Advanced Systems & Development

Science and Technology (S&T) Roadmap Collaboration between SMC, NASA, and Government Partners

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S&T Collaboration Way Ahead

- "Crossing the Chasm" (with fewer $$)
- National Space Policy
- DARPA Collaboration
- Space Cyber
- NASA-DARPA Manned GEO Servicing
- DARPA Phoenix Program
- S&T Collaboration with NASA/OCT
- SAF/AQR Rapid Innovation Fund (RIF)
- STEM - HMC, AFIT, USAFA
- S&T Collaboration Way Ahead

“Crossing the Chasm”* with few $

Most S&T results do not make it to the “market” or to space capabilities

- Collaborate: Define Tech Needs, Innovate, Transition
- Focus on pervasives: IP Enabled Space, Space Cyber, Solar Electric Propulsion (SEP), Advanced Materials, On-orbit Servicing
- Leverage Space Policy for Collaboration

* Geoffrey Moore 1991

Nat’l Space Policy (NSP) 2010 and S&T

- White house NSP: International, Commercial, Civil, NSS
- 2007 DARPA System F6: Fractionated Space Architectures
- Flexibility and Robustness, IP Enabled Space architecture

System F6 Government Team

- DARPA, SMC, AFSPC, AFRL, NASA, FFRDCs, SETAs
- Enabling technologies: IP Enabled Space, Cluster Ops, Econometrics
  - Value Centric Design Methodology (VCDM)
- F6 Tech Package (F6TP) - Pathfinder for Hosted Payload Interface Unit (HPIU)
- F6TP - Pathfinder for onboard cyber situational awareness

Collaboration and Transition

F6 Transition to Cyber S&T Concept On-board Cyber Monitor/Enforcement

Space Cyber Capability Gap

- Ground based cyber protection cannot identify all space based attacks (e.g. HW Trojan) or respond in time to protect the spacecraft. On-board Monitor/Enforcement capability is needed.

Estimated S&T Resources

- < $25M for proof-of-concept, > $50M to integrate space qualified appliance
- On-ramp to programs 5-10 yrs

Illustration - F6 Tech Package (F6TP)

Opportunities & Risks

- ✓ Thwart space based attacks
- ✓ Updates for future threats
- ✓ Attribution intelligence
- ✓ Appliance or embed in HW/SW
- ◆ Operational risks for autonomous defensive actions

Space Cyber

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- Merging of Space and Cyber missions by AFSPC
- AFSPC authored the Space Cyber portion of USAF Cyber Vision 2025 and led the Malware TEM (MTEM 2012) at SMC-Aerospace:

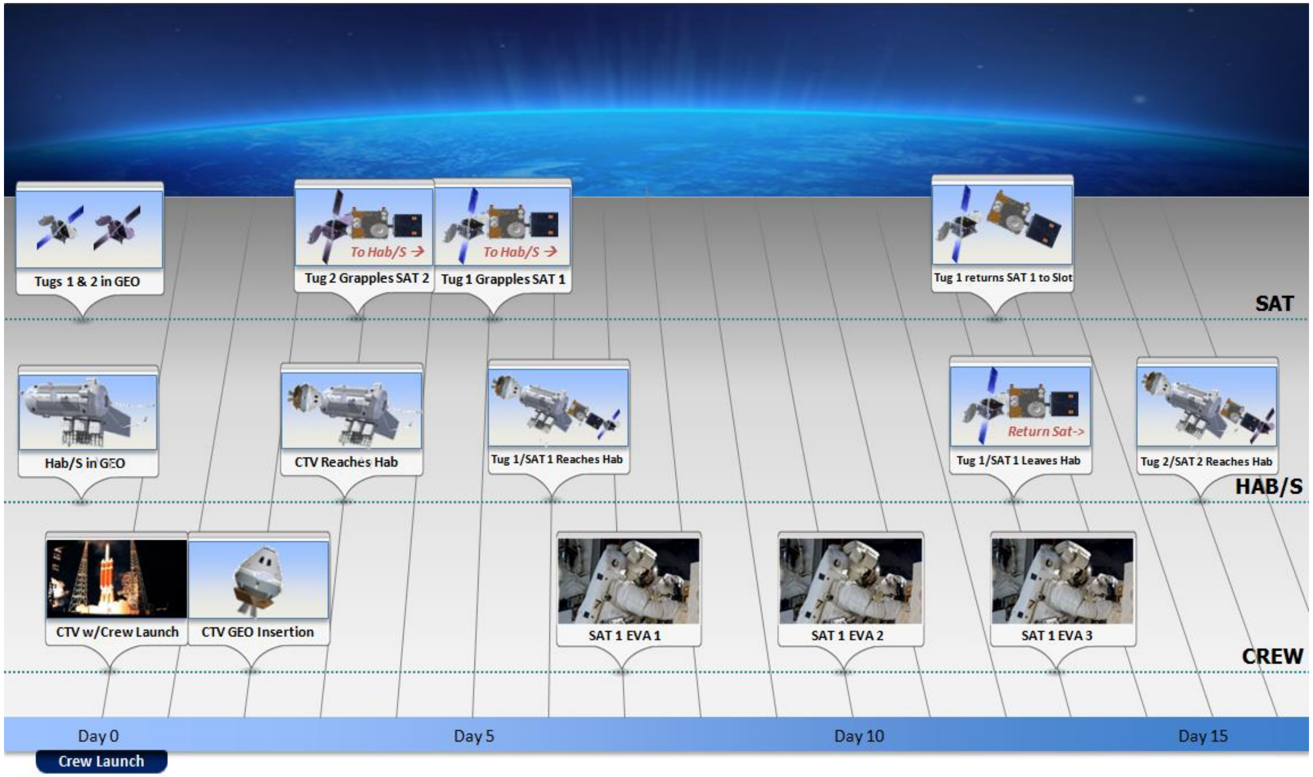
Technology Leader (L), Follower (F), Watcher (W)

Area	Near (F12-FY15)	Mid (FY16-20)	Far (FY21-25)
Assure and Empower the Mission	• Space/cyber test beds (fractionated, fight-through demos, shorter time to need) (L) • Space environment sensors for anomaly attribution (L) • Enable and exploit cloud computing (W)	• Survivable, assured real-time C3 in theater (Software Defined Radio) (L)	• Small, networked satellite constellations for communications, GPS, missile warning (L)
Optimize Human-Machine Systems	• Restructure cyber acquisition and operations policy - allow for full spectrum (F)	• Detect hidden functions, malware in the integrated space/cyber networks (hypervisors, etc) (F)	• Tools for intent and behavior determination (F)
Enhance Agility and Resilience	• Reconfigurable antennas and algorithms (L)	• Autonomous self-healing systems (F)	• Cognitive Communications - agile, reconfigurable, composable comm and sensors (L)
Foundations of Trust and Assurance	• Foundations of trust – hardware foundries, trusted software generation (W)	• Trusted satellite-cyber architectures (L) • Strong satellite C2 authentication (L) • Generate, detect single photons/radiation (W)	• Flexible, scalable high-rate encryption (F) • Space Quantum Key Distribution (QKD) (F) • Autocode generator generators that produce software that is correct by construction (W)

IPP process driven by S&T of Cyber Enhanced Space

DARPA-NASA Manned GEO Servicing (MGS)

- NSP 2010 MGS Program Initiated
- MGS Ops Concept



MGS Collaboration

- DARPA, SMC, AFSPC, AFRL, NASA(JSC, GSFC MSFC, HQ), NRL, FFRDCs, SETAs
- Enabling technologies: On orbit servicing, SEP, Life support
- Both MGS and F6 transitioned into Phoenix
- Repurpose large apertures in space

3-Way Transition F6-MGS-Phoenix

DARPA Phoenix Program

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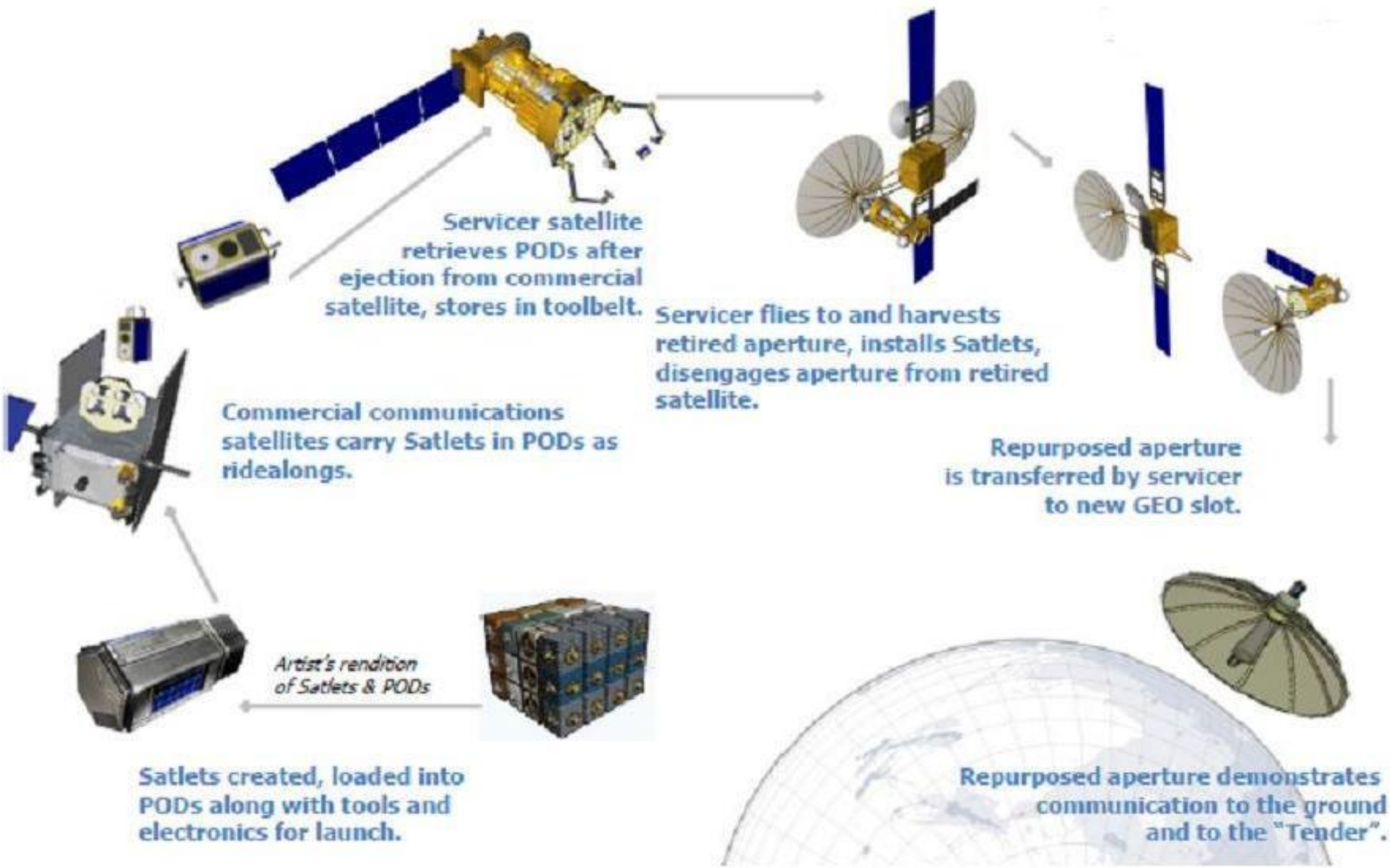


NASA Office of Chief Technologist – NASA/OCT Collaboration

- NASA-DARPA MGS involved NASA/OCT
- More recently increased collaborated on S&T roadmaps
- Some overlap among S&T, even though NASA is Science exploration mission, and USAF is NSS
- Focus on Common Pervasives such as:
  - Launch Technologies, SEP and Advanced Launch Architecture
  - Advanced Materials
  - On-Orbit Logistics
  - Space-Cyber
- Interest in STEM cultivation
- Collaboration with DARPA projects such as F6

NSS and Civil Collaboration

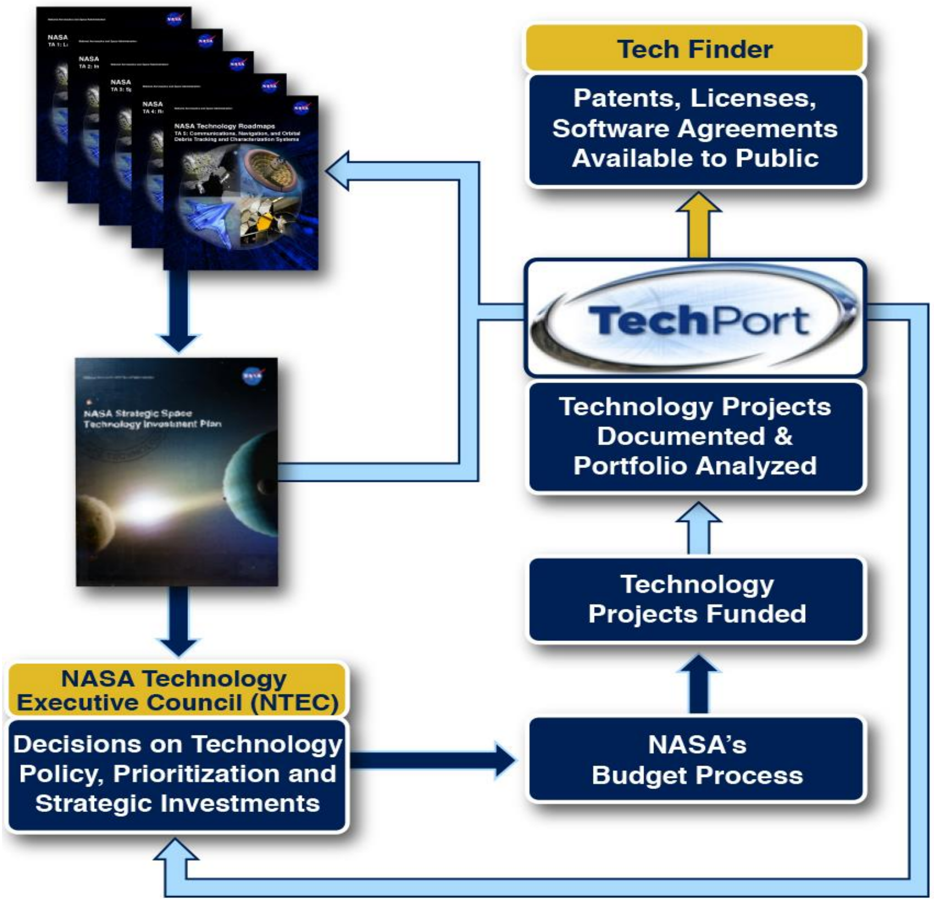
NASA OCT S&T Process

Roadmaps
What We Could Do

STIP (Priorities)
What We Should Do

NTEC and Budget Process
What We Will Do

TechPort
What We Are Doing



NASA Matches Technology to Needs

NASA OCT S&T Workflow

Mission Directorates - Decadals

2015 Roadmap Development Process

1	Mission Class	Extending Reach Beyond LEO
2	Design Reference Missions (DRM) Type	Crewed Mission to Surface
3	Capability	Entry, Descent and Landing
4	Capability Performance Goal	Earth, 10.99 km/s; Mars, 14 km/s
5	Capability State of the Art (SOA)	
6	Capability Performance Gap	
7	Technology Performance Goal	
8	Technology State of the Art (SOA)	
9	Technology Gap	
10	Technology Candidates	

Investment Plan

11	Current Investments
12	Unmet Needs (Technology Investment Gap)
13	Stakeholder Priorities / Possible Partnerships
14	NASA Technology Priorities

From Missions to Technology Priorities

NASA Technology Roadmaps

S&T Priorities Driven by Mission Needs

NASA OCT and AFSPC & SMC S&T Cross Walk

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NASA Need #	AFSPC Need #	Degree of Correlation	Funding	Impact	Activity Area	NASA Order #	AFSPC Order #	NASA Title
8.1.1	1034	H	Y	H	LD/MW	259	11	Detectors & Focal Planes
5.2.2	587	L	Y	H	COM-N	168	2	Power Efficient Technologies
5.2.6	241	H	Y	E	COM-N	172	8	Antennas
8.1.4	587	L	Y	H	COM-N	262	2	Microwave, Millimeter-, and Submillimeter-Waves
5.7.1	1030	H	Y	H	SSA & BA - SS	201	35	Tracking Technologies
5.7.1	1031	H	R	M	SSA & BA - SS	201	39	Tracking Technologies
1.2.2	384	H	Y	H	LRN	12	55	RP/LOX Based
8.1.1	861	H	G	H	LD/MW	259	10	Detectors & Focal Planes
8.1.2	1019	H	Y	H	per	260	87	Electronics
4.5.2	1042	M	R	H	C2	139	63	Activity Planning, Scheduling, and Execution
4.5.8	1042	M	R	H	C2	145	63	Automated Data Analysis for Decision Making
5.2.3	960	L	G	H	COM-N	169	1	Propagation
8.1.4	960	L	G	H	COM-N	262	1	Microwave, Millimeter-, and Submillimeter-Waves
8.1.4	241	M	Y	E	COM-N	262	8	Microwave, Millimeter-, and Submillimeter-Waves
1.4.5	1015	H	R	E	LRN	31	60	Health Management and Sensors
2.2.1	761	H	Y	M	LRN	61	50	Electric Propulsion
3.2.1	714	H	Y	M	per	88	99	Batteries
8.1.1	702	H	G	M	LD/MW	259	13	Detectors & Focal Planes
8.1.2	737	H	G	H	per	260	86	Electronics
8.1.2	743	H	G	H	per	260	88	Electronics
8.1.2	736	M	Y	H	per	260	89	Electronics
8.1.2	732	H	Y	M	per	260	90	Electronics
8.1.2	750	H	Y	M	per	260	91	Electronics
10	964	H	Y	M	per	305	100	Nanotechnology
10.2.1	714	H	Y	M	per	313	99	Energy Storage
11.1.1	743	H	G	H	per	326	88	Flight Computing
11.1.1	750	H	Y	M	per	326	91	Flight Computing

NSS and Civil Collaboration & Prioritization

NASA NSS Cross Walk Detail

NASA Need #	AFSPC Need #	Degree of Correlation	NASA Title	AFSPC Title
1.2.2	384	H	RP/LOX Based	Oxygen-rich staged combustion engine technology development and demonstration
1.2.3	384	L	CH4/LOX Based	Oxygen-rich staged combustion engine technology development and demonstration
1.2.6	301	M	Fundamental Liquid Propulsion Technologies	Combustion Stability Design Methods and Tools
1.4.1	760	M	Auxiliary Control Systems	Hydrazine replacement technology
1.4.2	1014	H	Main Propulsion Systems	Additive manufacturing technology maturation for launch vehicles
1.4.2	1002	M	Main Propulsion Systems	Light weight, low cost tank, vehicle, and fairing structures
1.4.5 *	1015	H	Health Management and Sensors	Launch Vehicle Health Management and Sensing Technologies

Lift and Propulsion S&T Detail

NASA Heat Shield for Extreme Entry Environment Technology (HEEET)

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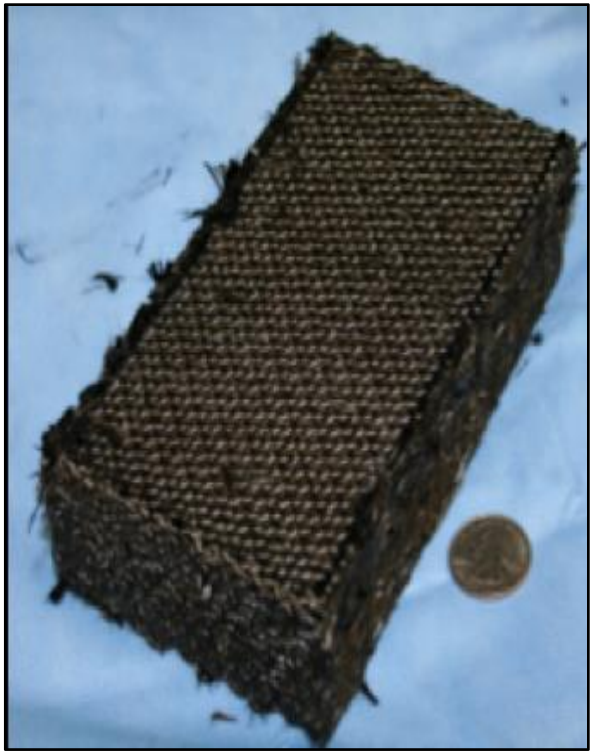


NASA and NSS May Benefit from Army's Work

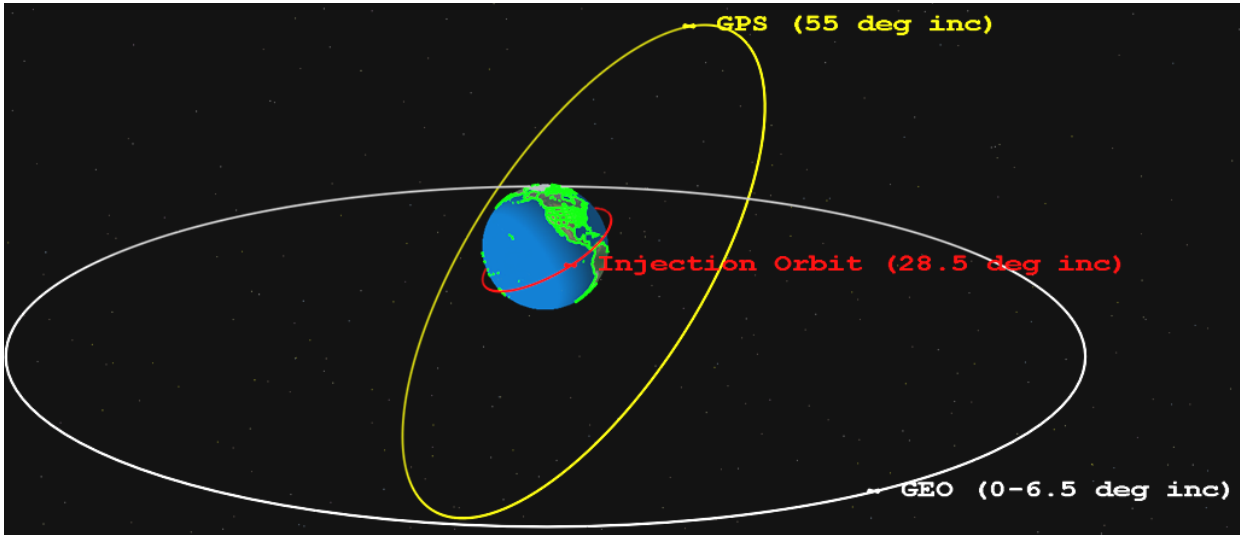
NASA and USAF NSS Collaboration

- NASA and NSS collaboration enhances capabilities
- Synergies identified and improved S&T investments
- Broad Awareness of multi agency S&T benefits all
- Building working relationships presents opportunities

Achieving Better Space S&T Performance

SEP Launch Architecture Concept

- the SMC launch enterprise can be re-imagined by using a LEO orbit as the standard injection orbit. All higher mission orbits can be achieved by SEP-powered orbit transfers [Penn et al 2014]:



Re-Imagined High Performance Launch Architecture

SEP Launch Architecture Benefits

- **Significant potential benefits include:**
  - **Downsizing spacecraft and launch vehicles**
  - **Lowering fleet-wide architecture costs: Smaller boosters, dual launching, and possibly launching all vehicles from a single launch site**
  - **Increased maneuverability**
  - **Increased resiliency ("graceful" failure mode with multiple SEP engines)**
  - **More efficient and effective constellation management**
  - **Provide extra power and enabling enhanced payload capability and performance**
  - **Enhanced end-of-life options (possible de-orbit) and reduced orbital debris**
  - **Enabling larger launch windows**
  - **Enabling previously infeasible/impractical missions: Maintaining unstable orbits or ground tracks and Dynamic orbit change flexibility (high number of orbit changes and repositions)**

Multiple Benefits to the Space Enterprise

USAF Rapid Innovation Program

- Led by SAF/AQR, SMC evaluates NSS
- Small investments (<$3M)
- Fast transition to capability (<2yrs)
  - Carbon Nanotubes harness (-30% weight)
  - IP Encryption (HAIPE) for small Satellites
- Bridge SBIR S&T to capability
- Leverage small, athletic companies

Meaningful capabilities for small investments

STEM - Harvey Mudd College (HMC)

- Leadership of Engineering Visitors Committee (EVC)
  - Accreditation, Curriculum, Faculty, Development
- Sponsorship of capstone projects
  - 25 annual projects on NSS topics
- Successful recruitment at all levels

Future capabilities for embryonic investments

STEM – USAFA, AFIT

- Work with AFIT faculty on thesis topics
- Recruitment of graduate students to SMC
- Work with USAFA graduates incoming to SMC at all levels
- Interest in academic cubesat programs
- Influence curriculum to make it relevant to S&T needs

S&T investments driving workforce impact

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NASA

AEROSPACE

Envisioning and Shaping the Future of Space