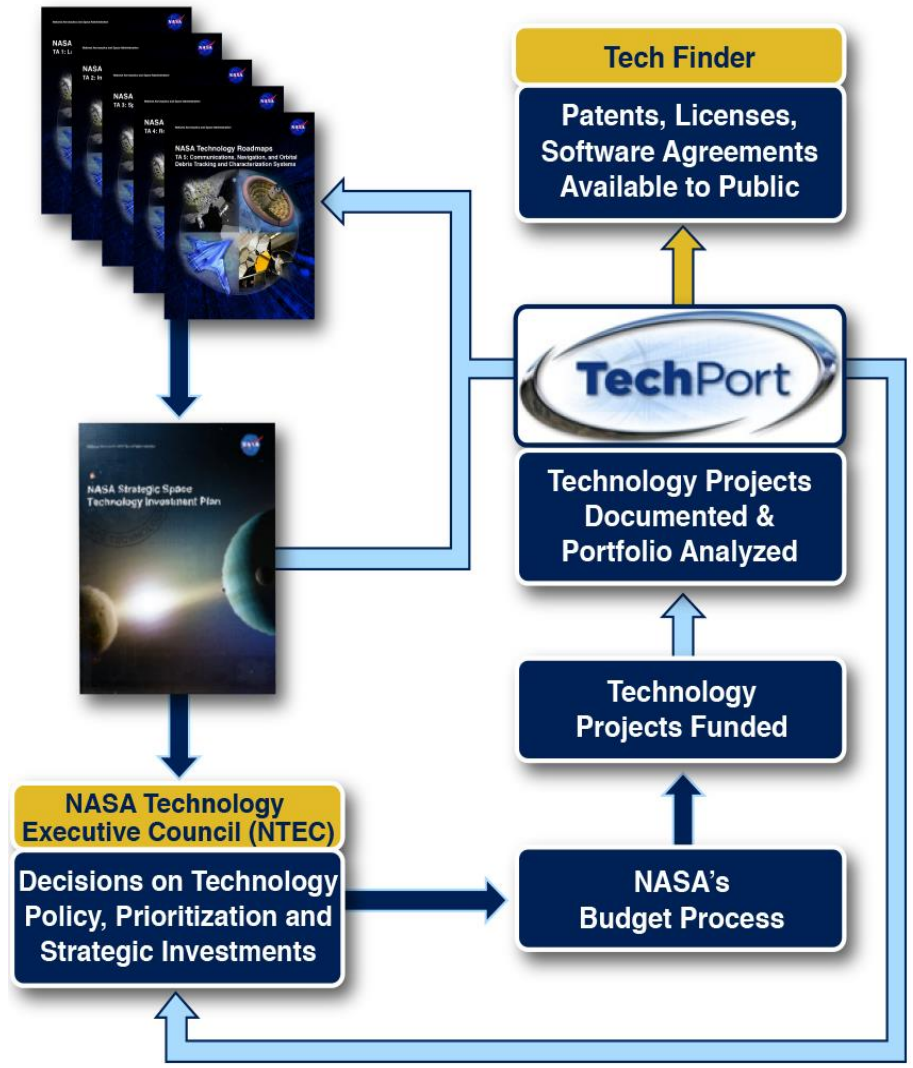
Strategic Technology Investment Plan (STIP)– An actionable plan that lays out the **strategy** for developing the technologies essential to the pursuit of NASA's mission and achievement of National goals. This plan provides the **prioritization** and guiding principles of investment for the **technologies identified in the roadmaps.**

*www.nasa.gov/offices/oct/home/**sstip**.html*

NASA Technology Executive Council (NTEC) - NASA's senior **decision-making body** for technology policy, prioritization, and strategic investments.

TechPort – Web-based software system that serves as NASA's integrated **authoritative technology data source and decision support tool**. Provides information on technology programs and projects.

http://techport.nasa.gov



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