



Applying Principals of Agile to Small Satellite Development with a System of Systems Approach

Lab77



November 21, 2016

v. 1.0.1



Stories



1. My Background



2. Small satellites

AGILE

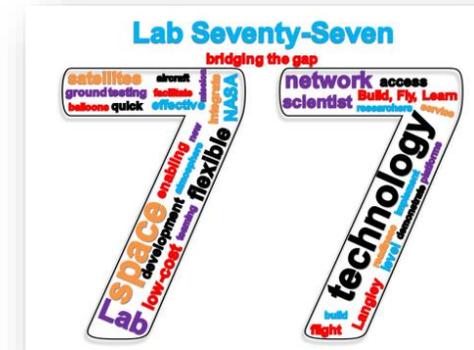
3. Agile principles



4. idea to Mission



5. Enabling Tools



6. Wrap Up



Agile and Developing Labs

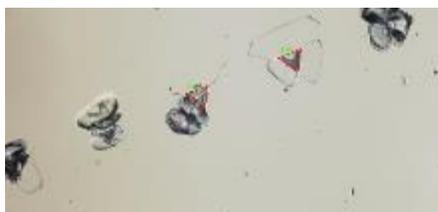


ODU: Space Systems Lab ⁰⁵⁻⁰⁹



Cancer, wireless comm, ISRU

ARC: Nano Indentation Lab ⁰⁶⁻⁰⁷



Nano-materials & manufacturing

NASA: Robotics and Intelligent Machines Lab ⁰⁷⁻⁰⁹



Behavioral robotics & science platforms

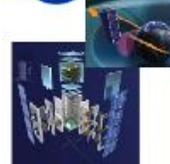
Lab77: Build, Fly Learn ¹²⁻



Small satellite utilization



Active LaRC Missions started with support from Lab77



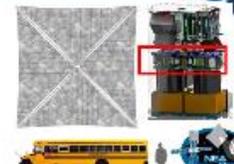
Shields-1 Radiation Shielding materials



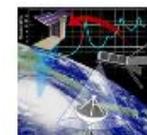
Rapid Response Radiation Survey, conformal satellite platform evaluation



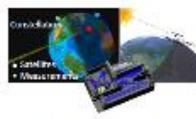
On-Orbit Autonomous Assembly from Nano-satellites (OoAN)



Solar sail deployment mechanism for Near Earth Asteroid (NEA) Scout



Differential Absorption Barometric Radar



SAGE-IV: Stratospheric Aerosol Gas Experiment



ARCSTONE: Calibration of Lunar Spectral Reflectance from Space



Sensor Enabling Photon Sieve Technology



Exposure to Agile



- July 2006: ICAM (International Conference on Agile Manufacturing)*
- 2009-2016: COFES (Congress On the Future of Engineering Software)
- November 2014: Langley Agile Boot Camp
- 6 months 14/15: Langley “Lean-n-agile thinking group”

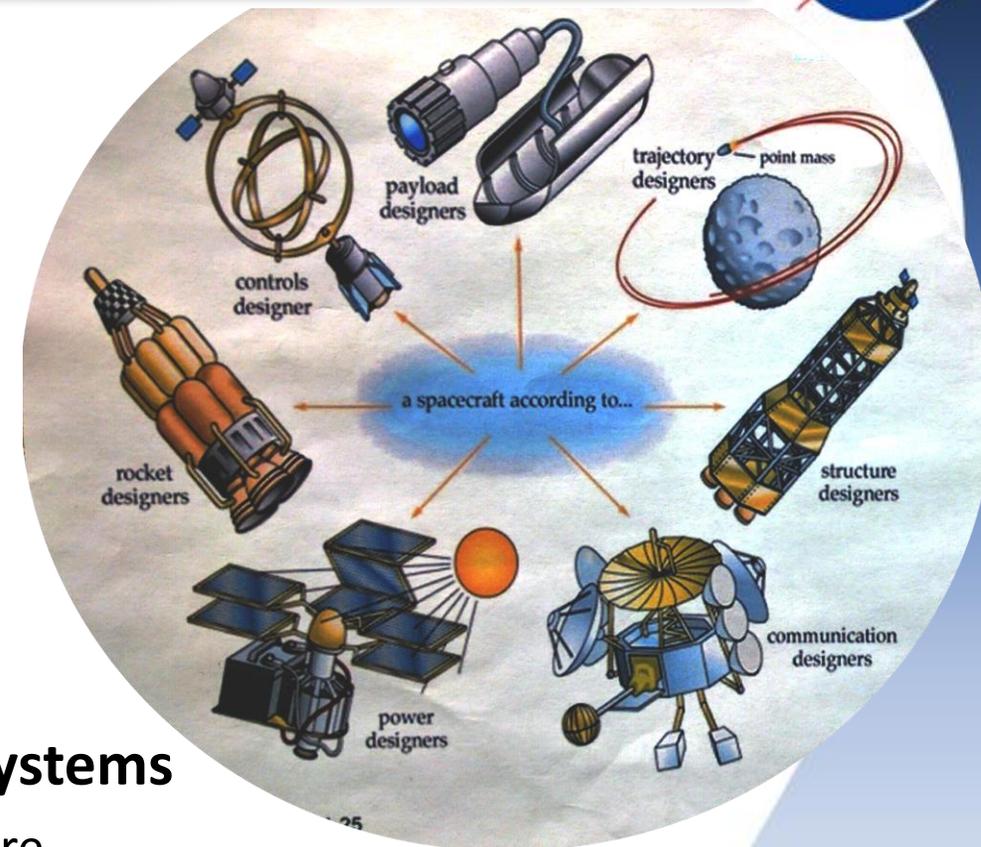
*Lean Institute and International Society of Agile Manufacturing,



Story 2: Small Satellites and the System of Systems Surrounding a Satellite Mission



➤ Definitions & Trends

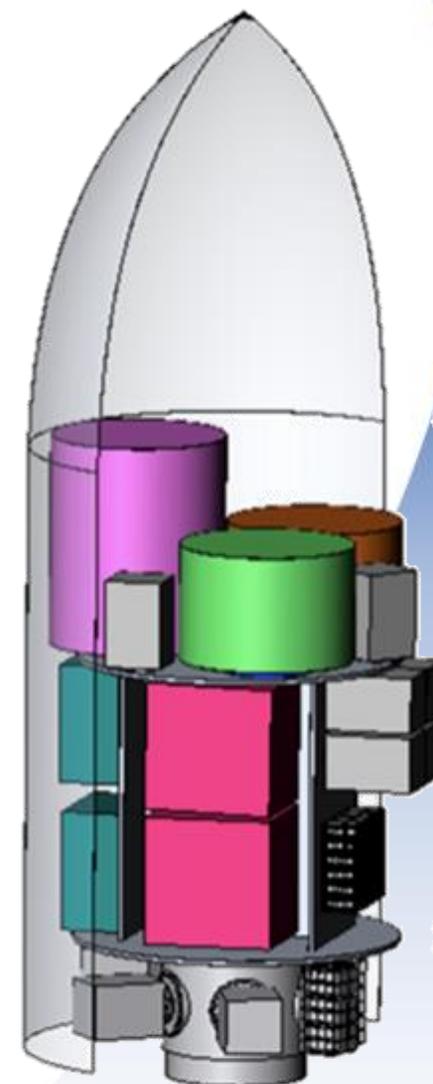
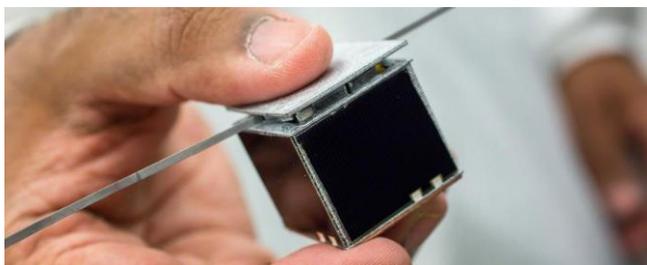


➤ 5 Interdependent Systems

- Political infrastructure
- Mission Classification
- Communication/Collaboration Infrastructure
- Satellite System
- Eco-system of the small satellite industry

➤ What they are?

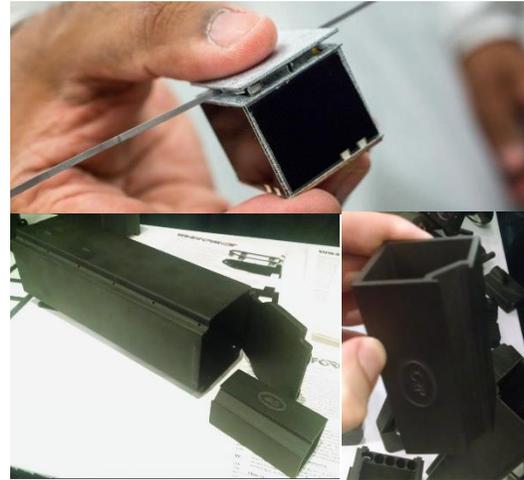
- NASA considers them to be up to 180kg, DoD and NRO up to 500kg
- Costs range from \$7k-\$100M+ depending on what the mission is and the instruments flying



Satellite Type

Providers

- SIL (Space information Laboratories)
- MAI (Maryland Aerospace)
- BST (Berlin Space Technologies)
- GOMspace
- Surry Satellite Technology
- Magellan Aerospace
- Tyvak
- Cannon
- AAC Microtec
- Pumpkin Space Systems
- Aerospace
- Astra Space
- Clyde Space
- Micro Aerospace Solutions
- OPUSAT-Kit
- ISIS - innovative solutions in space
- ARTSAT-KIT
- Astro-und Feinwerktechnik Adlershof GmbH
- NovaWurks -space for everyone
- SCS Satellite Systems
- UTIAS – SFL (Space Flight Laboratory)
- NanoAvionics
- ORS - operationally responsive manufacturing



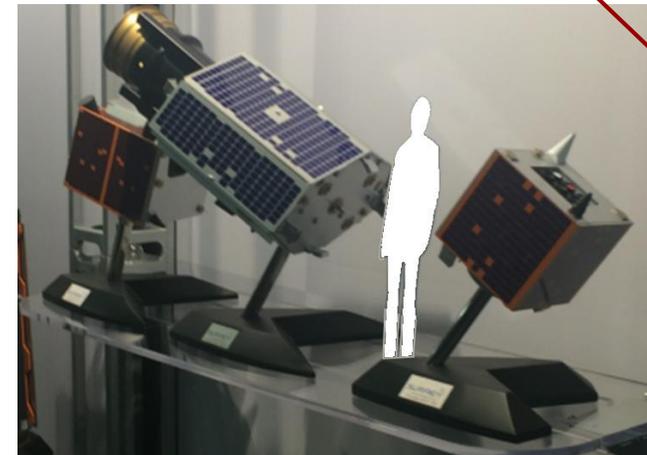
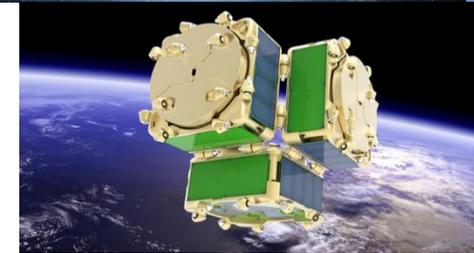
Sprite

CubeSat

ESPA

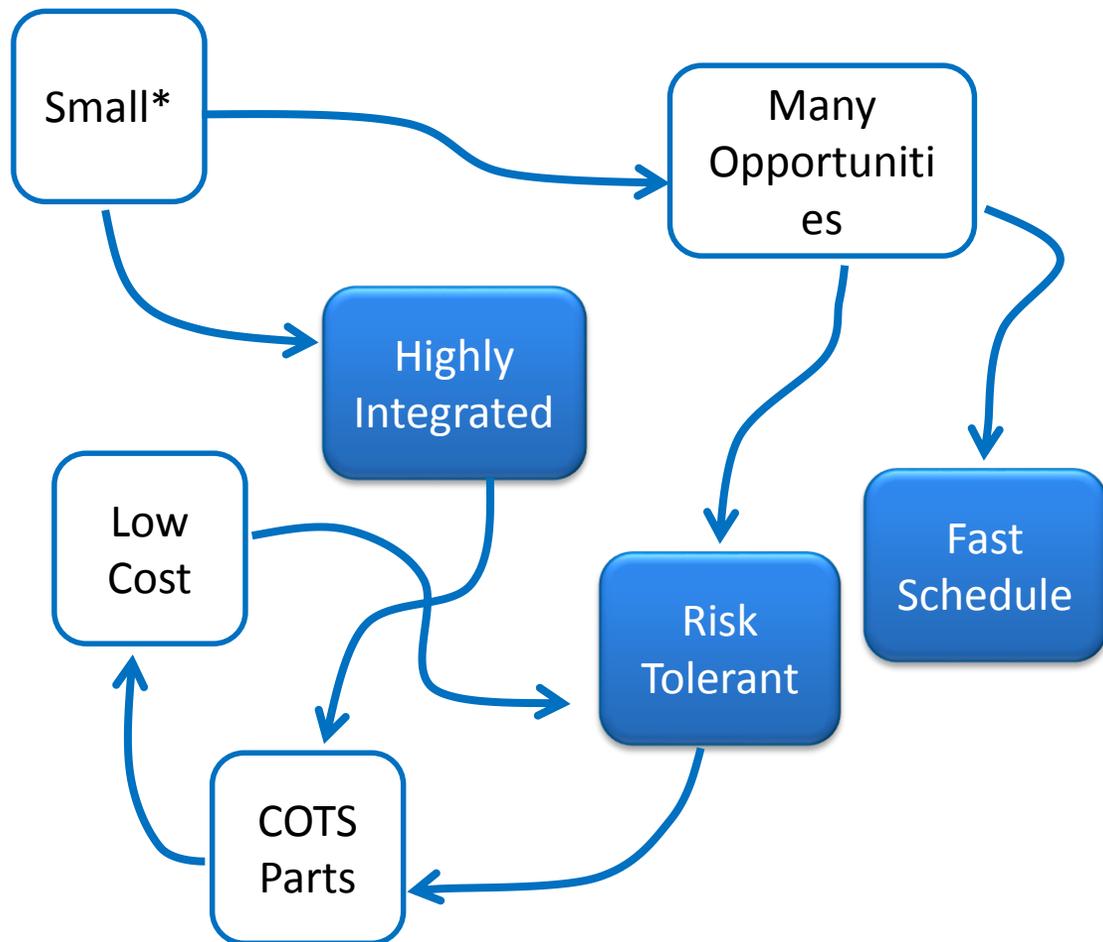
Conformal Satellite

Conventional but small

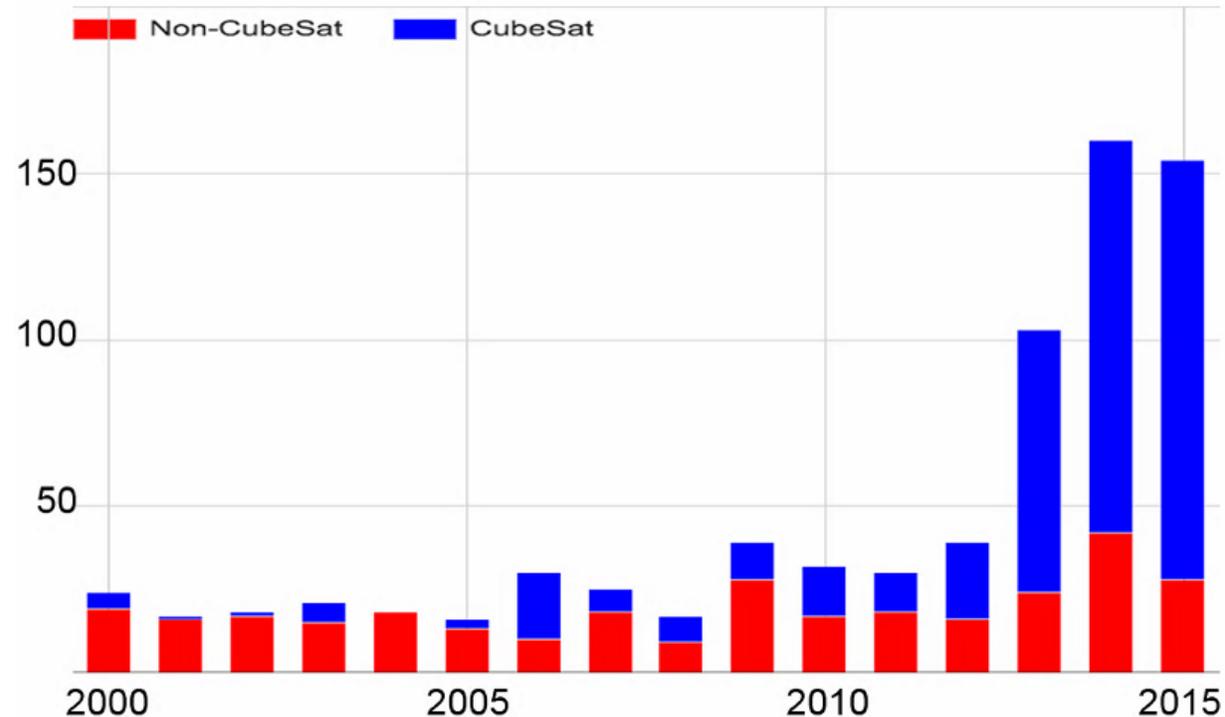




The effect of the CubeSat on the Space Industry



CubeSats vs. Non-Cubesats**

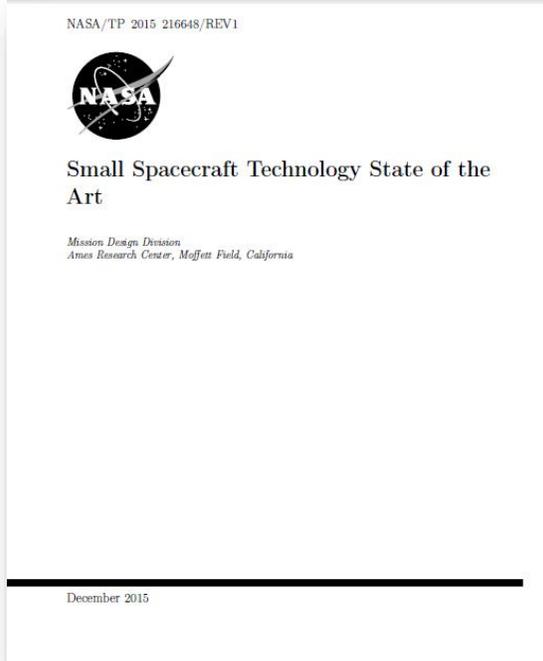


*Jordi Puig-Suari (Tyvak), MARS2C (Mid Atlantic Small Sat Community) meeting, July 2016

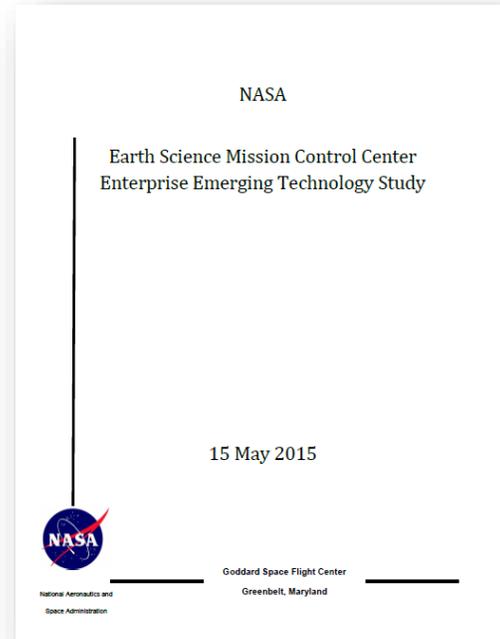
**Michael Swartwout, Mission Success in CubeSats: Improving the Data Collection, NASA Small Spacecraft Community of Practice, March 2016



Position Documents Published



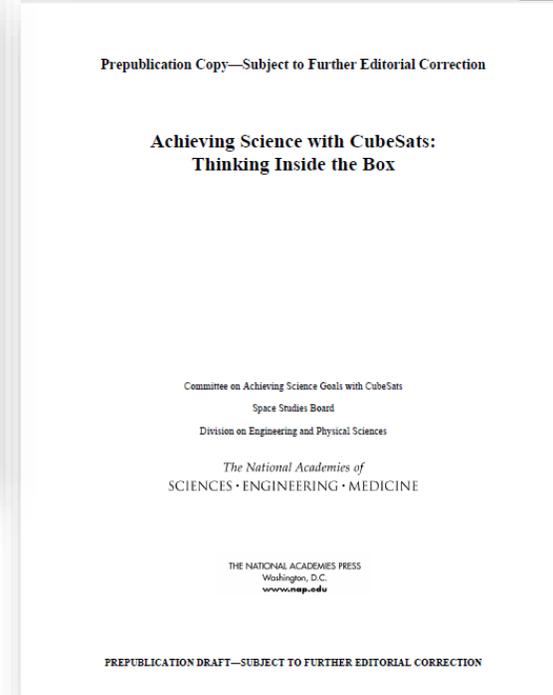
2014/2015: Small Spacecraft Technology State of the Art
~ Ames Mission Design Division



2015: Earth Science Mission Control Center Enterprise Emerging Technology Study
~ NASA Earth Science Technology Office



2016: NASA SmallSat Activities
~ NASA Science Mission Directorate



2016: Achieving Science with CubeSats: Thinking Inside the Box
~ Academy of Sciences



Small Sat Launch Providers Coming On-Line



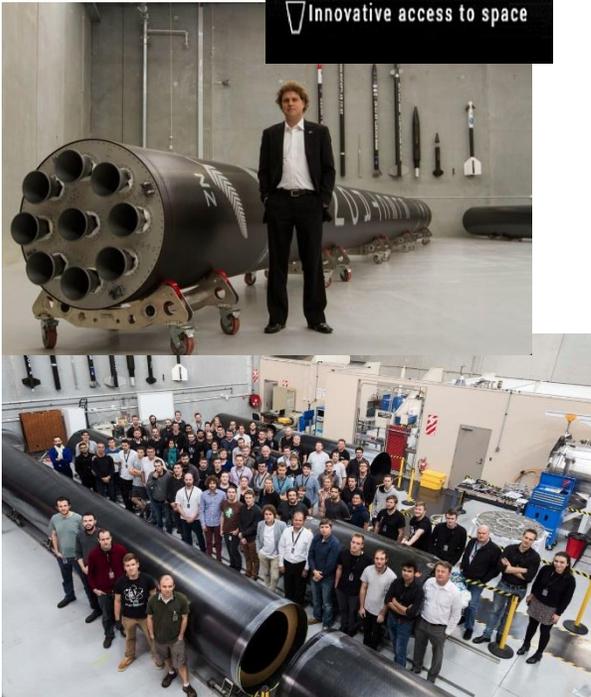
➤ Stats: (SmallSats won't be a secondary payload forever...)

- Many new dedicated launch vehicles coming on line
- >100 SmallSats launched in 2015
- Industry expect 600-800 per year

Virgin Galactic



Rocket Lab



Vector Space



Reaction Engines



Go Launcher





Trends

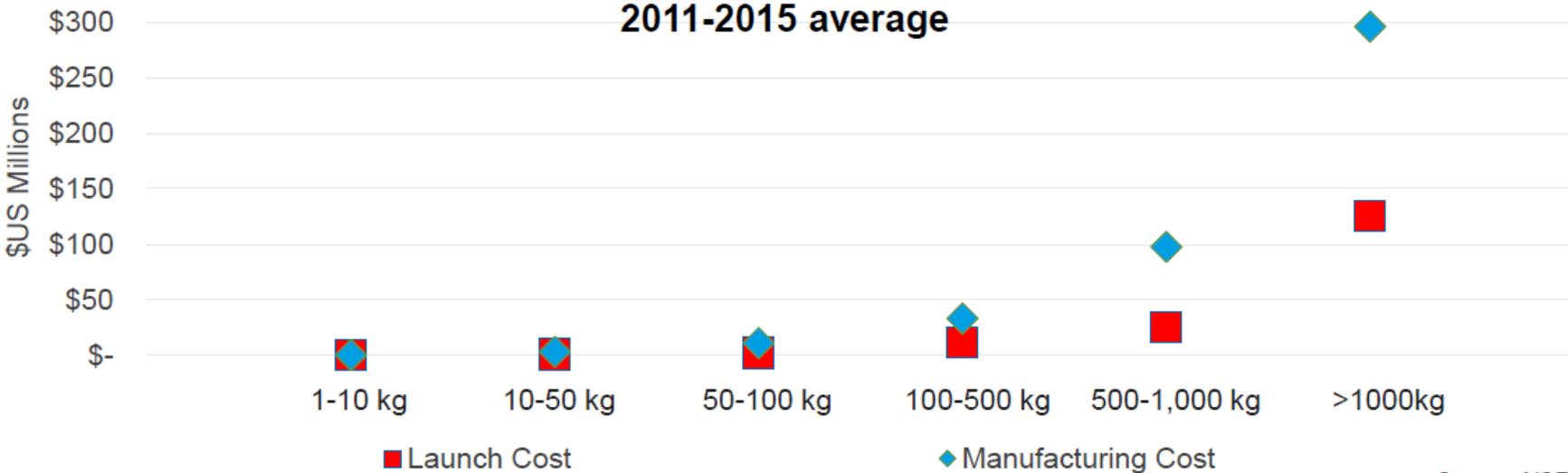


Independent Market Analysis* 8 August 2016

Smallsats Big Impact on Larger Sats

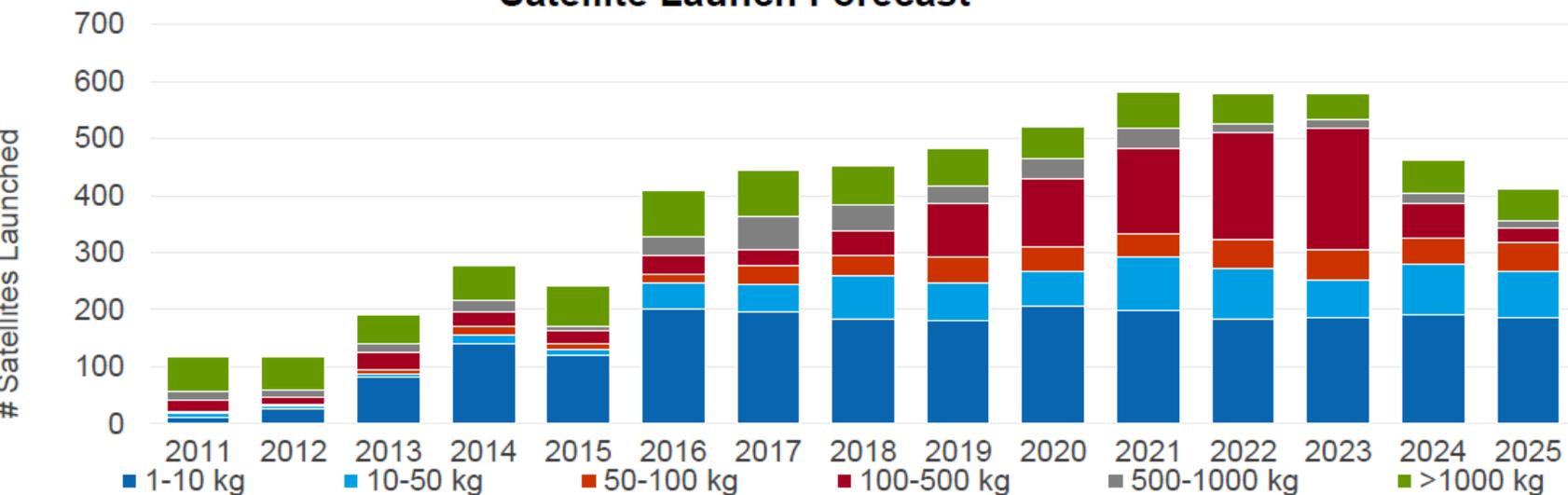


Manufacturing & Launch Cost per Satellite, 2011-2015 average



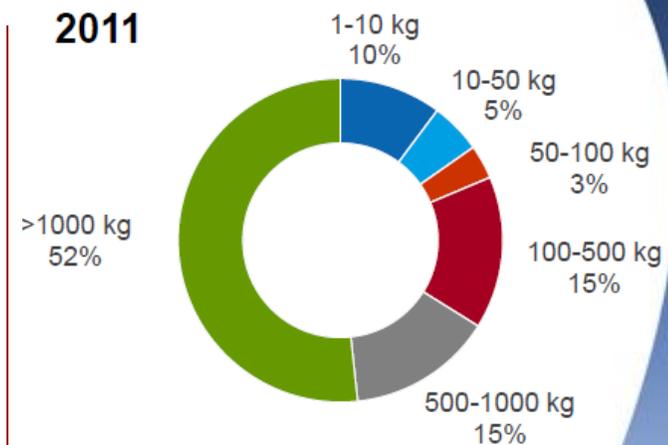
Source: NSR

Satellite Launch Forecast



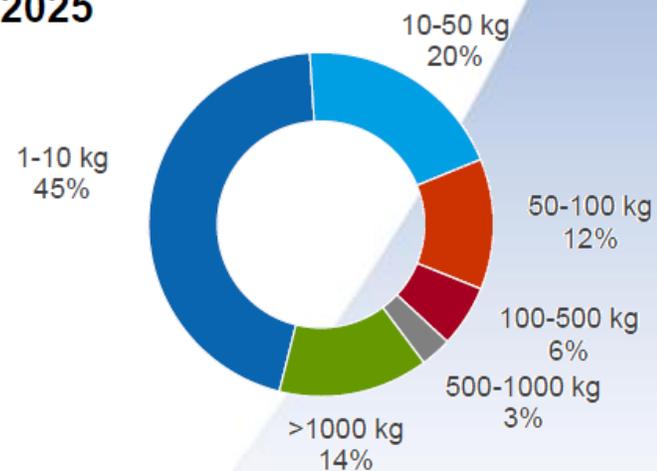
Source: NSR

2011



Source: NSR

2025

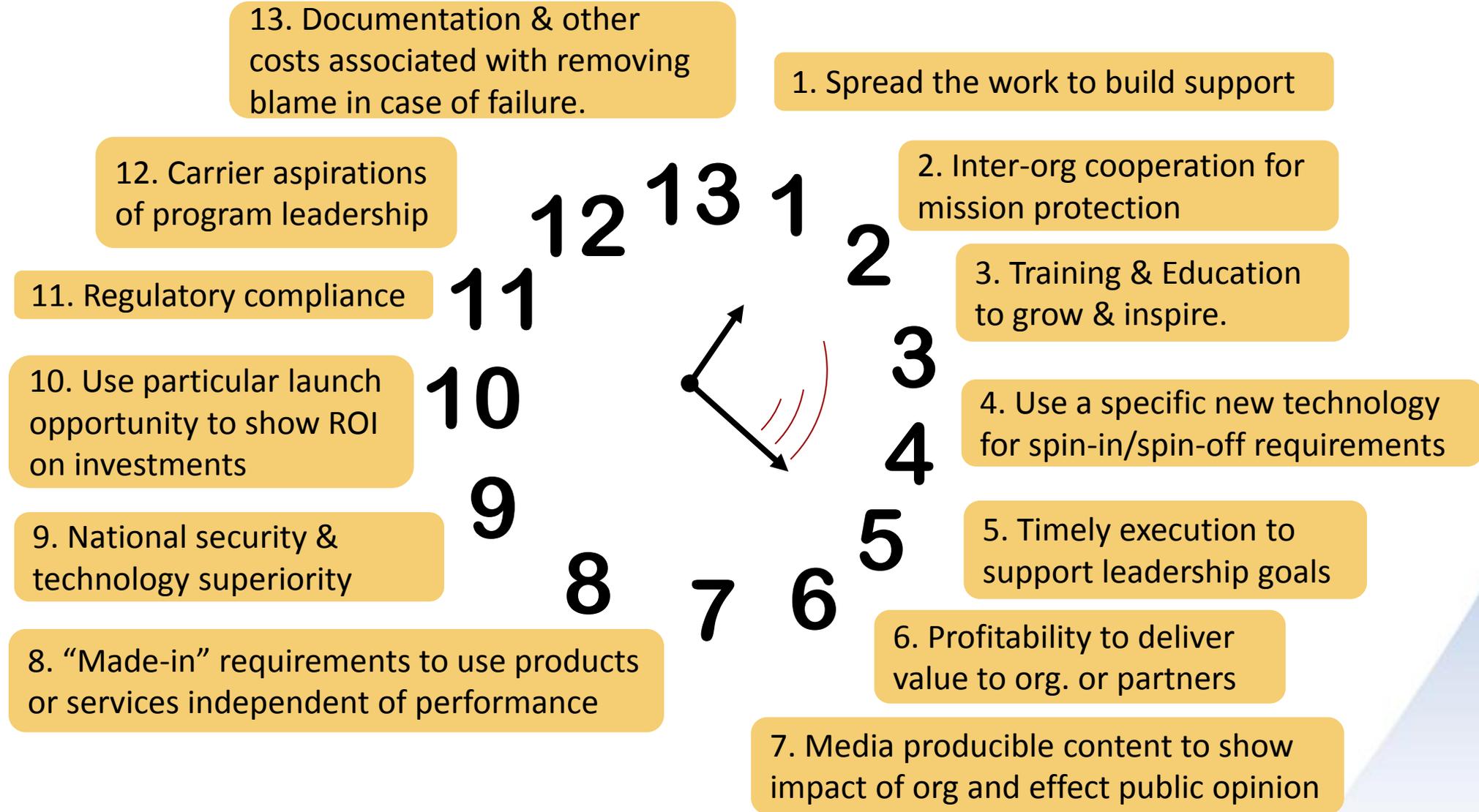


Source: NSR

*Carolyn Belle



System 1: Model of Political Infrastructure Required to Develop one Satellite





System 2: Model of Team, Tools and Technology Required to Deliver a Satellite



Composition layers	Interface	Tool	Work Products
Collaboration Team (human language & interactions)	Modes of Collaboration Audio Visual Devices Room Layout Remote Presence	Facilitation Facilities Prototypes Visual descriptions	Knowledge in the team
Capture (organization compatible artifacts)	Ubiquitous front end	Word, Excel, PowerPoint, Visio	Reports Documents Presentations
Mission Model (connected & updated data)	Domain specific views Non-expert Input collection Ubiquitous annotation	Model engine IT Infrastructure Security Permissions	Persistent and updated model
Subject Mater Expert (Native Language of Engn. Solution)	Remote Access to SME Home Systems	Discipline Specific Applications	Discipline Specific Design data

Synchronous Document Based Collaboration

1. Experiment/tech demo/risk mitigator

- The product is the learning
- The product is the trial
- High Risk
- 7120.8 Research/Technology Demonstrator Project

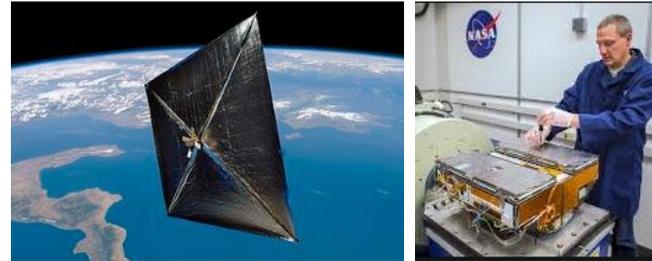


Phone Sat

Lab77 processes primarily works in the experiment and Tech Demo Area – but will help support/setup Science Demo and Flagship

2. Science/Space demo

- Advances an aspect of a new technology/measurement
- The product is proving
- Medium Risk
- Highly tailored 7120.5 Class E Project (per tailoring tool)
- Search Results

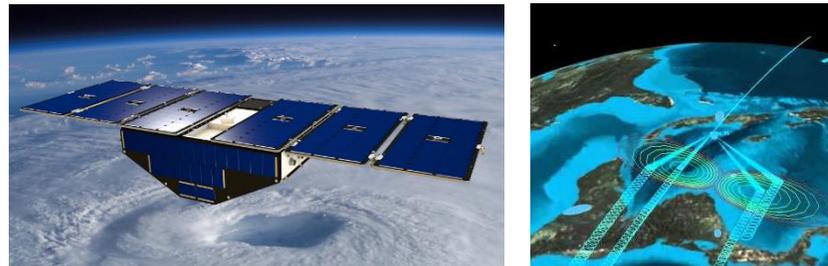


Nanosail-d

Lab77 does not on Science Demos and Flagships from post-proposal to flight.

3. Flagship

- Directly meets mission need
- Low Risk
- Tailored 7120.5 Class D Project



Cyclone Global Navigation Satellite System (CYGNSS)

Standard Execution Processes apply.



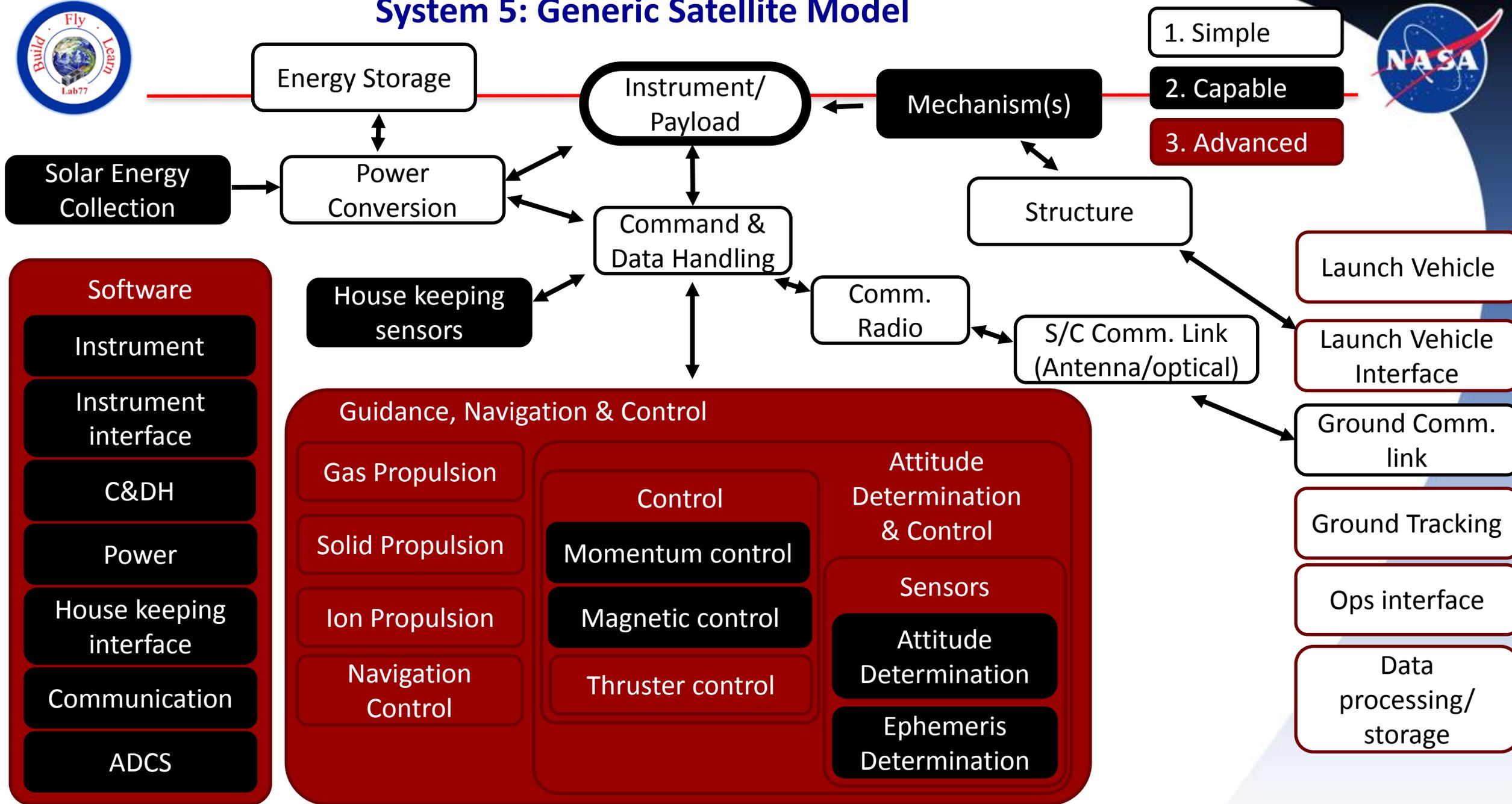
System 4: Model of Small Satellite Ecosystem



Satellite Type	Launch Vehicle Interface	Getting Manifested	Launch Opportunities
Sprite	Canisterized	Commercial Aggregator	Large vehicles (EM1) with Secondaries
CubeSat	ESPA ring	Government Aggregator	Government launches with Secondaries
ESPA	Conformal	Direct to launch provider	Commercial launches with Secondaries
Conventional but smaller	Vendor Specific Interface	Direct to payload owner	Dedicated Launch vehicles
Conformal Satellite			Payload integrated hosted payloads
			Conformal integrated hosted payloads



System 5: Generic Satellite Model





Story 3: Principles of Agile and How They Apply





Transformation Enabler: Culture of Learning

1. Non-fatal failure encouraged
2. Improvement Kata

Assess current condition

Establish target condition

Run experiments to overcome obstacles

Work in rapid cycles, adjust based on what you are learning along the way, and concentrate only on what you need to do



We are uncovering ways of **better** developing products by doing it and helping others do it

1. **Individuals and interactions** over processes and tools
2. **Working products** over comprehensive documentation
3. **Customer Collaboration** over contract negotiation
4. **Responding to change** over following a plan



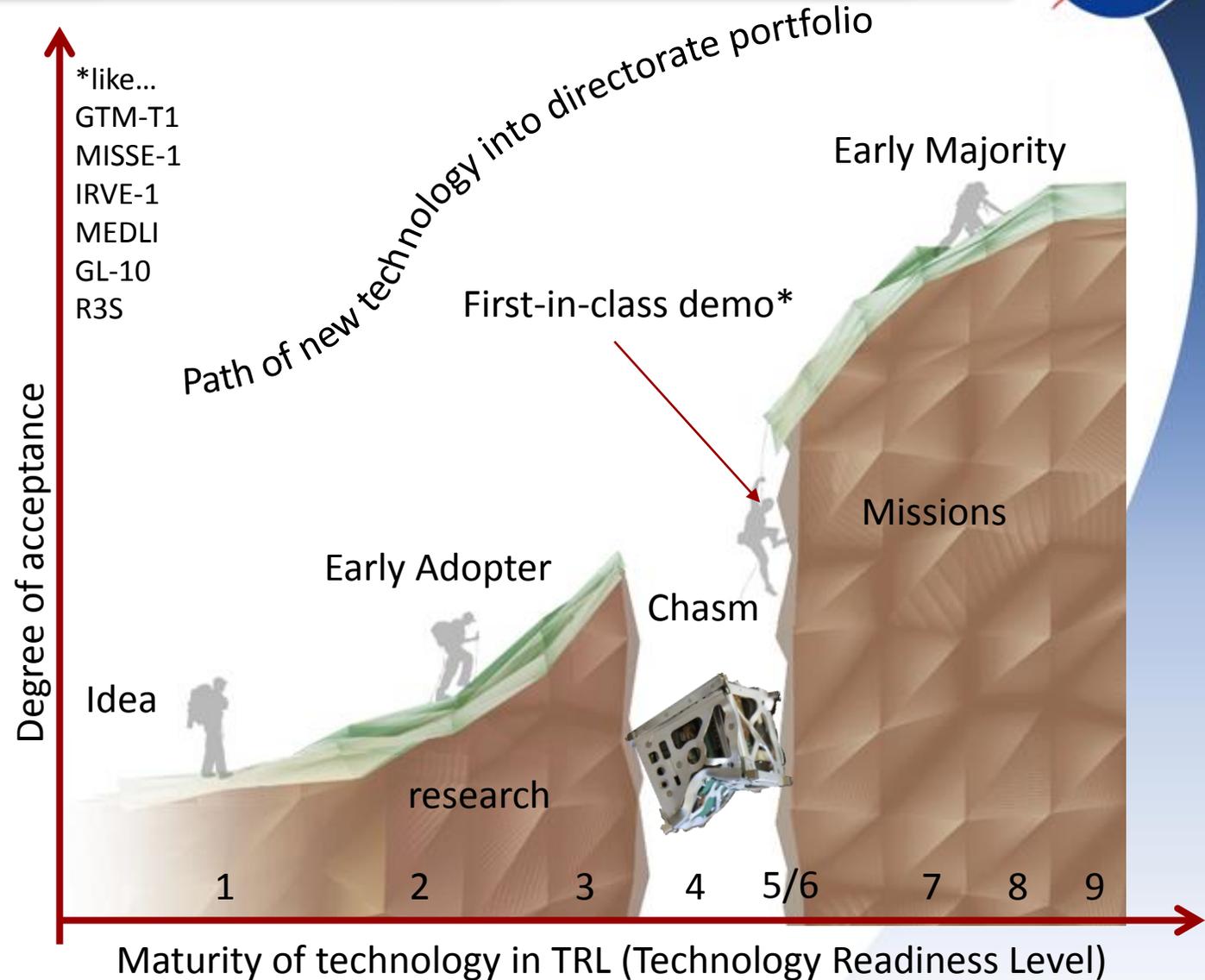
Story 4: Idea-to-Mission and the Natural Selection of a First-In-Class Mission





➤ Technology Readiness as Indicator of Market Acceptance of a New Innovation

- Adoption model
 1. The idea comes to an individual
 2. Initial development proves the idea
 3. Early adopting team develop a mission
 4. A first-in-class demo shows value
 5. Early majority acquires and applies
- TRL 6 marks the earliest possible transition to early majority.
- Research-to-operations transition occurs when large mission (early majority market) can see value.
- **The first-in-class mission demonstrates that value**





Example of a First In Class Mission



~15 attempts to enter inflated from space from 1964 to 2009*

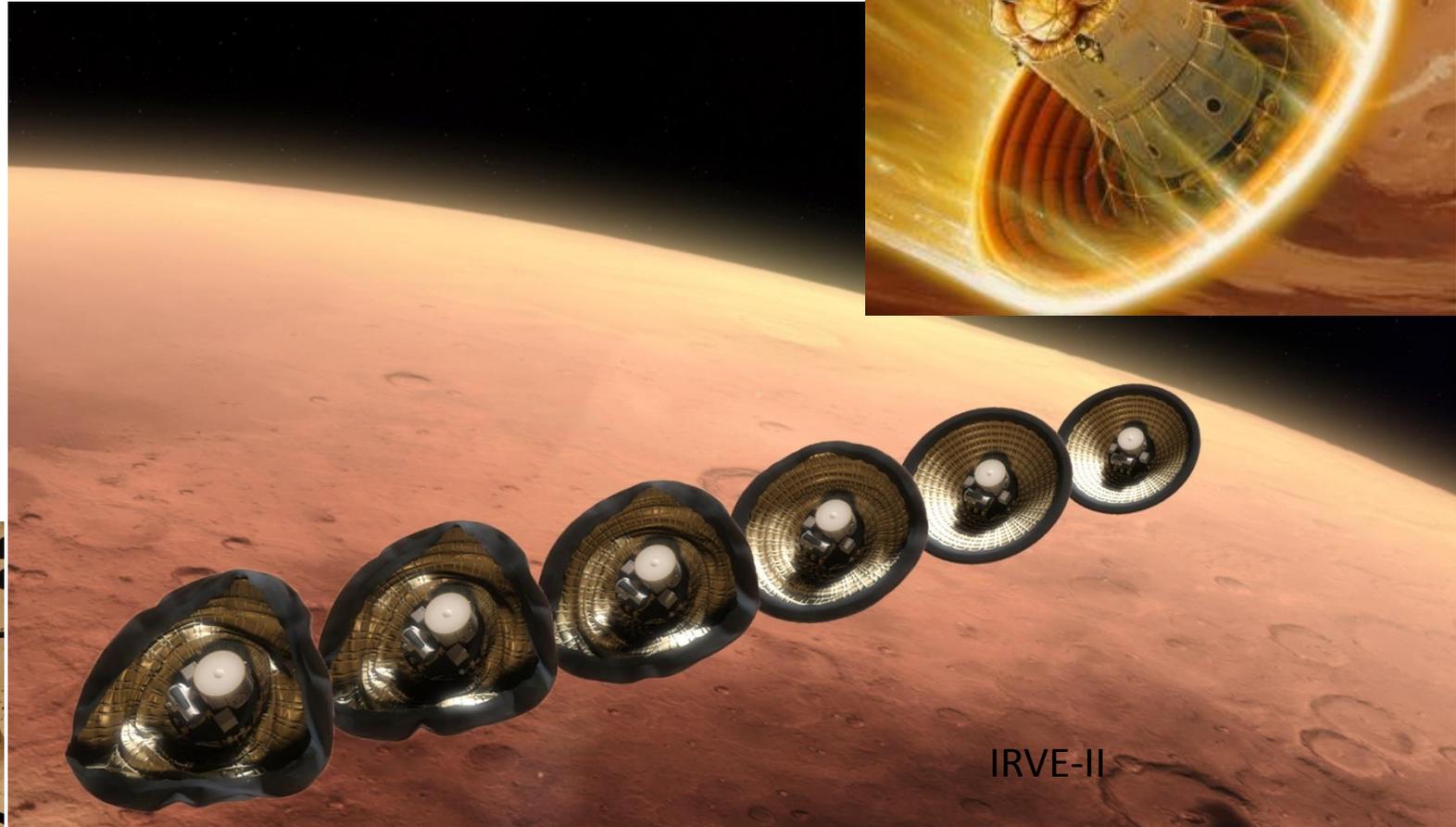
Now recognized as an enabling technology for Mars exploration



IRVE-II demonstrated stability of Inflated Aerodynamic Decelerator from Space



IRVE-3 followed

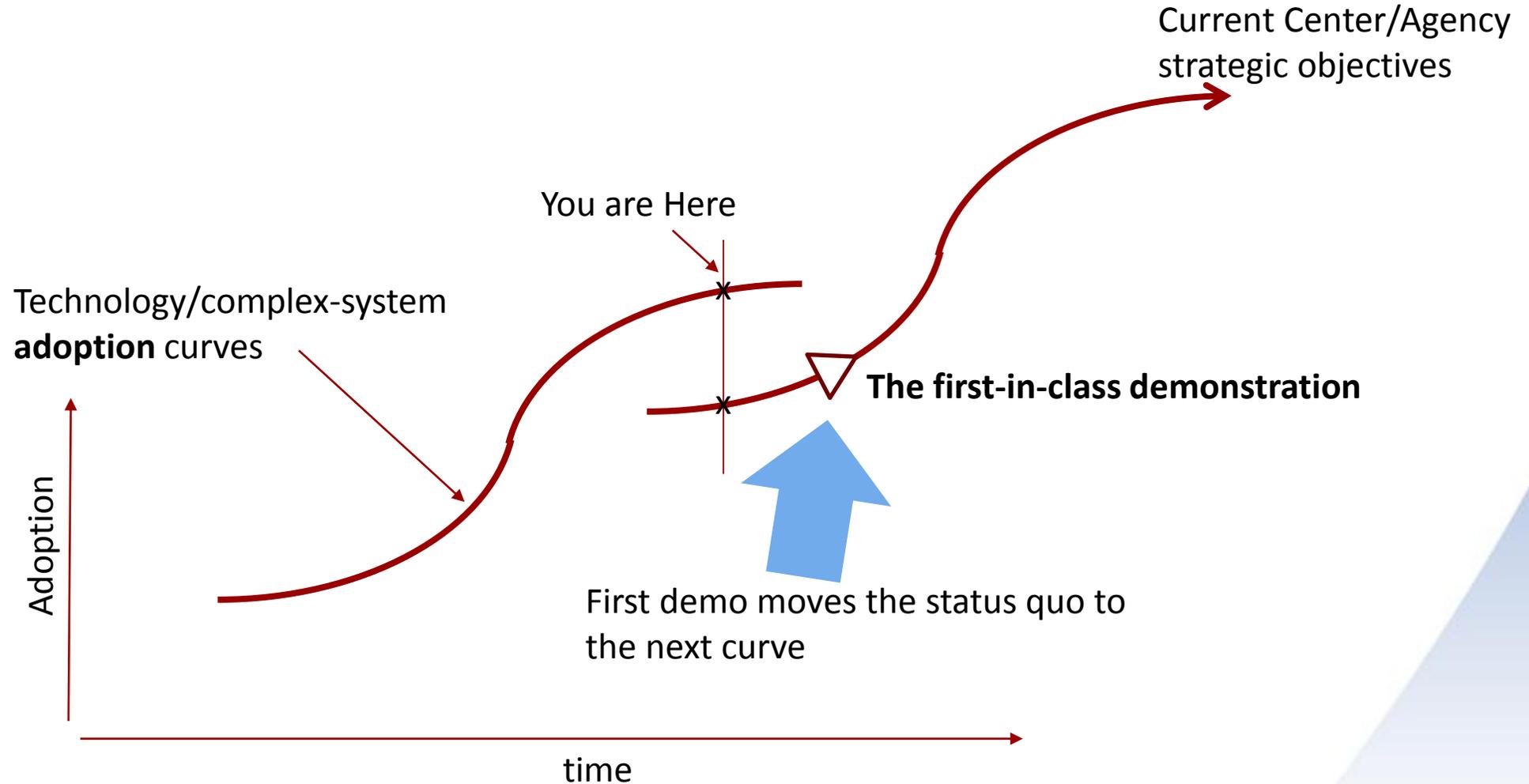


IRVE-II

*Smith, Brandon P., et al. "A historical review of inflatable aerodynamic decelerator technology development." *Aerospace Conference, 2010 IEEE*. IEEE, 2010.



1st In Class Mission Function





➤ What is a first-in-class demonstration?

- A high quality, technology incorporating, need-filling piece of hardware... ..that makes it through production and into first time operation.

“Any sufficiently advanced technology is indistinguishable from magic”

~Arthur C. Clarke

...who would invest in magic?

➤ Attributes of 1st-in-class mission

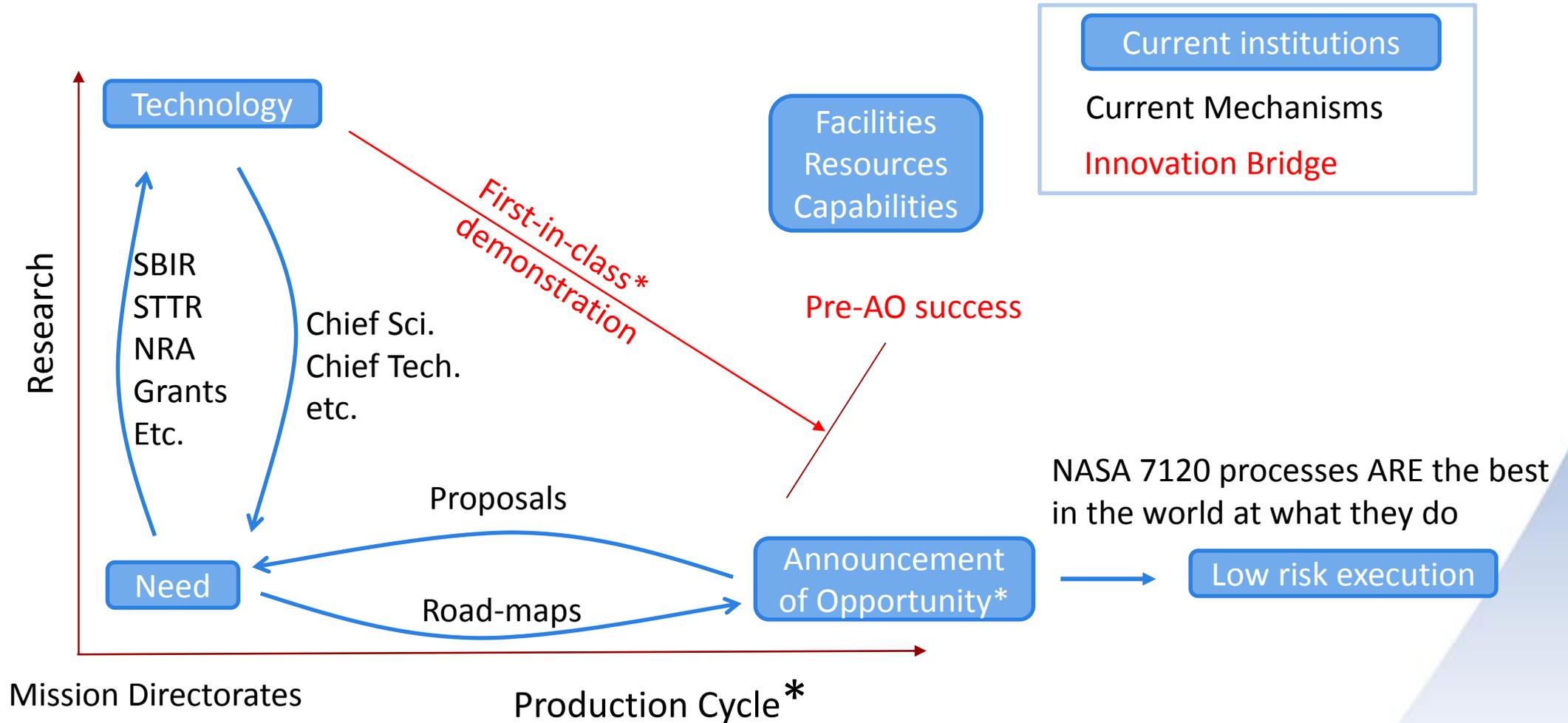
- Frequently originate outside dedicated established funding streams
- Led by super-human team competent to technically execute, institutionally coordinate, and programmatically sell.

➤ Examples

- MISSIE-1 (MEEP), GTM-T1, IRVE, MEDLI, GL-10, R3S

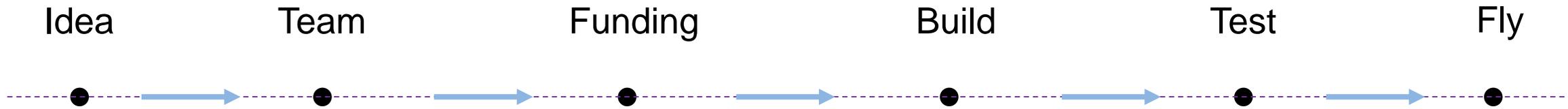


Interaction of Research & Spaceflight





Observed Path from Idea to Mission

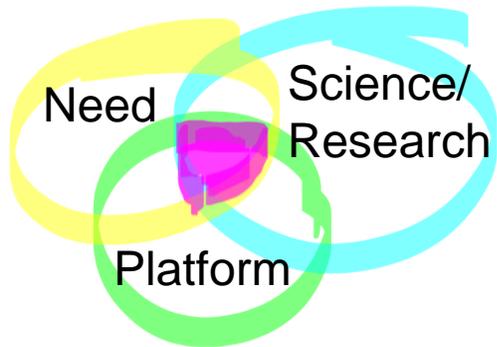




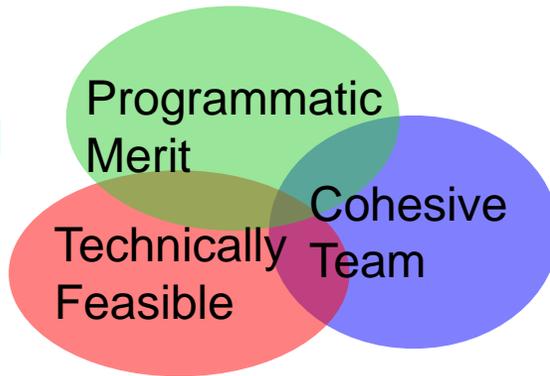
Natural Stages of a The Path



Structured Idea



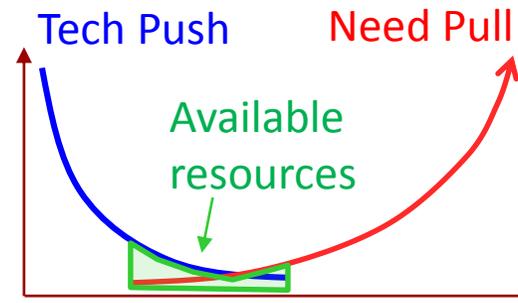
Tentative Team



Planning

- Cost
- Schedule
- Risk

Aggregation of Resources



Forward paths to build fly learn

- 2. New Products
- 1. Build Fly Learn**
- 3. New Research Topic

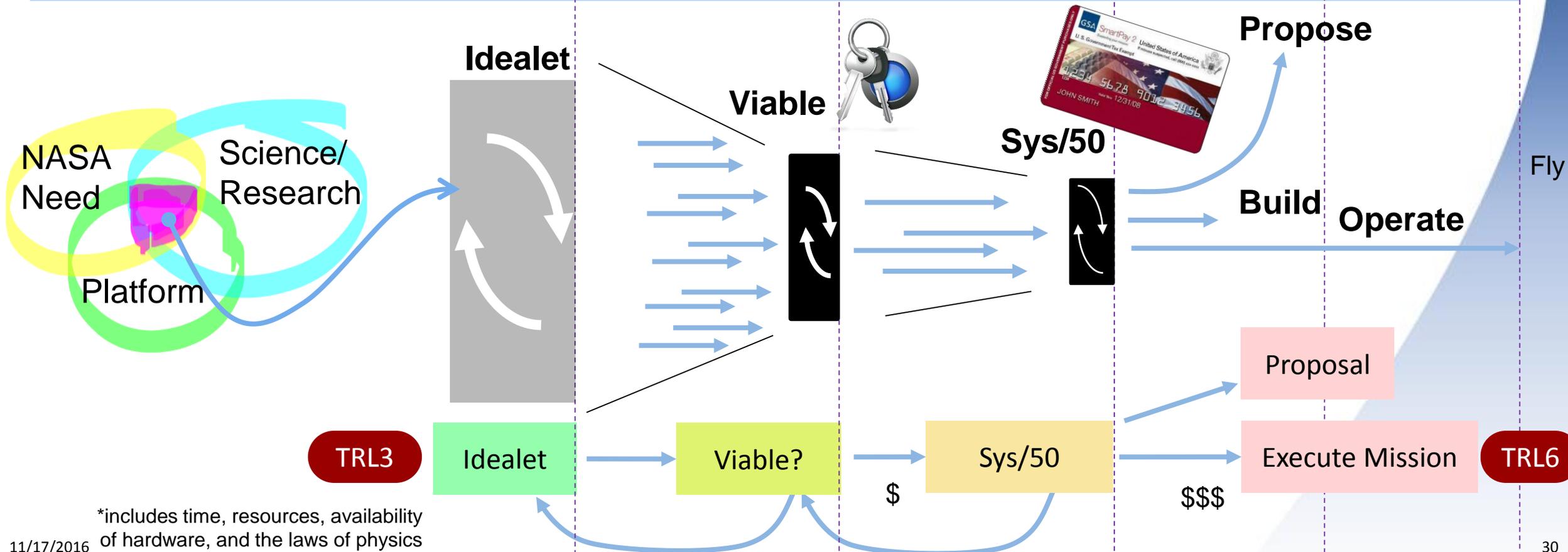


Lab77 Operating Model: Mission Natural Selection



Level of Authority:	Lab77 Team	Branch	Directorate
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Criteria for Advancement:	Meets a stated need Tech/Science in place Fit's in a platform	NASA/LaRC aligned 1 st order feasible Cohesive team	Engineered System 50% of Design No gotchas!*	System is built
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*includes time, resources, availability of hardware, and the laws of physics

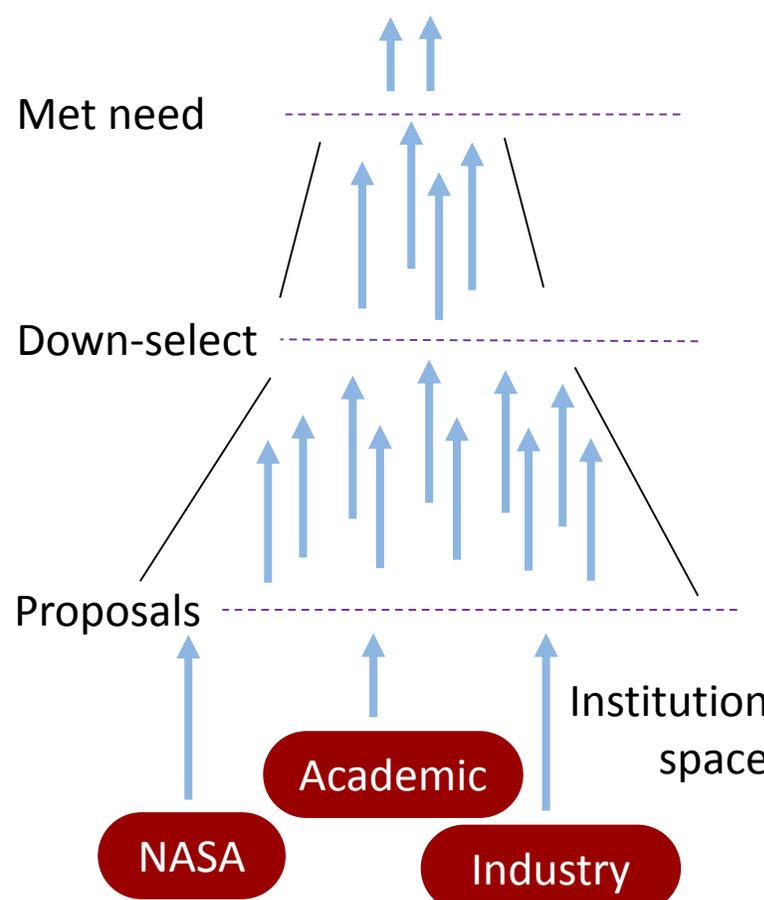


Mission Natural Selection Among other Operating Models



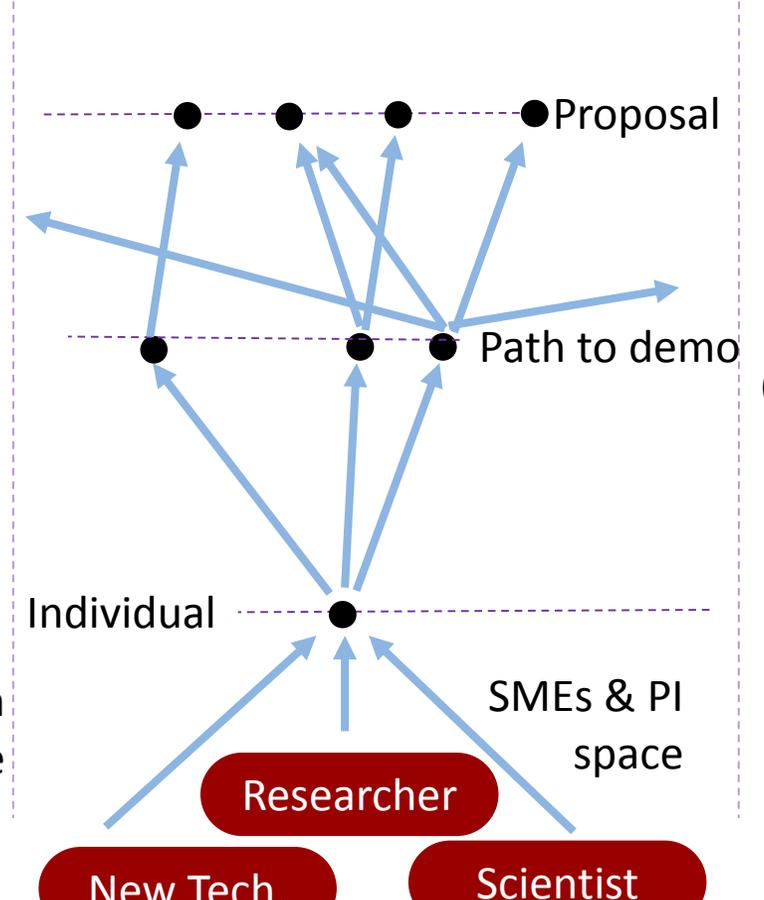
NASA mission directorate

Mission Directorate

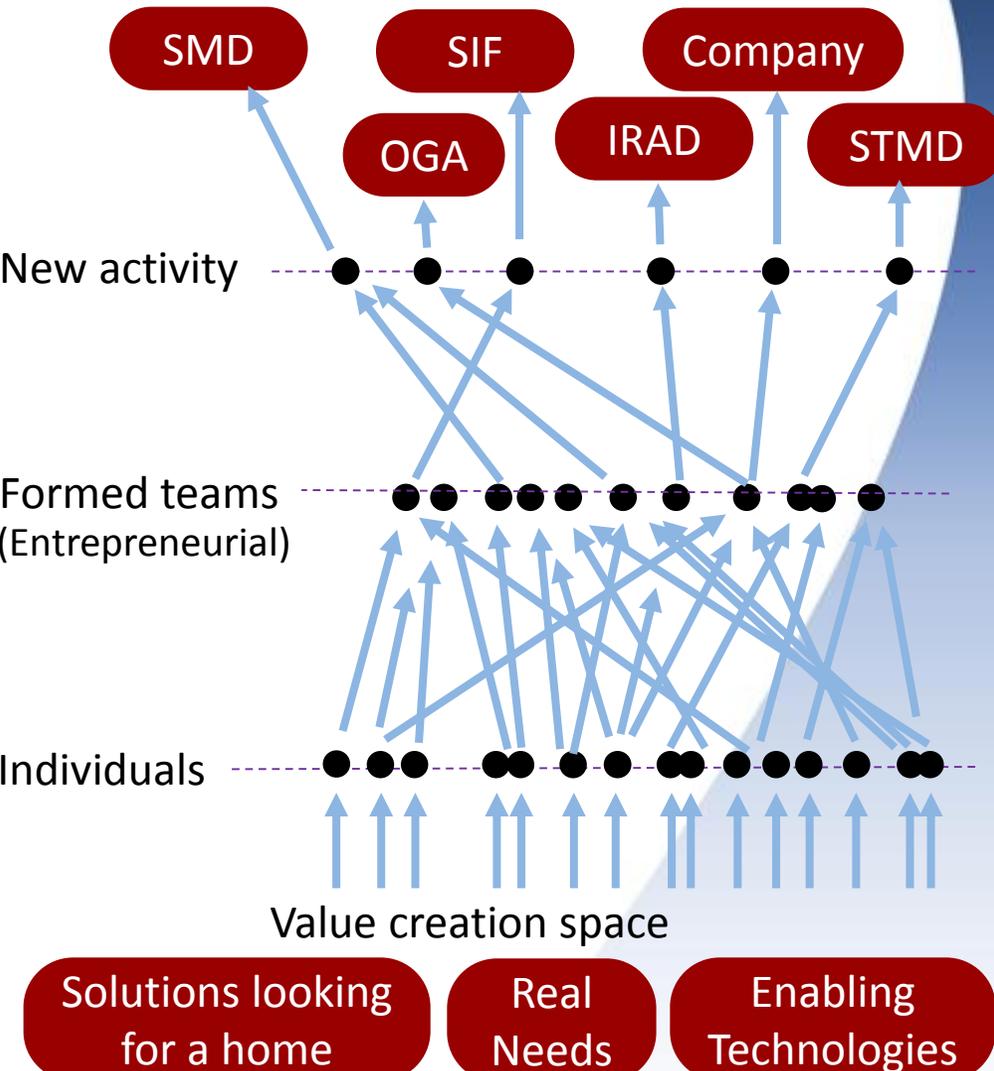


Typical Researcher, Technologist, Scientist

\$



Mission Natural Selection



Business Development

- Develop Products
1. Proposals
 2. Demonstrations
 3. Research topics
- Develop Partnerships
- University/academic
 - Private industry
 - Other NASA Centers

Idealets generation

NASA Need

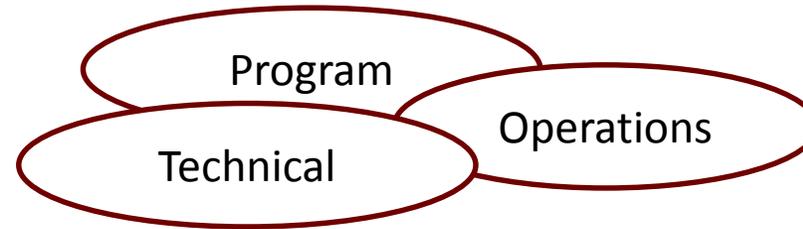
Science/
Research

Fits in
platform



Mature Idealets
to Missions

Lab77 team



Workforce Development

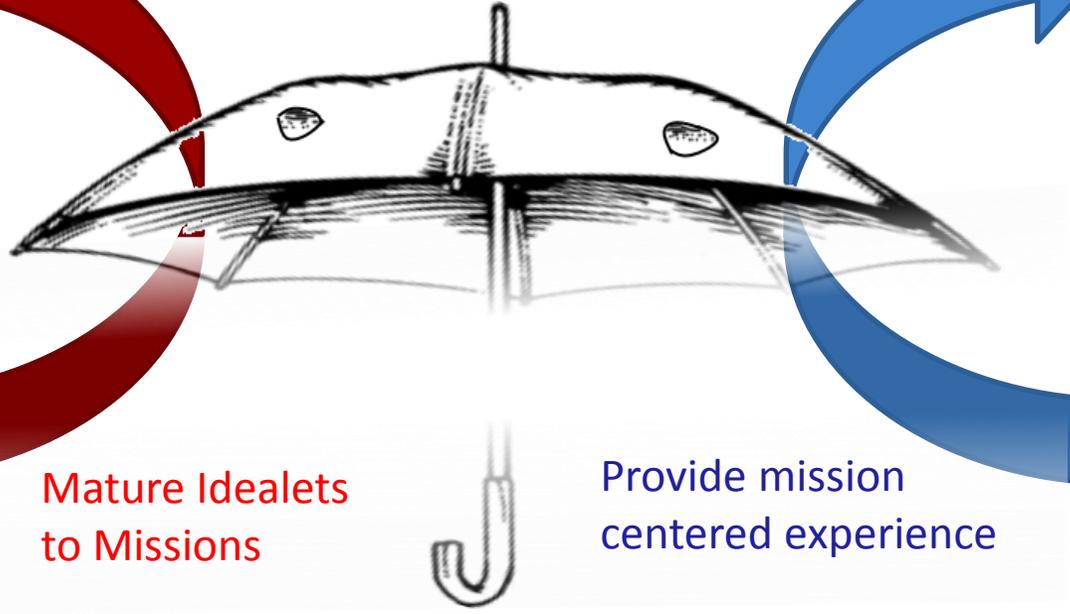
Multi-discipline
system engineers

Inspire and create
opportunity

Early-career
Career transitioning
Students



Provide mission
centered experience



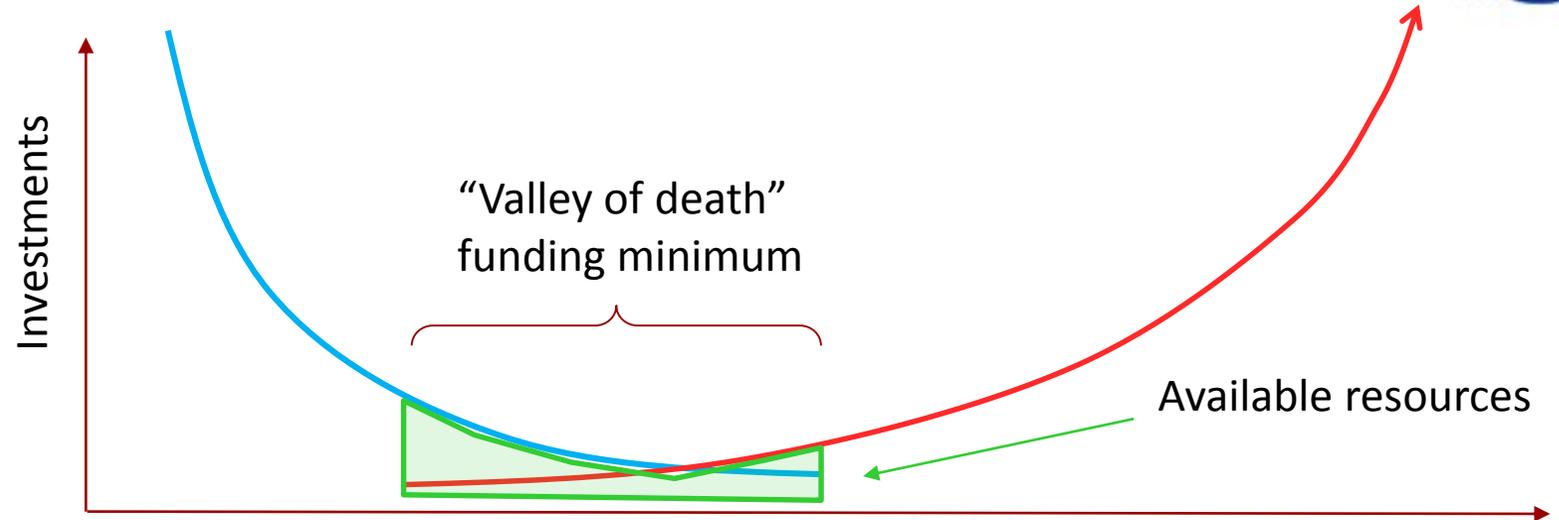


The Missing Piece: Lab77 - Home of the 1st in class mission



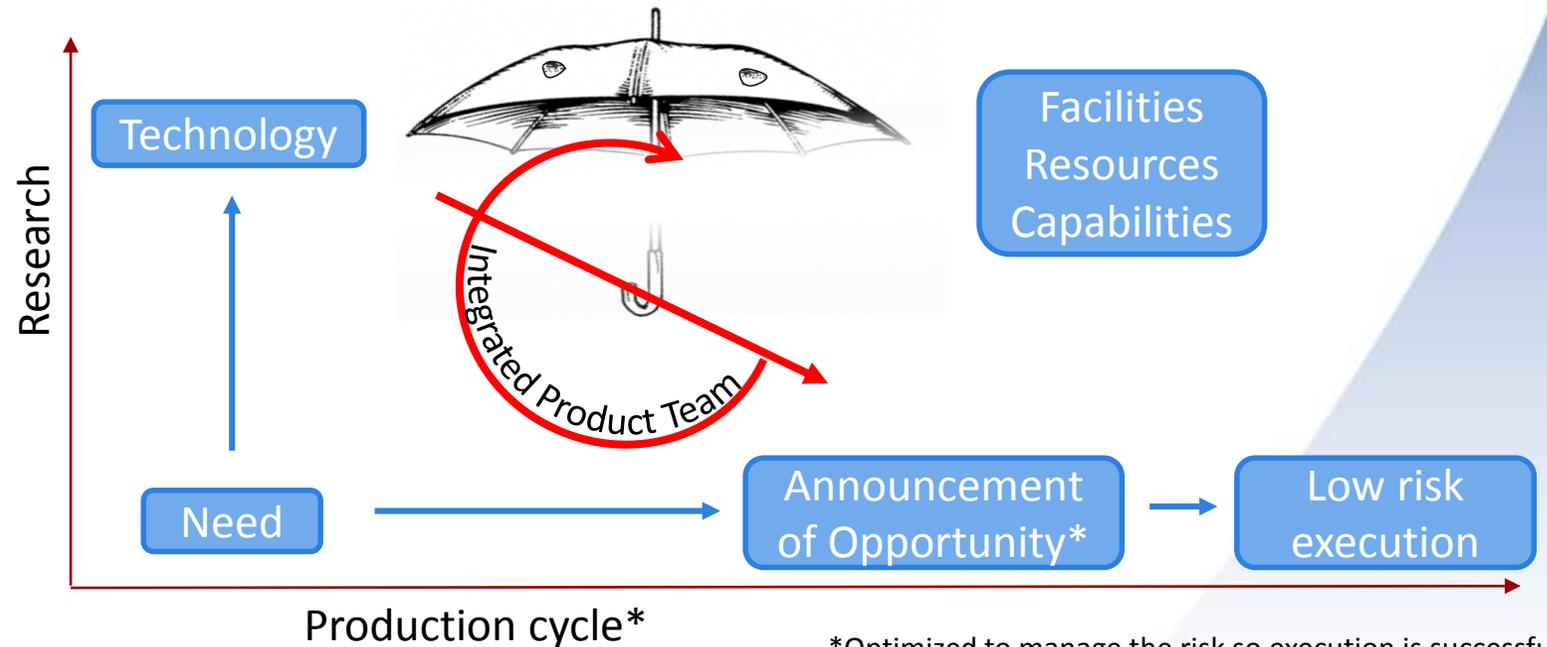
➤ Aggregate Investments

- Facilities
- Resources
- Capabilities



➤ Accelerate the 1st in-class-mission

- Create value by mapping solutions looking for a home to needs
- Facilitate transitions from idea to mission





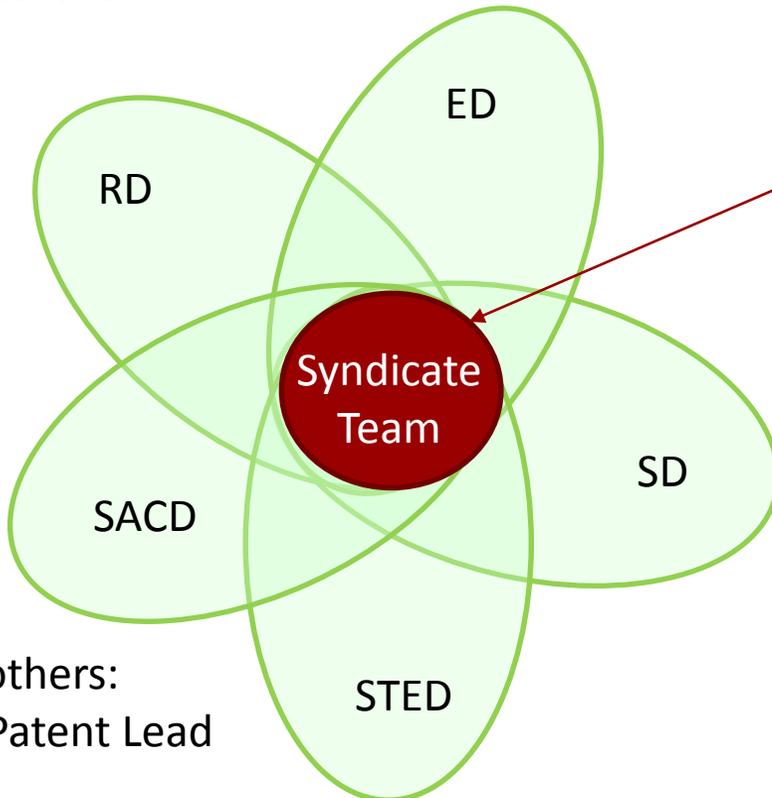
Story 5: Tools that Enable Agile Operation Within the Institution





➤ The LaRC Syndicate

- At least one Senior member from each Directorate that knows who is doing what in the Directorate
- At least one junior member (5-10 years in) from each Directorate that knows who is doing what in the Directorate



This team will get together and discuss needs and new technology and try to make connections between Directorates.

2 concepts in work

1. Individuals bring their concepts/needs
2. Just the team presents concepts/needs

Junior Team members will make the connections and then help team draft a short idea project summary/plan

Possible others:

- Legal Patent Lead
- ARMD



Tool Lab77 depends on



- **EDS concurrent engineering**
- **3-D Printing and Microprocessor utilization**
 - Geometric models illustrating the concept
 - Prototypes of functional aspects
- **Comprehensive Digital Transformation**
 - Concurrent Document-based collaboration (SharePoint, Google Docs, OneNote)
 - Augmented Reality /Virtual Reality
 - Grass Roots Partnership Explorer
- **MBSE (Model Based System Engineering tools)**
 - Persistent and updated model of the developing product
- **Hands On Training**
 - Early career Hands on opportunities
 - Retraining experienced engineers for new technologies and making them in demand by current projects
- **Agile working models**



Model of Team, Tools and Technology Required to Deliver a Satellite

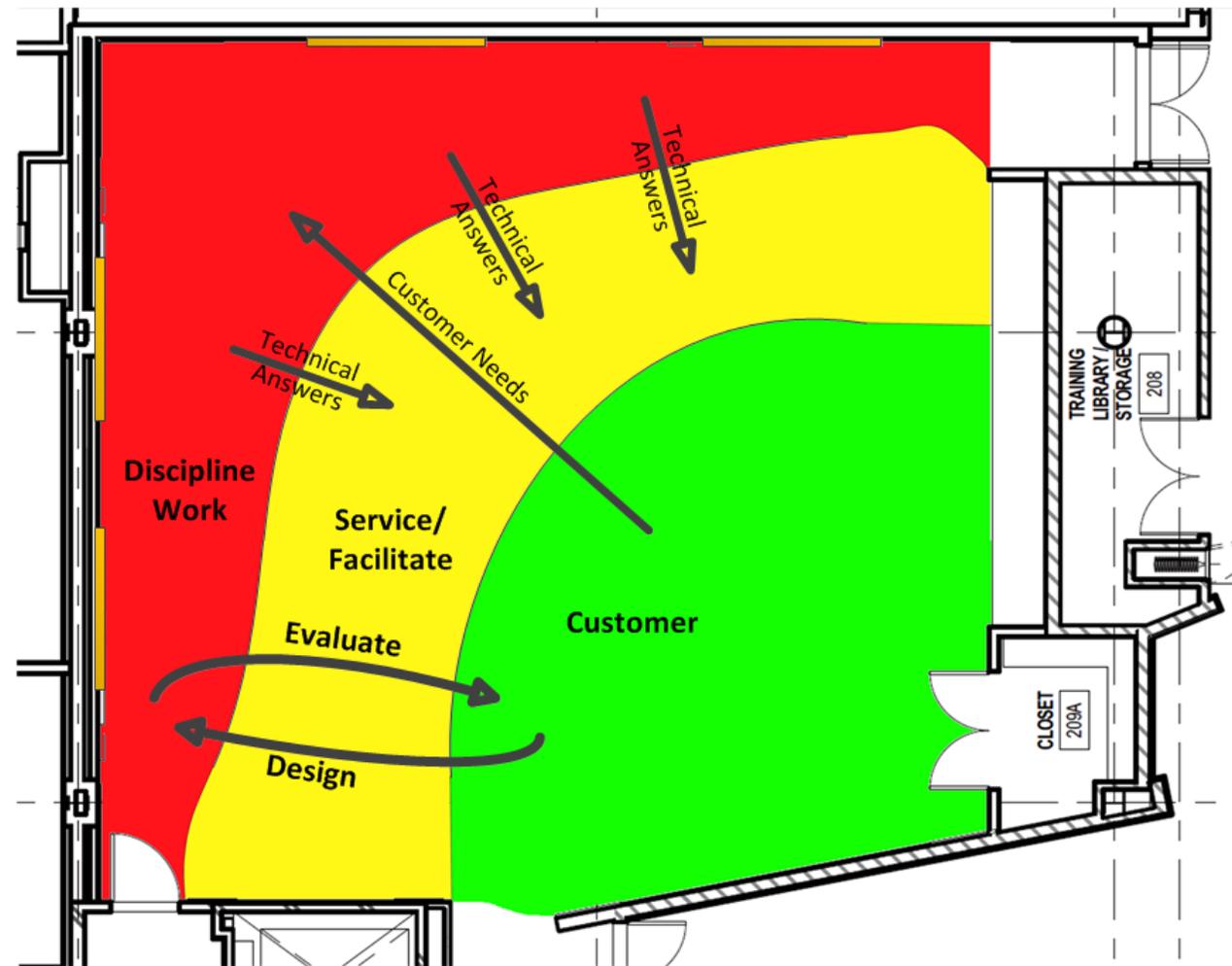
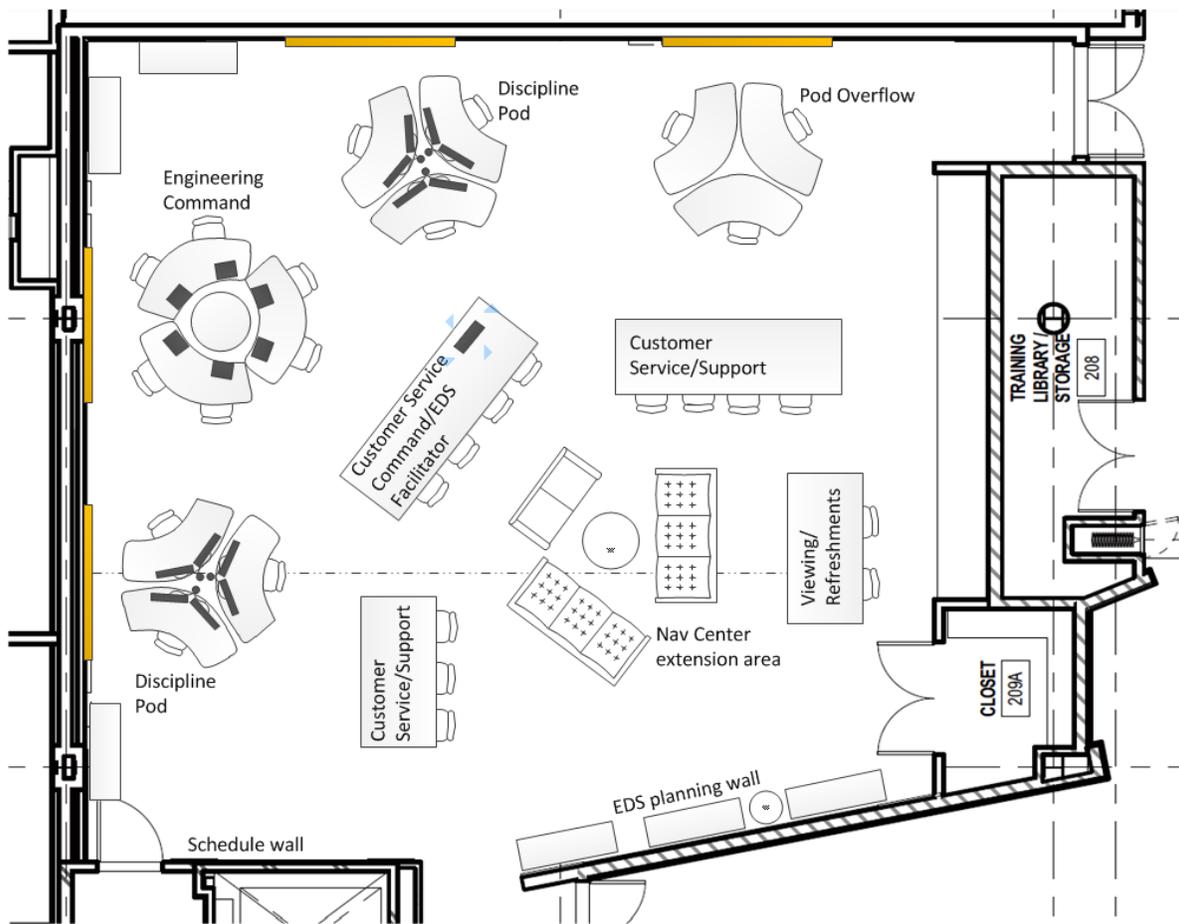


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Synchronous Document Based Collaboration



Engineering Design Studio for Facilitated Concurrent Engineering

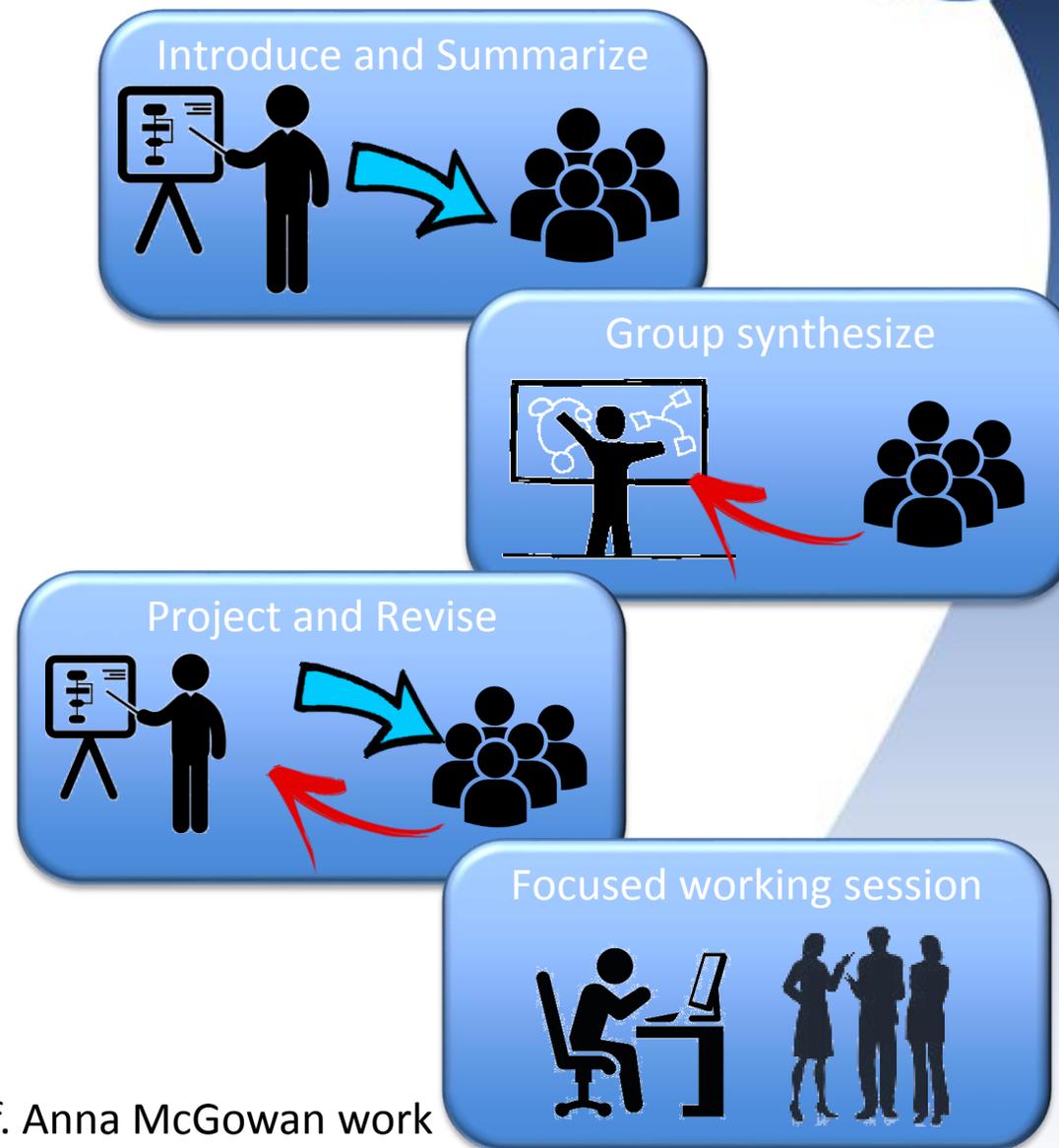


➤ Trajectory of conversation

- Modes of conversation are organized to achieve the objectives of the session
- The schedule is built around switching between modes to deliver the product.

➤ Modes

- Introduce and summarize
 - Prepared message to shape conversation
 - Combined data products to summarize report
- Group synthesize
 - Facilitated frame work
 - Structured solicitation of the knowledge of the team into a cohesive story/visualization/document
- Project and revise
 - 2D Visualization presented
 - Solicited group feedback to correct the visualization
- Focused working session
 - Individual focus on deliverables
 - Proximity to other disciplines
 - High productivity driven by the context of the work segment.



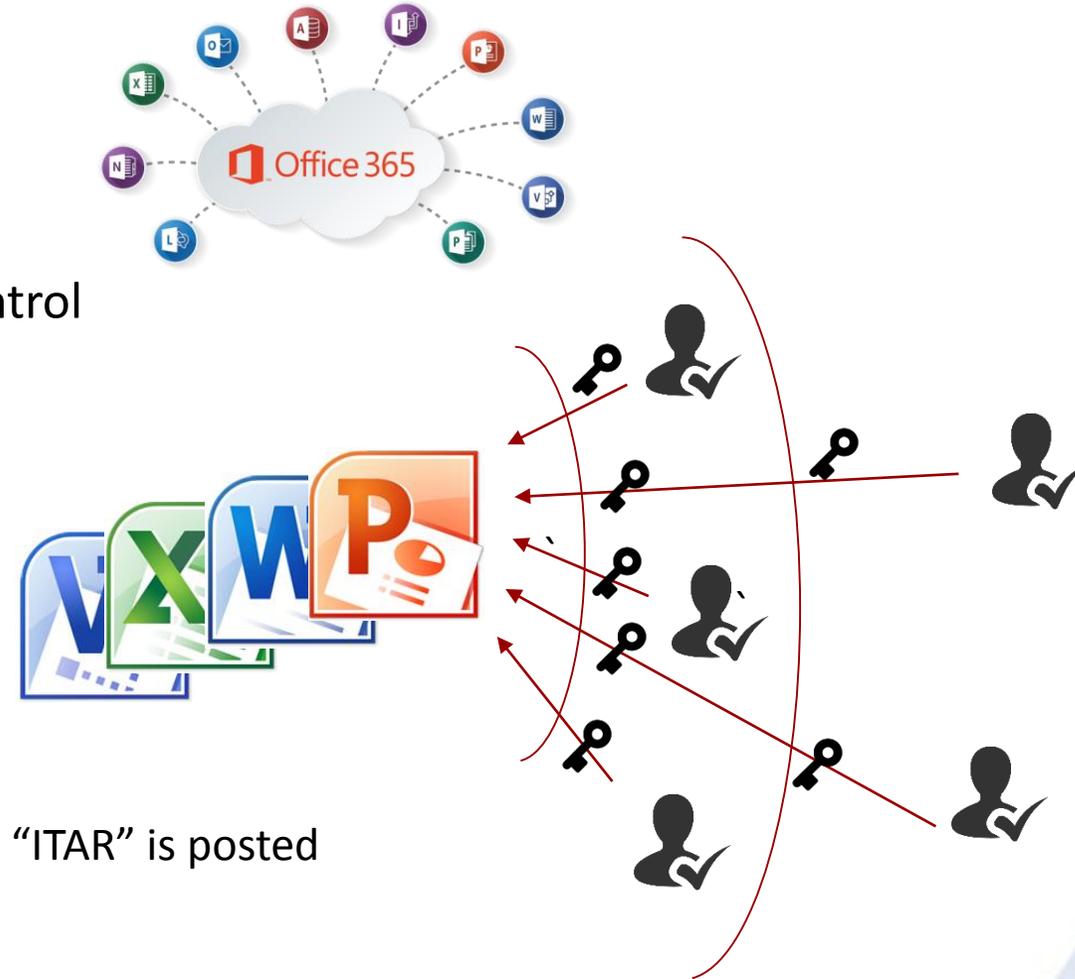
Ref. Anna McGowan work

➤ Work flow needs

- Automatic version history
- Graduated permissions
- Document configuration control
- Outlook/Lync integrated.
- Simple on-roads to archive

➤ Enterprise features

- Legal holds
- ITAR/SBU/PII
- Dirty word search...
 - e.g. auto notification when “ITAR” is posted
- Backup and restore
- Active directory integration:
 - e.g. tied to NOMAD account



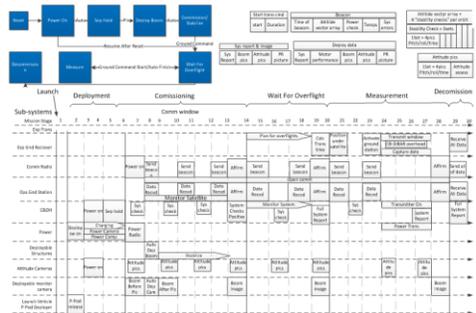
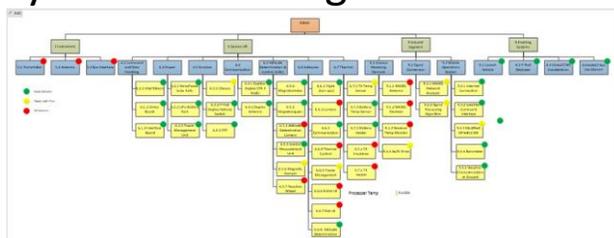


Decision Velocity Support

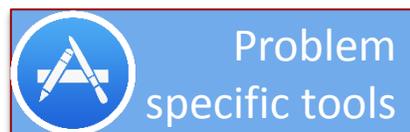
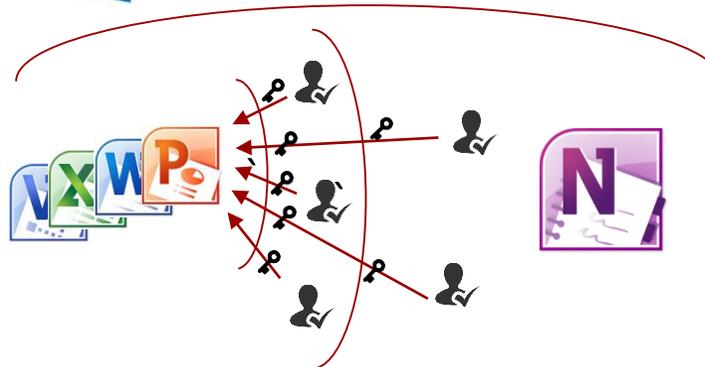


1. Visual Description of System

- Mission Context diagrams
- Risk/Architecture diagram
- System Con-Ops diagram
- System block diagrams



2. Synchronous Document Based Collaboration



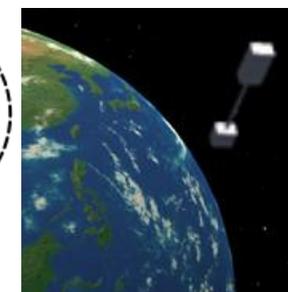
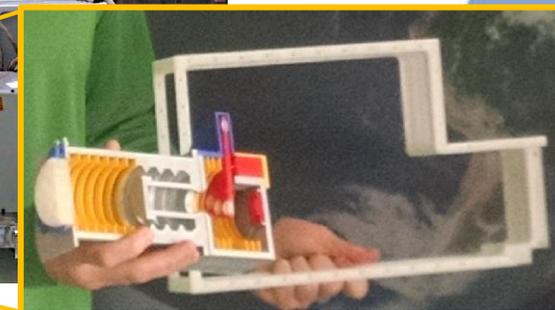
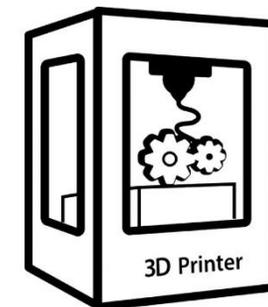
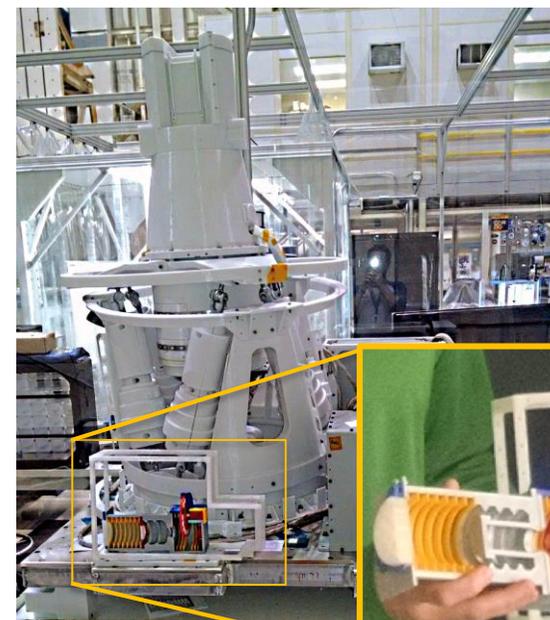
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Discipline specific applications and data



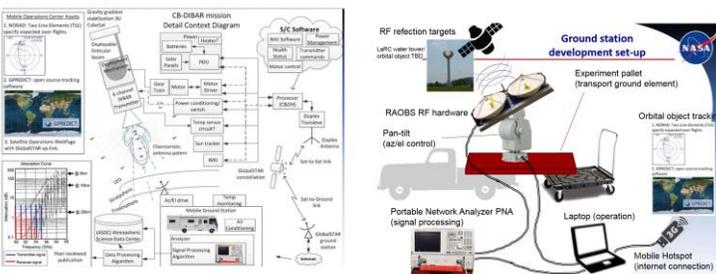
3. Printed model prototypes

4. Immersive View of system (con-ops, mechanism, etc.)



Visualization Libraries

- GTO orbit around earth
- 3U & 6U cubesat
- Ground station antenna
- etc.





The Grass Roots Partnership Explorer



Proposal:

- Prototype data-visualization to reduce the level of effort required to find inter-department/inter-agency partners at a grass roots level. (A range of tools will be evaluated)

Approach:

- Extend the current Lab77 mission-accelerator by enhancing mission opportunity discoverability
- Prototype with a two node network (JPL/LaRC) that explores potential mission concepts

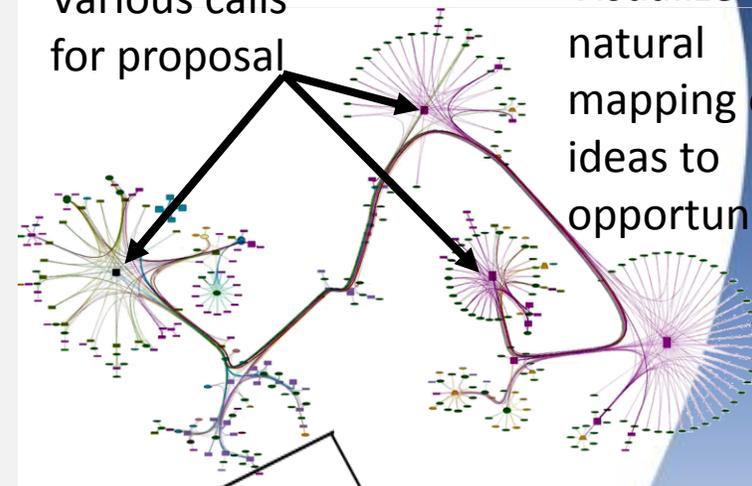
Use of the tool

1. Map connections between developing research activates, new technologies and science needs.
2. Provide team members visibility between their work and the work others are doing.
3. Facilitate the connection with the intent to advance to the activities into a partnership.
4. Assess where to propose the partnerships amongst many opportunities from diverse funding sources. (e.g. Mission Directorates, DARPA, Center IRAD, DoD, other reimbursable, etc.)

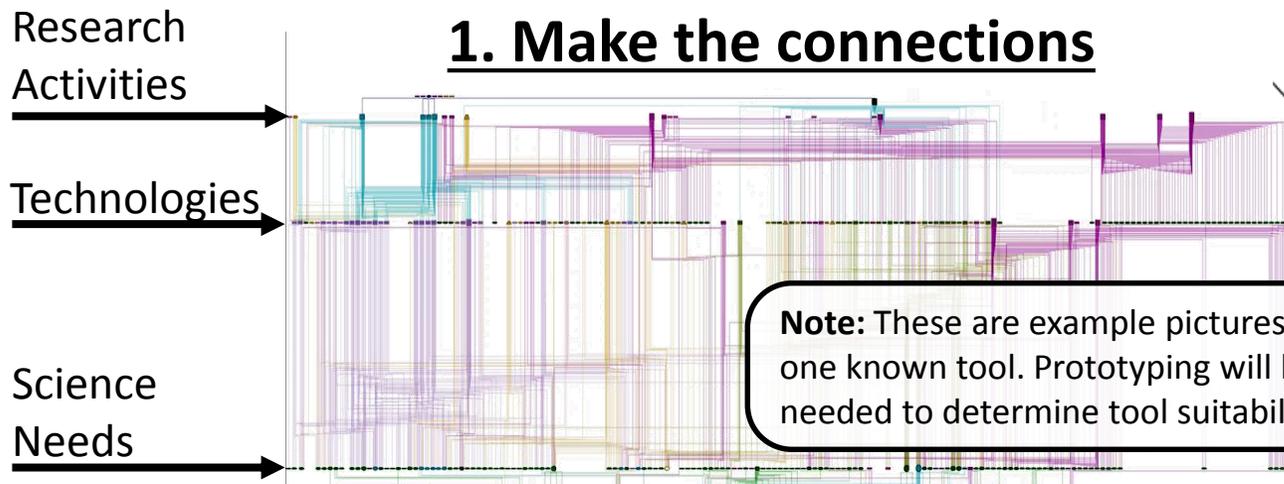
3. Match to Opportunities

Various calls for proposal

Visualize natural mapping of ideas to opportunity



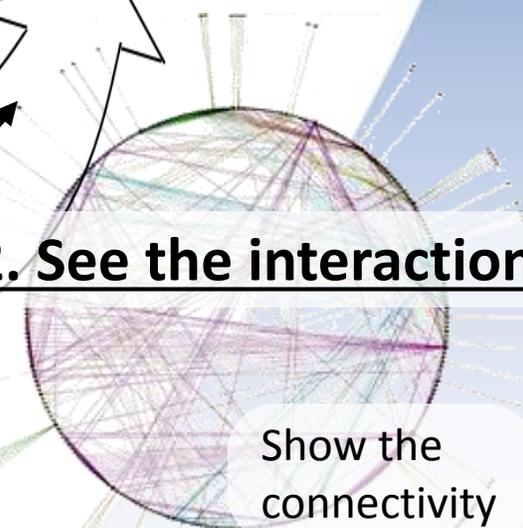
1. Make the connections



Note: These are example pictures of one known tool. Prototyping will be needed to determine tool suitability

Ideas to connect

2. See the interactions

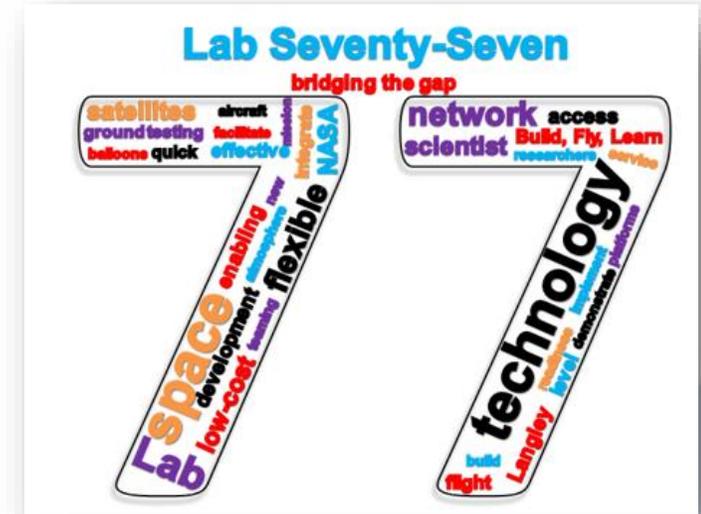


Show the connectivity

Requesting: \$10,000



Story 6: Wrap up





Demonstrated Success



Awarded/Executing



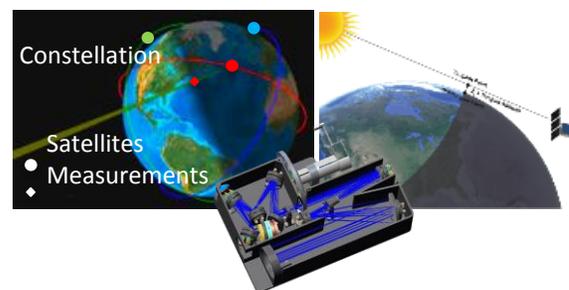
On-Orbit Autonomous Assembly from Nano-satellites (OAAN)

Proposed



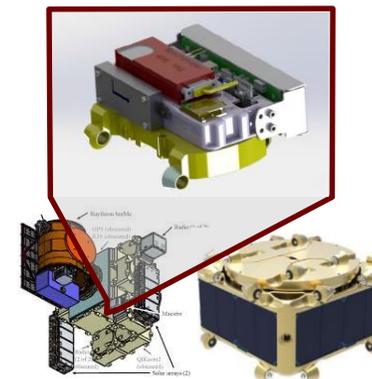
ARCSTONE: Calibration of Lunar Spectral Reflectance from Space

Just Awarded



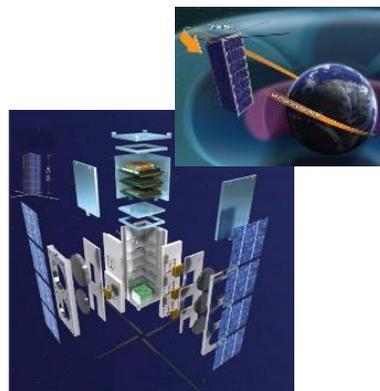
SAGE-IV: Stratospheric Aerosol Gas Experiment

Manifested



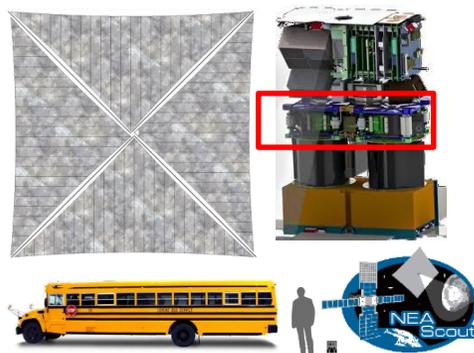
Rapid Response Radiation Survey, conformal satellite platform evaluation

Started Lab77: now manifested



Shields-1 Radiation Shielding materials

Proposal in work



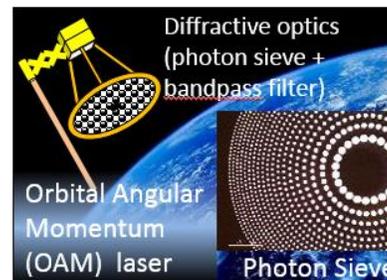
AES Solar sail

2. New Products

1. Build Fly Learn

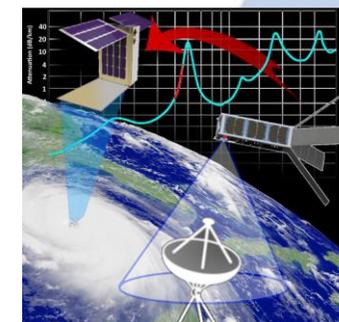
3. New Research Areas

Targeted research project



Sensor Enabling Photon Sieve Technology

In development



Differential Absorption Barometric Radar



Lab77: How the Model is Operating



➤ **Idealet**

- PI with a need matched with Researcher who has new/developing technologies with possible platforms identified

➤ **Viable**

- Is the instrument feasible, have we defined stakeholders that will form the needed team, and is there merit.

➤ **Sys/50**

- 50% engineered & design of the system (EDS is held)

➤ **Build/Propose**

- Actually write the proposal to get funding or build the Spaceflight hardware/satellite

➤ **Idealet**



- Working model

➤ **Viable**



- We struggle with getting teams formed because lack of support/priority and matching cross directorates
- Stakeholder buy-in who can bring resources are hard to find.

➤ **Sys/50**



- Few make it this far.
 - Stakeholders wait to see high-risk model demonstrated
 - Slowed by concern of impact on future work

➤ **Build/Propose**



- Even fewer make it to here.
- Small funding is extremely competitive
- Effort to award ratio of small proposal calls is high inhibiting



Lab Seventy-Seven

bridging the gap

space **enabling** **new**
 development **atmosphere**
low-cost **learning** **flexible**
Lab

satellites **aircraft**
ground testing **facilitate**
balloons **quick** **effective** **integrate** **NASA**

network **access**
scientist **Build, Fly, Learn**
researchers **service**

technology
Langley **level** **implement** **platforms**
build **flight** **demonstrate**

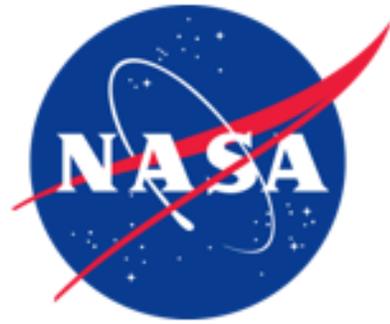


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Staged Advancement Through Graduated Multi-Baseline Evaluation



➤ Value is co-develop to deliver first-in-class demonstrations

- Team functionality: develop the team
- Technical feasibility: Develop the mission concept
- Programmatic merit: Develop the applicability

➤ Don't commit too much too early. Soft launch the mission from a stable team

1. Let the idea ripen (3 years for SAGE-IV)

- Collect every idea

2. Let the team prove cohesion, technical prowess, programmatic merit

- Graduate the team, tech, and merit...
- ...or set aside for ripening*

3. Invest in full mission development effort

- prove you can't kill the idea...
- ...or find the "gotcha" and articulate the well understood reasons why it can't be done.**

4. Allocate resource to demonstration of a **first-in-class mission**

- Execute High-risk/High-pay-off mission and advance the technology TRL 3 to TRL 6
- ...or exceed the directed funding cap and write a proposal to secure resources.***

*improves quality of concept pool
**articulates valuable research topic
***produces high-quality proposal

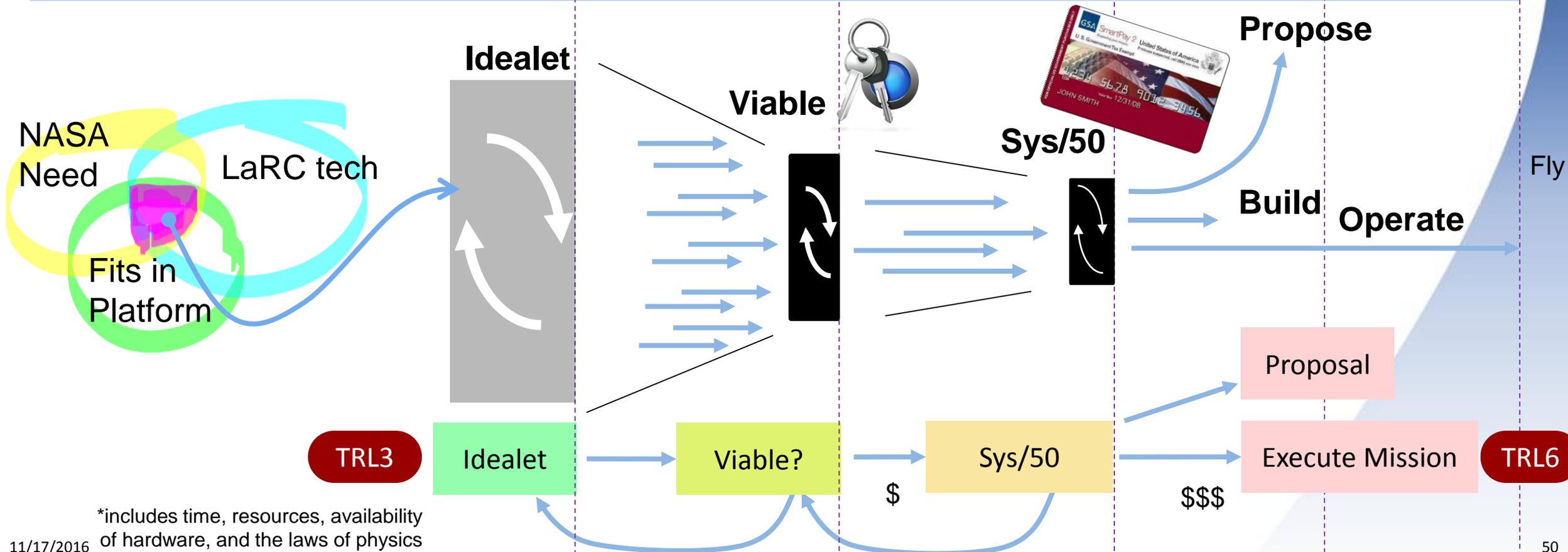


Mission Natural Selection



Level of Authority:	Lab77 Team	Branch	Directorate
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Criteria for Advancement:	Meets a stated need Tech + Team in place Fit's in a platform	NASA/LaRC aligned 1 st order feasible Cohesive team	Engineered System 50% of Design No gotchas!*	System is built
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*includes time, resources, availability of hardware, and the laws of physics



The Lab77 Idealet and the Viability Test



➤ Idealet:

- Written by anyone at any time
- Follows the format
 - The need. Why would you do that?
 - The concept. What are the critical pieces and parts?
 - The objective of the effort. What do you need to show?
 - The origin. Who gave you the idea?

➤ Viability Testing

- Merit Review: Team brings the idealet to branch and directorate level leadership
- Merit is established: Consensus shows that the idealet is valuable and aligned to NASA and Center strategy/roadmaps
- Feasibility Review: Expounded on key technical challenges and presents them to relevant SMEs
- Feasibility is established: no laws of physics are broken and critical assumptions are sound.

➤ Team

- Demonstrate cohesiveness in through viability and Sys/50 tests.

➤ Rapid concept developments

- Engineering of the system
- 50% design complete
- No “Gotchas”



Technical Feasibility Test

Elements of a Sys/50 Analysis

Systems Engineering	Design Engineering	Programmatic
<ul style="list-style-type: none"> - Needs, Goals, Objectives - Mission Requirements - Con-ops - Architecture - Interface definition - System block diagrams - Con-ops system diagram 	<ul style="list-style-type: none"> - Detail design in all disciplines - Requirements - Mechanical model - Electrical block diagram with parts list - Power budget - Comm. design - Cabling estimate - Thermal analysis - Structural analysis - Software architecture - Sensor system - Testing and evaluation plan 	<ul style="list-style-type: none"> - Cost - Schedule - Risk - Review Comments