Space Science & Technology Partnership Forum

Value Proposition, Strategic Framework, and Capability Needs for In-Space Assembly

AIAA Space 2018 Forum

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Introduction

- **Space paradigm undergoing a revolution enabled by autonomy and robotics**
  - Large, persistent space assets assembled and routinely upgraded
- **In-space assembly (iSA), in-space servicing (iSS), and ultimately in-space manufacturing (iSM) will transform space operations capabilities with:**
  - Significant economic and performance benefits
  - For government and commercial space endeavors
- **Current state-of-the-art (SOA)**
  - 5-10 year-old technology at launch
  - 25+ year-old technology at end of mission life
- **iSA and iSS enable advancements beyond SOA**
  - Incorporate modules with rapidly-improving technology
  - Through modifications to upgrade and extend the life (persistence) of the space asset
  - Ensure capabilities remain on the cutting edge

Introduction

- **Traditional way of building spacecraft leads to cycles of spiraling costs**
  - Higher-cost payloads motivated higher-reliability launch vehicles, which increased launch costs
  - Increased performance with larger payloads mandates larger and heavier-lift launch capabilities
- **New, low-cost commercial launch systems have potential to break the spiral**
  - iSA will take advantage of these launch systems
- **Advances in automation and robotics make iSA possible**
  - Building up large structures beginning with relatively simple components
- **iSA technologies will reduce cost of developing and launching new systems**
  - Enable repair or upgrade satellites

Why In-Space Assembly?: Potential Benefits

- **iSA improves value of space assets by lowering life-cycle cost and achieving higher performance**
- **iSA brings new capabilities enabled by spacecraft dimensions, masses, or configurations that cannot be launched from Earth**
- **iSA allows individual spacecraft to evolve in response to new knowledge, techniques, and technologies**
- **iSA makes mission success less dependent on launch or on-orbit failure by offering options for recovery, which in turn could reduce the costs of making systems extremely reliable**
- **iSA improves cost-effectiveness through reusability and by enabling the phased accretion of capabilities through upgrades in operation**

Why In-Space Assembly?: Potential Benefits

Benefits of In-Space Assembly

Bring about new capabilities enabled by spacecraft dimensions, masses, or configurations that cannot otherwise be launched from Earth

Reduce Cost

Improve Performance

Limit Risk

- Structures assembled in space designed for **operational loads**, not launch loads
- Avoid system complexity and parasitic mass of on-orbit deployment
- **Extensible/reusable** spacecraft support broader range of missions and conditions
- **Remove/replace** modules during operation -> improve life cycle costs & mission risk
- **Modularity** enables launches of small components on lower-cost comm vehicles
- Only lose modular elements if failure, not entire spacecraft
- **Incremental buildup** distributes cost across time -> pay as you go approach
- **Facilitates cost sharing** by multiple programs and multiple government agencies

When mature, in-space assembly, combined with in-space servicing, could produce significant advantages in spacecraft cost, performance, and risk

In-Space Assembly: Current Activities

- **Government and commercial already investing in the new paradigm in iSA and iSS**
- **iSA development and continual capability improvements will require a public-private partnership**
- **Technology and capability maturation will benefit from cooperation towards a shared goal**
- **Common core of high-leverage technologies should provide the nucleus of a capability that would form the basis path towards a robust and flexible capability for the spectrum of users.**
- **Space Science & Technology Partnership Forum**
  - U.S government space agencies produced agreement to explore the next steps in a possible cooperative endeavors

Space Science & Technology (S&T) Partnership Forum: Introduction

Allow large, persistent space assets to be assembled and routinely upgraded in space

Transform space operations capabilities with economic and performance benefits for both U.S. Government and commercial space endeavors

The Space Science & Technology (S&T) Partnership Forum is a strategic forum established in 2015 to identify synergistic efforts and technologies.

Interagency Science & Technology Partnership Forum

Leverage synergies and influence agency portfolios

Principal Partners: USAF, NASA, NRO

Affiliate Partners: AFRL, AFOSR, NRL, OUSD, AF SMC, DARPA, NOAA

The S&T Partnership Forum has identified and prioritized pervasive goals (collaboration topic areas) that focus on key game-changing technologies across government space

Other Topics
- Small Satellite Technology
- Big Data Analytics
- Cybersecurity

1. Facilitate cross-agency collaboration and strategize on technical solutions to common pervasive needs
2. Maintain awareness of each agency's space S&T investments to reduce duplication and identify areas worthy of collaboration
3. Identify impediments to collaboration and formulate solutions

In-Space Assembly

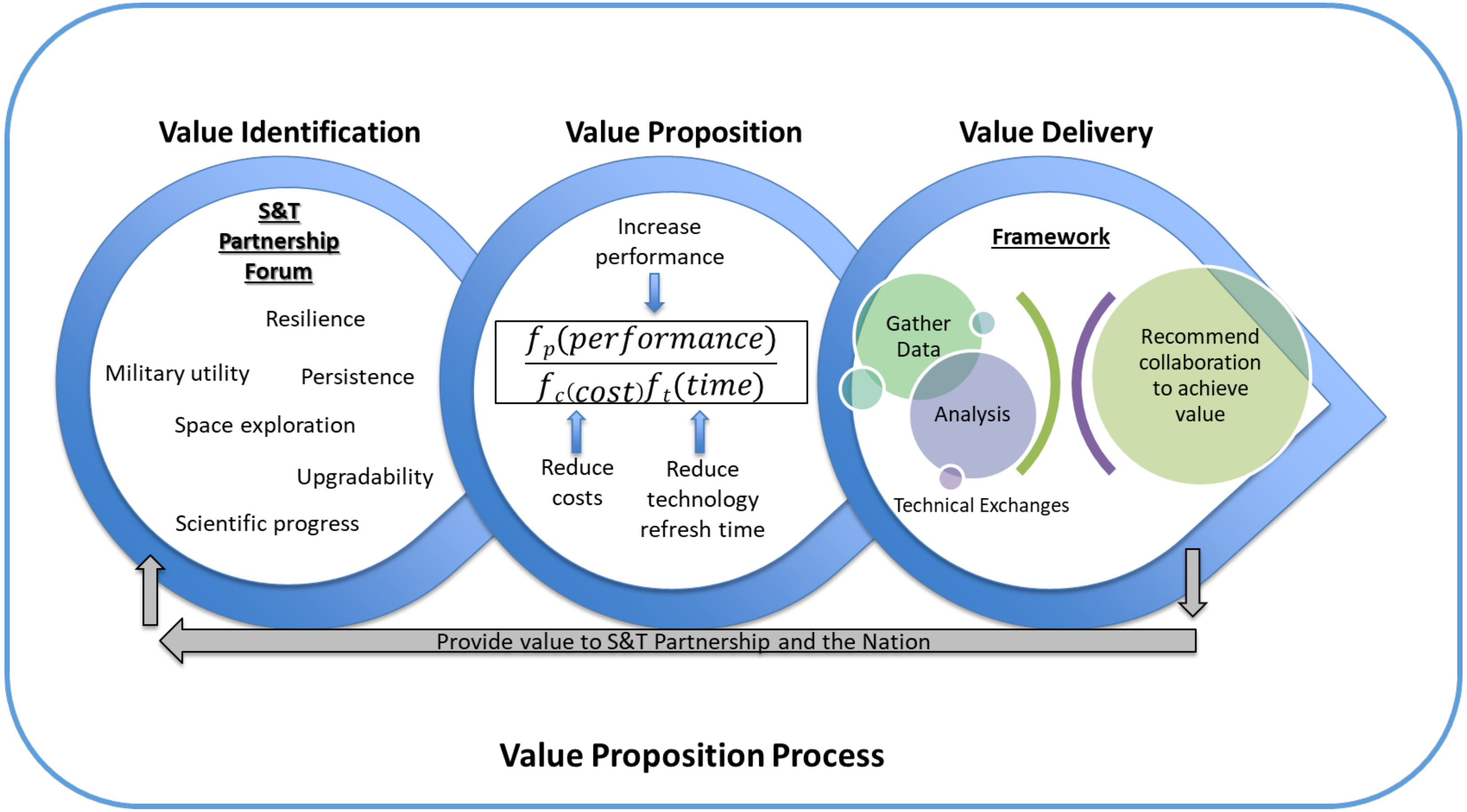
Space Science & Technology (S&T) Partnership Forum: iSA

- **Autonomous and semi-autonomous in-space assembly (iSA) is the focus of the collaboration topic area that NASA, under the direction of the Office of Chief Technologist (OCT), is currently coordinating among the S&T principal partners and affiliate partners.**
- **Aim to identify cross-cutting applications and benefits of developing a robust iSA capability for future space assets**
- **The S&T iSA facilitation and analysis team, led by NASA OCT, collected data from the participating agencies on their current developments, activities, and needs in the area of in-space assembly.**
- **Herein is presented an overview of the S&T iSA facilitation and analysis team's efforts in:**
  - establishing the value proposition and strategic framework for interagency collaboration in iSA within the partnership as a foundation to deliver value and achieve iSA topic objectives across government space agencies
  - defining of the iSA capability needs, design drivers, and stakeholder goals to facilitate dialogue within the partnership and the larger community

S&T Value Proposition: Process Overview

- Introduction
- In-Space Assembly
- S&T Partnership Forum
- Value Proposition
- Strategic Framework
- Stakeholder Goals & Design Drivers
- Capability Needs
- Conclusions

Value is how the S&T Partnership Forum stakeholders find worth, utility, benefit, or reward for their respective contribution to the enterprise.



Credit: NRL

1. Value Identification: Identify the stakeholders and their value expectations

2. Value Proposition: Develop a robust value proposition to meet stakeholder expectations

3. Value Delivery: Deliver on the promise with excellent technical and programmatic performance.

S&T Value Proposition: Process - Step 1

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1. Value Identification: Identify the stakeholders and their value expectations

Resilience

level of invulnerability of a system in the presence of stress or in the event of an adversarial attack.

Military Utility

capability of the space system to achieve military objectives through operational effectiveness, suitability, availability, interoperability & affordability.

Upgradability

ability to improve performance and/or effectiveness of a system architecture by replacing sub-systems with newer & better capabilities.

Scientific Progress

_advance science & technology to enhance knowledge, education, innovation, economic vitality and stewardship of Earth.

Space Exploration

pursue missions through critical research and technology demonstrations, promotion of a robust U.S. commercial space industry, and space systems and robotic exploration of Earth from orbit and of the cosmos beyond.

Persistence

continued or prolonged existence of a space system and its required capabilities and operations.

S&T Value Proposition: Process - Step 2

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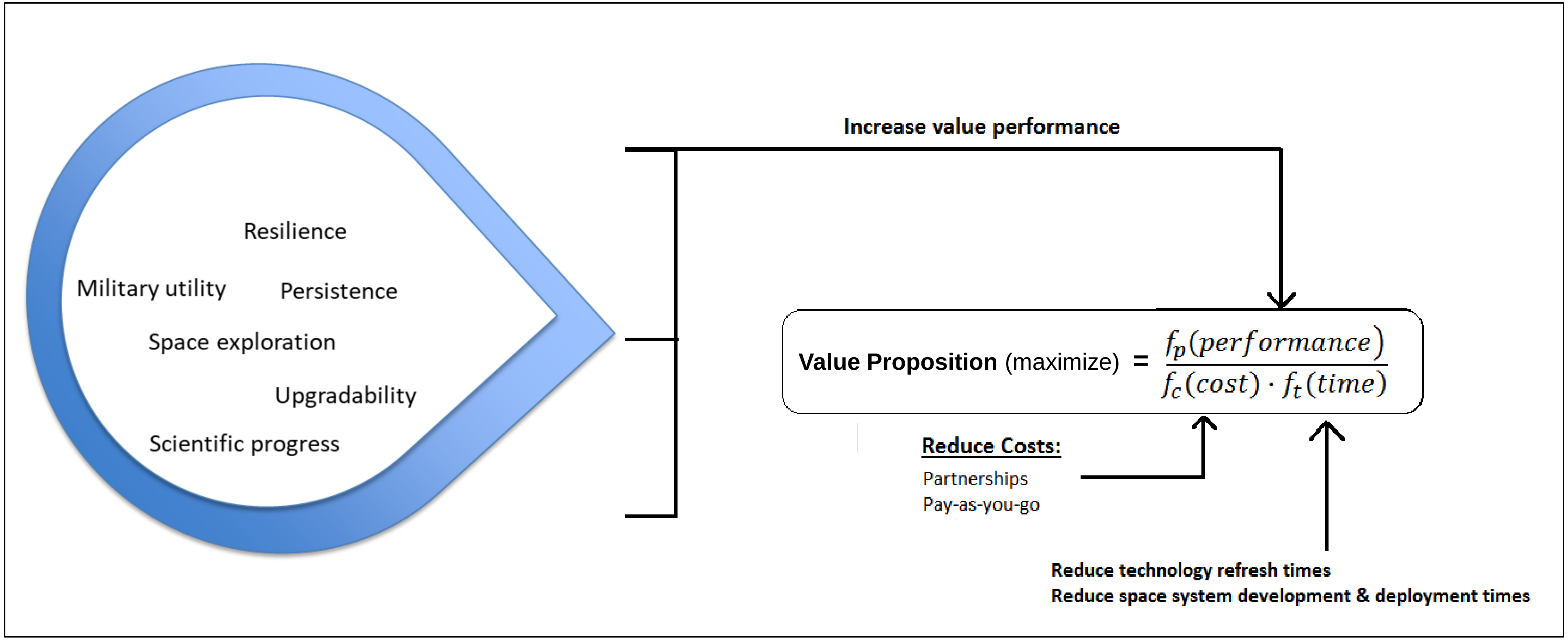
2. Value Proposition: Develop a robust value proposition to meet stakeholder expectations

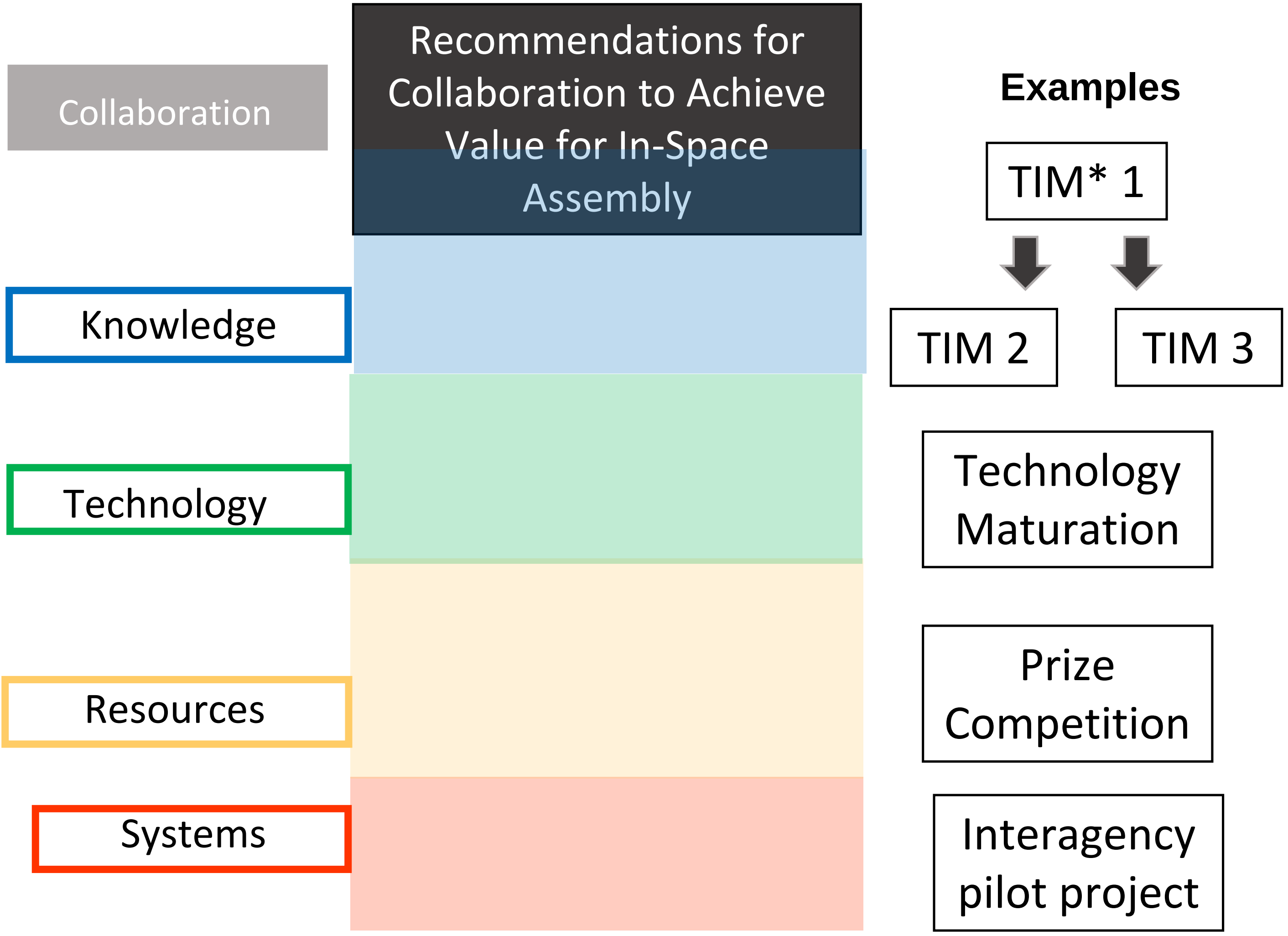
S&T iSA Value Proposition addresses the most basic question:

Why does the government, in a partnership arrangement, want to invest in in-space assembly?



S&T Value Proposition: Process - Step 3

3. Value Delivery: Deliver on the promise with excellent technical and programmatic performance.



* Technical Interchange Meeting

Strategic Framework for the S&T Partnership Forum

Value Delivery Goal

Execution of in-space assembly that is both efficient and effective

Value Process Summary:

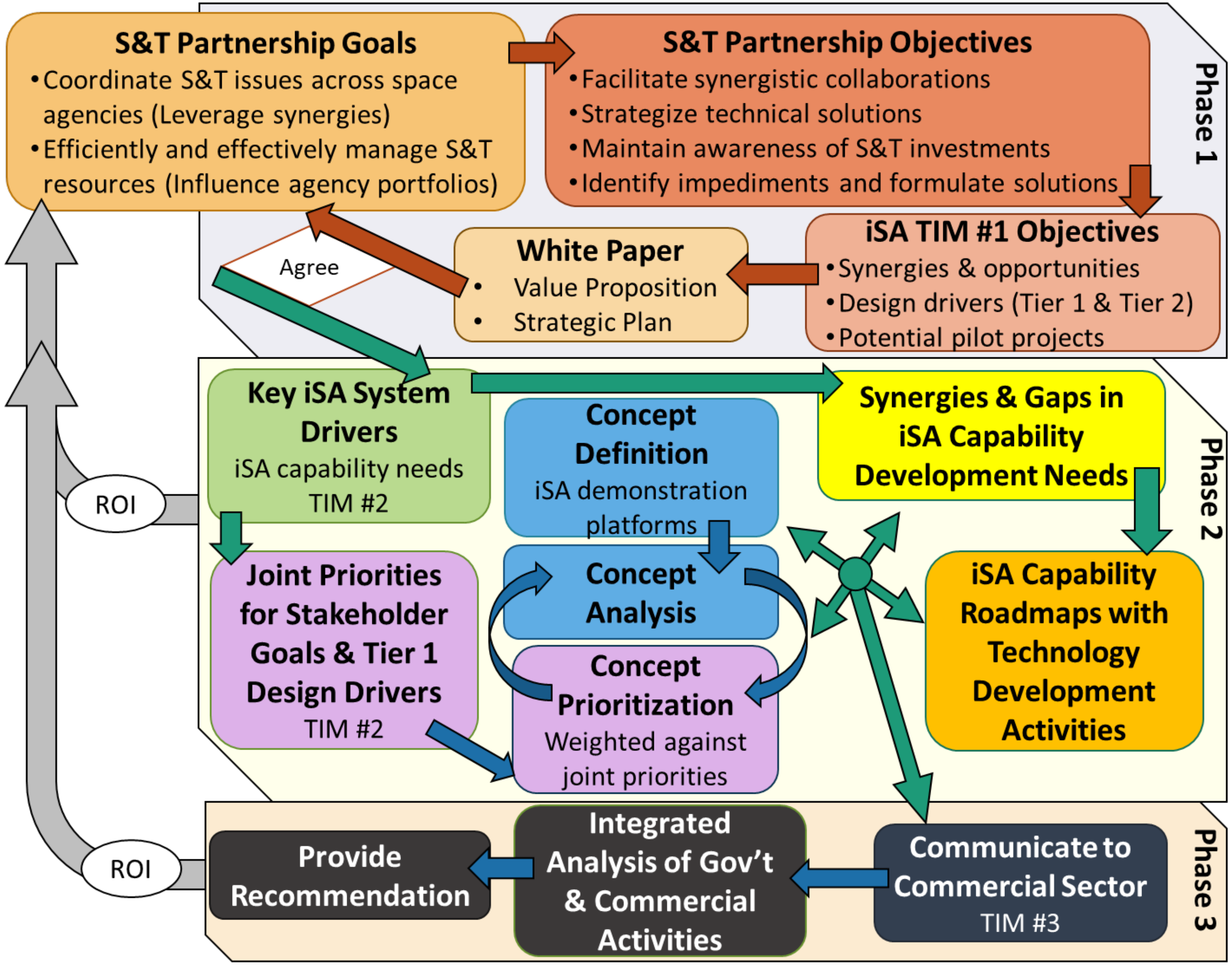
The government is facing a rapidly changing environment where new technologies and capabilities are entering the market place at an ever increasing rate.

To exploit the impacts of technologies and innovations, the government can anticipate the future of in-space robotic capabilities, rather than react to them.

Strategic Framework:

The strategic framework lays out how the advantages of new robotic technologies with government and commercial engagement will enhance in-space capabilities and reduce future costs.

S&T Strategic Framework for iSA: Overview



Strategic Framework:

The strategic framework lays out how the advantages of new robotic technologies with government and commercial engagement will enhance in-space capabilities and reduce future costs.

S&T Strategic Framework for iSA: Glossary of Terms

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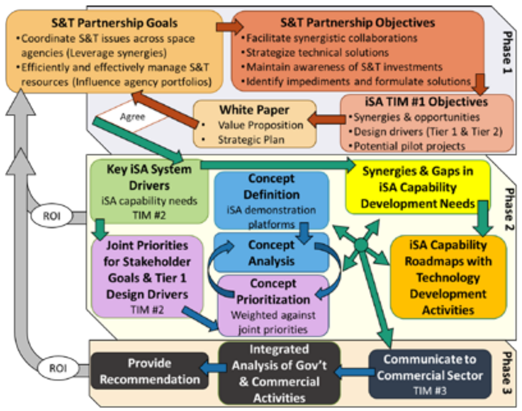
- **(Functional) Capability:** the ability to perform lower level functions that combine to perform tasks to assemble a mission system. It represents basic functionality needed to perform a given task.
- **Technology:** solution that enables functional capability developments and thus the capability. Multiple technologies may be matured to enable a functional capability.
- **Operational Mission:** where the ISA capabilities are applied to perform a mission in the future (e.g. large telescope, artificial gravity habitat)
- **Technology Demonstration Mission (TDM):** where ISA capabilities are demonstrated on flight missions (e.g. Restore-L, RSGS)
- **Technology Development Activity:** activities performed to advance capabilities (e.g. specific technologies like manipulators/robotics, algorithms for autonomous operations)
- **Relevance:** relevance of capabilities to an organization's in-space assembly operational missions, assessed as Enabling or Supporting
- **Prioritization:** degree to which a capability supports a stakeholder goal (strategic desires) and Tier 1 design drivers (technical attributes) identified in TIM 1
  - **Stakeholder Goals:** long-term performance targets for the S&T Partnership Forum stakeholders
  - **Tier 1 Design Drivers:** a particular property or application of a concept that serves as the rationale for the concept's design to achieve its goal. Tier 1 design drivers are those that were rated highest during a preliminary collective prioritization at TIM 1.



S&T Strategic Framework for iSA: Phase Timeline

	Prework	TIM	Analysis	Deliverables
Phase 1	Present planned & current efforts in specific iSA areas and identify challenges	TIM #1 Synergies & Opportunities Potential Pilot Projects	Prioritization of Demonstration Objectives and Proposed Collaborative iSA Concepts	iSA Value Proposition White Paper Strategic Framework
Phase 2	Define key iSA system drivers	TIM #2 Gaps in iSA Capability Needs Joint Priorities	Gaps, Synergies, Roadmaps, Demo Platform Readiness	Gov't Roadmaps, Data Visualization, Capability Prioritization, Platform Recommendations
Phase 3	Define iSA non-government market analysis questionnaire	TIM #3 Communication to Commercial Sector Industry Open Forum	Integrate industry input to gov't capability analysis	Recommendations for Gov't & Comm. Bridging Activities

S&T Strategic Framework for iSA: Phase Timeline : Current Status

	Prework	TIM	Analysis	Deliverables
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Phase 3	Define iSA non-government market analysis questionnaire	TIM #3 Communication to Commercial Sector Industry Open Forum	Integrate industry input to gov't capability analysis	Recommendations for Gov't & Comm. Bridging Activities

★ We are here

S&T Strategic Framework for iSA: Phase 1

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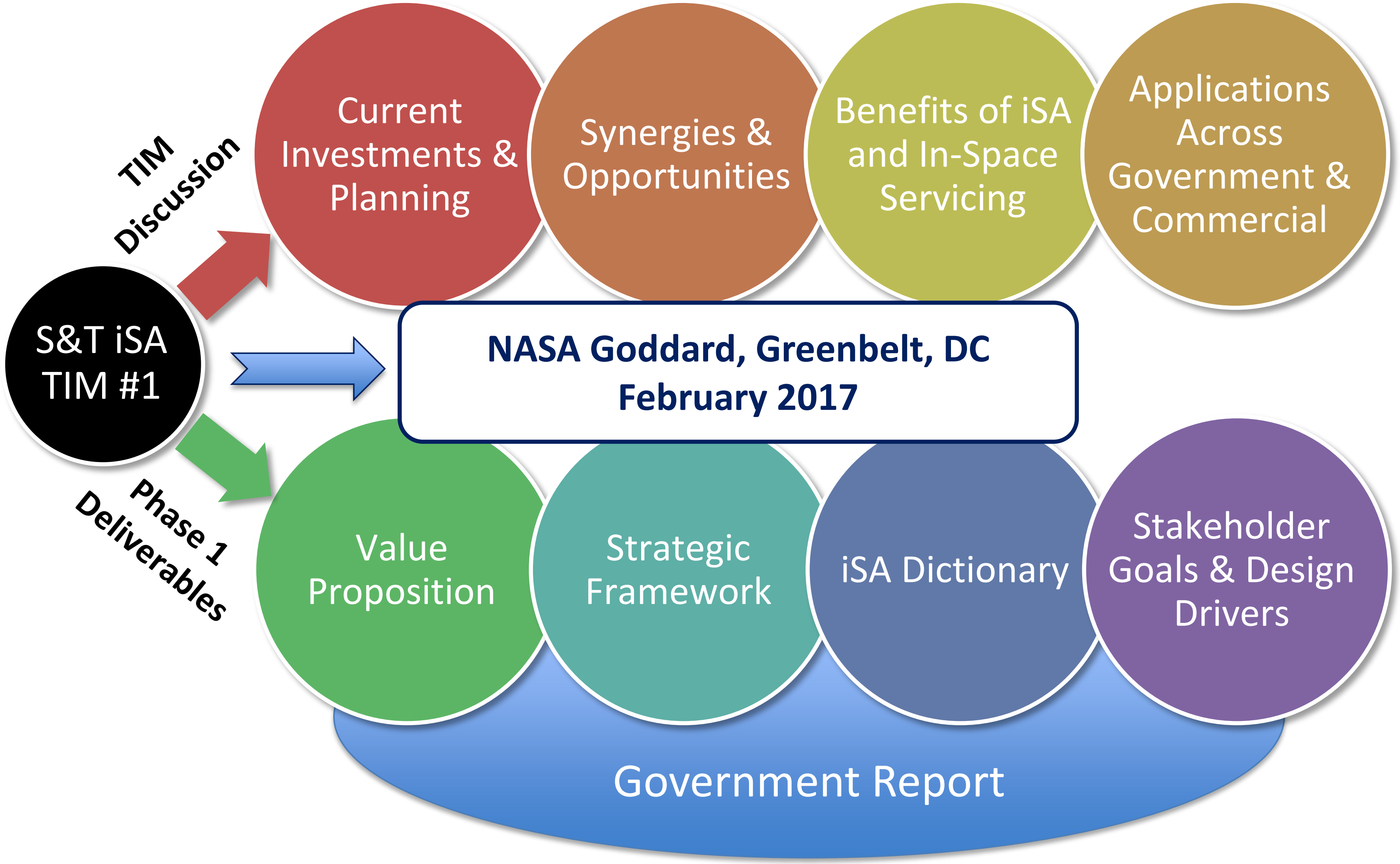

S&T Strategic Framework for iSA: Phase 1

- **Key Results**

1. Conducted TIM, described govt activities, documented govt iSA planning

2. Strategized on partnering activities, defined value proposition & strategic plan

3. Categorized capabilities, document benefits, documented potential concepts, identified applicability of commercial sector

4. Integrated TIM data into document, established nomenclature, delivered and communicated document

S&T Strategic Framework for iSA: Phase 2

S&T Strategic Framework for iSA: Phase 2

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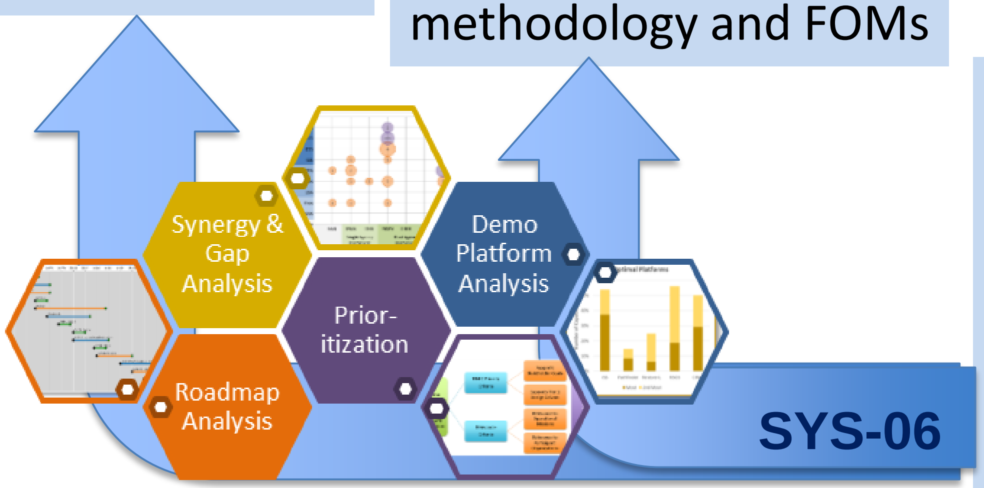
- **Key Results**

1. Developed analysis framework, held TIM, collected and prioritized data

2. Defined synergies, gaps, constructed roadmaps, bridged analysis to prioritization

3. Determined and assessed potential demo platforms, developed analytic methodology and FOMs



4. Integrated analyses to make gov't partnering recommendations, shared data analysis with principals, **published public papers (2018 AIAA SPACE)**

S&T Strategic Framework for iSA: Phase 3

Phase 1, TIM 1: Stakeholder Goals and Design Drivers

- **Stakeholder Goals**: long-term performance targets for the S&T Partnership Forum stakeholders
- **Tier 1 Design Drivers:** a particular property or application of a concept that serves as the rationale for the concept's design to achieve its goal. Tier 1 design drivers are those that were rated highest during a preliminary collective prioritization at TIM 1

Stakeholder Goals (from TIM 1)
Supports Near term demo - A demo or mission that could be completed within the next 1 or 2 budget cycles
Affordable - Ability of a mission to meet budget targets
Lower Cost (in future) - The capabilities developed in early missions could potentially lower the cost of future missions
Industry transitioning - Capabilities demonstrated in missions that open up a new market for commercial space entities to pursue

Tier 1 Design Drivers (from TIM 1)
Stability - The tendency of a system to return to its desired state after being acted upon by outside influences.
Assembly - The capability to assemble or construct spacecraft or space system components by joining components through a variety of methods.
Upgradability - Refers to design choices that allow for the insertion of new technologies or enhanced capabilities after launch
Scalability - Part count stays the same, but the size or dimensions change (Dorsey et al., 2006).
Interfaces - Place at which independent systems meet and act on or communicate with each other.

Capability Needs

1. Deployable modules
- 1.1 Deployable subsystems
- 1.2 Inflatable components

2. Structural Assembly
- 2.1 Robotic assembly with joining
- 2.2 Long-reach manipulation
- 2.3 Ability to assemble low mass structures
- 2.4 Ability to assemble high strength structures
- 2.5 Ability to assemble high stiffness structures
- 2.6 Ability to assemble structures with micro-stable joints
- 2.7 Ability to assemble structures with high dimensional stability
- 2.8 Ability to assemble structures with near isothermal control
- 2.9 Ability to assemble structures on planetary surfaces (e.g. Moon, Mars)
- 2.10 Ability to deploy hybrid assembly and in-space fabrication processes, such as additive manufacturing.
- 2.11 Conductive heat transfer across assembled joints

3. Connecting utilities
- 3.1 Ability to route electrical power and data across assembled joints
- 3.2 Ability to route coaxial cables across joints
- 3.3 Ability to route fiber optical conductors across joints
- 3.4 Ability to route fluids across joints

4. Ability to disjoin
- 4.1 Ability to reversibly assemble structural, electrical, and fluid connections.
- 4.2 Ability to disconnect structural, electrical, and fluid connections without propagating damage to other system components.

5. Sensing, Modeling, Simulation, Verification
- 5.1 Means of verifying the continuity of interface connections / disconnections.
- 5.2 Sensors to accurately and precisely measure the quality of the build-up in progress.
- 5.3 Sensors to accurately and precisely measure the as-built configuration.
- 5.4 Sensors to detect failures and/or unacceptable quality of the assembly process after it has been completed.
- 5.5 Modeling and simulation for verification and validation
- 5.6 Modeling and simulation for assembly sequencing / planning
- 5.7 Quantitative performance prediction for autonomous systems

6. Interoperability
- 6.1 Standard protocols and ports to accommodate visiting vehicles and communication traffic.
- 6.2 Standard but secure communication protocols to accommodate interaction with other (TBD) associated systems.

7. Automation/Autonomy
- 7.1 Intelligence to make stereotyped decisions correctly without human input.
- 7.2 Intelligence for full autonomy
- 7.3 Fail-safe modes of behavior on failure detection.
- 7.4 Multi-agent autonomy (distributed situation assessment & coordinated control)

8. Precision
- 8.1 Jigging and joining processes capable of achieving a high level of precision open-loop.
- 8.2 Known precision limits of any and all assembly agent elements across the assembly site's environmental envelope

9. Adaptive Correction
- 9.1 Tools and approaches to alter a build-up in progress to correct build up errors.

10. Design
- 10.1 Tools and component parts capable of accommodating a continuous spectrum of design options.
- 10.2 Assembly agent geometries, systems, and tools that do not preclude dimensional or mass growth of the client system.
- 10.3 Modular design
- 10.4 Design for assembly
- 10.5 Design for serviceability

11. Tunability
- 11.1 Ability to accommodate structural members with active length control.
- 11.2 Ability to accommodate power and data control interfaces associated with active structural members.
- 11.3 Ability to accommodate TBD sensors for length and/or structural geometry.

12. Stability
- 12.1 Ability to accommodate passive vibration damping.

13. Standard Interfaces
- 13.1 A limited number of standard mechanical, electrical, thermal, and fluid connection approaches with well-characterized properties.

14. Docking/Berthing
- 14.1 Soft docking / berthing of modules

Conclusions

- **Space S&T Partnership Forum, an interagency collaboration effort among NASA, the USAF, the NRO, DARPA, and the NRL, serves to coordinate and facilitate partner dialog, collect data and perform data analysis, and assemble data products into recommendations for partnerships to be executed within the S&T community.**
- **S&T iSA facilitation and analysis team coordinates efforts for the iSA collaboration topic area within the Forum with results described herein from Phases 1 & 2:**
  - iSA value proposition
  - strategic framework
  - capability needs
  - stakeholder goals and design drivers
- **Aforementioned efforts within phases of strategic framework feed into:**
  1) the data collection and analysis of iSA capabilities, including the development of government roadmaps for iSA efforts and
  2) the prioritization of iSA capability needs and potential demonstration concepts for advancing iSA capabilities via interagency collaboration.
- **Preliminary results of these efforts will be presented in the 2018 AIAA SPACE session SYS-06 on Tuesday, September 18th**

Conclusions: AIAA SPACE 2018 Presentations on Phase 2 Data Analysis

Tuesday, September 18, 2018
SYS-06. In-Space Assembly and Manufacturing
Room: Celebration 2

5:00 PM - 5:30 PM	Space Science and Technology Partnership Forum: Analysis for a Joint Demonstration of High Priority, In-Space Assembly Technology *Doris Hamill; Sharon A. Jefferies; Robert W. Moses; Frederic Stillwagen; Carie Mullins; Elaine Gresham*
5:30 PM - 6:00 PM	Space Science and Technology Partnership Forum: In-Space Assembly Data Collection and Analysis *Dale C. Arney; Phillip A. Williams; James A. Dempsey; Erica Rodgers; Karin Bozak; Camryn Burley; Daniel Long; Riaz Husain*

Thank you for your attention!