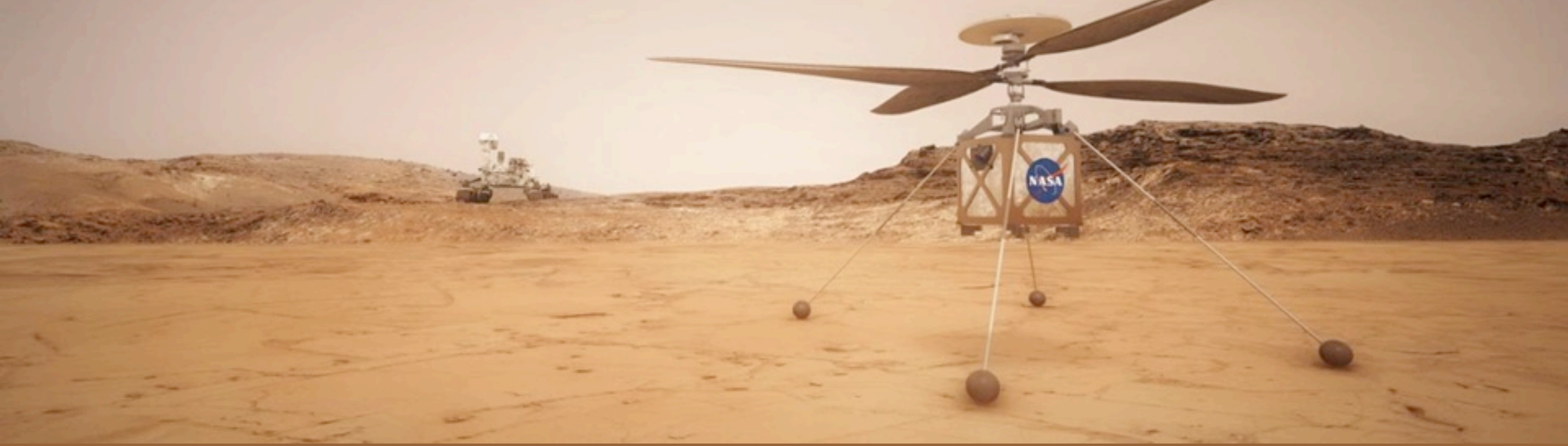
2018 Workshop on Autonomy for Future NASA Science Missions

October 10-11, 2018



DRM Breakout Report

<DRM WORKING GROUP NAME (e.g. “Venus”)>

<List of DRM team members>, <Name>, <Name>, … <Name>

DRM Working Group Guidelines

THIS SLIDE FOR GUIDANCE ONLY – REMOVE PRIOR TO PLENARY REPORT-OUT PRESENTATION

- Three key questions to help guide your autonomy concept brainstorm:
    1. What capabilities that are critical to your DRM can only be accomplished with advanced autonomy?
    2. What autonomous capability would enable expanded mission goals at reduced costs/risk, and/or improved scientific outcome?
    3. Are there any *technical* reasons why your DRMs are not possible today, and can autonomous technologies help to address those challenges?

- Scenarios that demand autonomy include (but are not restricted to):
    - Constrained communications (e.g. light-speed latency, occultations, bandwidth, etc.)
    - Time-critical decisions (e.g. crisis management, fleeting scientific anomalies, etc.)
    - Data-heavy decision processes that exceeds bandwidth (e.g. soft landing final approach)
    - System architecture simplification (e.g. local control-system feedback loops)
    - Situational complexity that exceeds the limits of useful human input

<NAME of DRM Autonomy Capability>

→ One slide for each of the autonomous capabilities needed to support a DRM object or requirement. ←
Example…
DRM Requirement: *Fetch-rover to minimize the infrastructure of the Mars sample-return platform*
<NAME of DRM Autonomy Capability>:
Slide 1) *"Long-distance AutoNav for Mars sample-fetch rover"*
Slide 2) *"Autonomous reporting of opportunistic science by sample-fetch rover during traversal."*

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ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	e.g. *Mars sample return: use a "fetch" rover to retrieve previously cached sample by traversing 5+ km.* <Replace this example with your response>
B	Describe an autonomous capability that could be used to accomplish (A).	e.g. *Long-distance / multi-sol autonomous surface navigation.* <Replace this example with your response>
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table on the last slide for a list of technologies.	e.g. *Sensing and perception (1.1), state estimation and monitoring (1.2), knowledge and model building (1.3), hazard assessment (1.4), motion planning (2.3), execution and control (2.4)* <Replace this example with your response>
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	e.g. *lidar with 10m range that can be accommodated on a rover, high-performance computer (better than RAD 750).* <Replace this example with your response>
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	e.g. *"Visual Teach and Repeat (Barfoot / Univ. of Toronto)High-Performance Spacecraft Computing (STMD GCD). With some modifications, flash lidar technology from commercial partners may help to accelerate development of this capability (https://sbir.nasa.gov/SBIR/abstracts/16/sttr/phase2/STTR-16-2-T9.01-9825.html) "* <Replace this example with your response>
F	Is (B) enabling or enhancing for (A)? Can this capability only be enabled with autonomous technology? Explain.	e.g. *Enhancing - autonomous surface navigation could increase the average "speed made good" while traversing from point to point.* <Replace this example with your response>
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	e.g. *This capability will require investment comparable to the development cost of MSL AutoNav. This capability would decrease the amount of time required for surface operations, with corresponding reduction in mission control cost.* <Replace this example with your response>
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance, schedule, etc.	e.g. *This capability would greatly decrease ground traversal time and therefore mission operational risks associated with the probabilities of encountering rover-disabling metrological/seasonal conditions.* <Replace this example with your response>
I	Optionally list any comments, key points, questions, etc. not covered in the sections above.	e.g. *MER and MSL have previously demonstrated "AutoNav", which is sufficient for short-range waypoint driving with autonomous hazard avoidance.* <Replace this example with your response>

Anomaly Detection

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	The system shall be able to autonomously and safely detect and mitigate faults and anomalies without compromising the assembly, itself and the overall mission
B	Describe an autonomous capability that could be used to accomplish (A).	*Multi sensor fusion and world model development for situational awareness, FDIRs etc. agility in responses to hazards*
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	1.6 Anomaly Detection 2.6 Fault Response
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	1.1 Sensing and Perception, 1.2 State Estimation and Monitoring, 1.3 Knowledge and Model Building
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	RESTORE-L RSGS XSS-11 (RPO) Tipping Point (IRMA)
F	Is (B) enabling or enhancing for (A)? Can this capability <u>only</u> be enabled with autonomous technology? Explain.	Enabling. Via Autonomy in Execution In short term autonomy mode (daily human supervision), the system should detect anomalies and faults. In long term autonomy mode (no daily human supervision), the system should detect and mitigate anomalies and faults. This is enabling as the DRM includes a large number of deliberate contacts and interactions that are best handled autonomously.
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	*O(10s millions) in tech development cost* *Critical for mission success and will have large savings (e.g. cost of 1 HST servicing mission)*
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance	*Decreasing risk of catastrophic mission failure due to collisions, loss of asset, improperly assembled elements, lack of optical performance*

Autonomous Maneuvers, Mobility and Manipulation

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	Robotic system(s) should be able to safely, assemble all the different modules into a fully functional observatory while maintaining safe and bounded motion
B	Describe an autonomous capability that could be used to accomplish (A).	*Free-flyer autonomous RPO and berthing, Robot truss walking, dexterous forceful interactions, manipulation of soft goods, collision free onboard motion planning, resource-aware onboard trajectory planning and maintenance, manipulation of gossamer structures, agility in responses, managing uncertainty (e.g. CM or inertia, CP),* distributed actuation, sensing and control, manipulation of soft goods
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	2.3 Motion Planning, 2.4 Execution and Control, 1.0 Situation and Self Awareness
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	Manipulation, sensing and control technologies from RESTORE-L and RSGS Learning and Adaptation (for systems with deliberate contacts) Engineering Integrity DoD and commercial activities in multi-agent systems
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	
F	Is (B) enabling or enhancing for (A)? Can this capability <u>only</u> be enabled with autonomous technology? Explain.	*Enabling. This is fundamental to both orbital maneuvers (e.g. trajectory generation and SC relative motions), as well as robot interactions for mobility and manipulation during deliberate, safe contact events*
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	*O(10s millions)*
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance,	*Reduce operations costs, improve performance, and reduce overall schedule impact*

Autonomous (in-space) V&V and Ground Test and Evaluation

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	System shall be able to autonomously V&V (in-space) all assembly steps; and autonomous behaviors shall be tested on the ground before launch. *In space V&V as we cannot assembly and test the whole observatory on the ground.*
B	Describe an autonomous capability that could be used to accomplish (A).	*Real time sensing, on-board model building, "sense-making", situational awareness, modeling and simulation, disparate sensor fusion (e.g. metrology and FTS), new sensing capabilities, FDIR,*
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	New sensors, algorithms in sensor fusion, distributed actuation, sensing and control
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	Borrow from building and bridge inspection, automotive assembly sensing, NDE approaches, ground based telescope assembly
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	*In space V&V of autonomous assembly and servicing is a fairly new area with sparse (if any) set of projects*
F	Is (B) enabling or enhancing for (A)? Can this capability only be enabled with autonomous technology? Explain.	*Enabling. This is critical towards certifying the telescope for ops*
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	*O(10s millions) for autonomy behaviors* *Reduce risk in engineering performance, overall schedule and ops staffing*
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance, schedule, etc.	*Reduce operations costs, improve performance, and reduce overall schedule impact*
I	Optionally list any comments, key points, questions	*Fusion of non-conventional set of sensors for onboard sense-making, algorithm*

DRM Autonomy Summary

(Single-row summary for each DRM objective or requirement.. duplicate this slide if you need more rows)

DRM Scenario	Autonomy Requirements/Goal	Key Question & Knowledge Gaps	Technology Innovations and Partnerships	Current SOA, Projects and Products
<DRM mission objective or requirement>	<List of all the autonomy capabilities needed to address this DRM requirement>	<Key questions and technical unknowns in developing these autonomy capabilities>	<Key areas of required technology innovation, approach to achieve solutions, including commercial partnerships >	<Current state of the art of technology which constitutes a basis for development, including commercial systems>
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Candidate DRM White Papers

Propose one or more white papers that should be published in order to define and promote the key autonomy innovations identified by this working group.

- Architecture and autonomy design for ISA
- Autonomous trajectory planning and maintenance for ISA
- Temporal and spatial multi-agent coordination for ISA
- Onboard autonomous V&V of ISA
- Dexterous, force controlled manipulation and mobility
- Agile and reactive motion planning for dynamic response
- Fusion of disparate and unconventional sensor suites for situational awareness of ISA
- Trusted autonomy for ISA
- Incremental demonstrations towards ISA risk reduction
- Physics-infused, multi-agent autonomy and GNC for ISA
- Multi-agent motion planning, control and coordination for ISA

Autonomous Systems Taxonomy
Summary Table – for your reference

1.0 Situation and Self Awareness	2.0 Reasoning and Acting	3.0 Collaboration and Interaction	4.0 Engineering and Integrity
1.1 Sensing and Perception	2.1 Mission Planning and Scheduling	3.1 Joint Knowledge and Understanding	4.1 Verification and Validation
1.2 State Estimation and Monitoring	2.2 Activity and Resource Planning and Scheduling	3.2 Behavior and Intent Prediction	4.2 Test and Evaluation
1.3 Knowledge and Model Building	2.3 Motion Planning	3.3 Goal and Task Negotiation	4.3 Operational Assurance
1.4 Hazard Assessment	2.4 Execution and Control	3.4 Operational Trust Building	4.4 Modeling and Simulation
1.5 Event and Trend Identification	2.5 Fault Diagnosis and Prognosis		4.5 Architecture and Design
1.6 Anomaly Detection	2.6 Fault Response		
	2.7 Learning and Adapting		

For complete document, click here: https://go.usa.gov/xPTZa

Fong, Terrence W. et al, "Autonomous Systems Taxonomy", *NASA Technical Report, Autonomous Systems CLT Meeting*, NASA Ames Research Center. 5 May, 2018.