RESILIENCY

IN FUTURE CISLUNAR SPACE ARCHITECTURES

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1 MOTIVATION

Resiliency is an aspirational metric, and it is a common goal for complex systems – be they engineered space architectures, geopolitical networks, or the human immune system. However, despite the ubiquitous desire for resiliency, the concept is surprisingly difficult to define and apply to future planning efforts. We assert that resiliency can emerge from a layered approach of deliberately chosen capabilities with overlap and flexibility that, in aggregate, result in a resilient system. The challenge is to identify capabilities that contribute to resiliency and to accurately characterize their value. Resiliency is discussed through the lens of future architecture planning, outlining how the National Aeronautics and Space Administration (NASA) can benefit from a shift in approach when transitioning focus to the cislunar environment.

2 OBJECTIVE

The objective of this work is to introduce and explore the concept of resiliency as it relates to future cislunar space architectures by:

1. citing examples of its growing demand across government
2. describing potential characteristics of resilient systems
3. introducing a framework for evaluating the linkages between resilient capabilities and visions for future cislunar architectures
4. exercising the framework to identify and evaluate resiliency-enabling technical capabilities for cislunar space architectures.

A NASA analysis team along with a technology working group and an architecture working group were established to complete these objectives.

3 RESILIENCY REFERENCES

1	***Resiliency** is the ability of a system architecture to continue providing required capabilities in the face of system failures, environmental challenges, or adversary actions* Resiliency and Disaggregated Space Architectures, Air Force Space Command, 2016
2	***Resilience** is defined as the ability to deliver the mission in the face of manmade or natural interference* Resiliency of Space Systems, The Aerospace Corporation, 2017
3	***Resilience** is the ability of an architecture to support the functions necessary for mission success in spite of hostile action or adverse conditions. An architecture is "**more resilient**" if it can provide these functions with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions and threats. **Resilience** may leverage cross-domain or alternative government, commercial, or international capabilities* Department of Defense (DoD) Fact Sheet, 2011
4	**Resilience:** *The ability of an architecture to support the functions necessary for mission success with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats, in spite of hostile action or adverse conditions* **Resilience:** *An internally-focused characteristic of an architecture that is extremely difficult to characterize in a closed form analysis… [developed into] the fewest categories into which resiliency could be sufficiently organized. We arrived at six discrete characteristics to describe resilience approaches: disaggregation, distribution, diversification, protection, proliferation, and deception* Space Domain Mission Assurance Resilience Taxonomy, Office of the Assistant Secretary of Defense for Homeland Defense & Global Security (2015)
5	**Resilience**: *The ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies* Presidential Policy Directive 8: National Preparedness, Obama White House, 2011
6	*The characteristic or capability to maintain functionality and structure (or degrade gracefully) in the face of internal and external change* Mission Assurance Policy for the Defense Intelligence Enterprise, DoD, 2015
7	*System **resilience** is defined as the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risks* On the Definition of Resilient Systems, Haimes, et al., 2008; Haimes, 2009
8	***Resilience** is designed to have systems self-heal with no intervention from humans. In the cyber context, a resilient cyber system must continue to operate as intended, even if compromised (for example, if unauthorized access is achieved)* Understanding Today's Cyber Challenges, TASC, 2011
9	*The ability to quickly adapt and recover from any known or unknown changes to the environment. **Resiliency** is not a process, but rather an end-state for organizations. The goal of a resilient organization is to continue mission essential functions at all times during any type of disruption. **Resilient** organizations continually work to adapt to changes and risks that can affect their ability to continue critical functions* Contingency Planning Guide for Federal Information Systems, National Institute for Standards and Technology (NIST), 2010

The blue verbs inspired and informed the Resiliency Aspects of the Resiliency Framework. The green nouns inspired and informed the Resiliency Types of the Resiliency Framework.

4 RESILIENCY FRAMEWORK

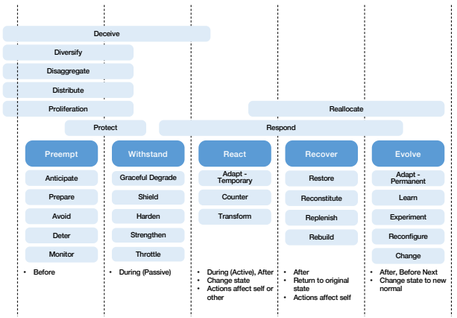
[Capabilities exist at the cross section of Resiliency Types and Resiliency Aspects]		Resiliency Aspects (Verbs) High-level goals which define functions, methods, or actions used by a resilient system				
		Preempt	Withstand	React	Recover	Evolve
Resiliency Types (Nouns) Types of stressors to which aspects of resiliency are applied to ensure continued utility	Environment	[Capability]	[Capability]	[Capability]	[Capability]	[Capability]
	Human	[Capability]	[Capability]	[Capability]	[Capability]	[Capability]
	System	[Capability]	[Capability]	[Capability]	[Capability]	[Capability]
	Support	[Capability]	[Capability]	[Capability]	[Capability]	[Capability]

Rather than establishing a single definition, our technology and architecture working groups were able to characterize resiliency through a descriptive framework to provide a comprehensive assessment of resiliency. The framework, a matrix, describes capabilities in terms of five aspects (i.e., the ways in which a system can be resilient) and four types of resiliency (i.e., the types of stressors to which a system can be resilient), detailing a tool to evaluate a technology's ability to preempt, withstand, react, recover, and evolve to known and unknown stressors including those originating within the environment, human, system, or support.

Resiliency Aspects

Which functions, methods, or actions may be used and when?

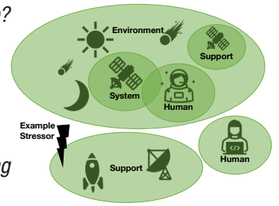
- ***Preempt:** Taking action, making choices, predictions, or allocations before a stressor*
- ***Withstand:** Maintaining full or partial capability during a stressor due to inherent qualities*
- ***React:** Taking action to avoid, affect, or mitigate the cause or impact of a stressor*
- ***Recover:** Taking action after a stressor to return to an original operating state*
- ***Evolve:** Changing a nominal state after a stressor to improve future performance*



Resiliency Types

Where does the stressor or disruptor originate?

- ***Environment:** Inherent challenges and uncertainties from the natural environment*
- ***Human:** Human interaction*
- ***System:** System design, characteristics, or flaws internal to the system*
- ***Support:** Interaction with external supporting systems, infrastructure, or processes*



5 RESILIENCY ENABLING TECHNICAL CAPABILITIES

Once the framework was complete, the technology working group exercised the creativity matrix by identifying technical capabilities at the intersections of the Resiliency Aspects and Types. The brainstormed capabilities, such as 1) fast, efficient, and cheap dexterous robotics and 2) built in soft and hard stops, were compiled into a database of 52 resiliency-enabling technical capabilities, each with cislunar considerations. The listing and characterization of the technical capabilities in the database demonstrate the potential of the Framework to be used as a rubric to evaluate and aggregate resiliency. For example:

Example Tech Capability A: Fast, efficient, and cheap dexterous robotics						
Description: Ability to perform regular, external spacecraft inspections by remotely operated or autonomous robotics. For example, consider the robotic implementation of all astronaut EVAs on ISS.						
Resiliency		Resiliency Aspects (Verbs)				
		Preempt	Withstand	React	Recover	Evolve
Resiliency Types (Nouns)	Environment	X			X	X
	Human	X			X	
	System	X			X	X
	Support					X

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Example Tech Capability B: Built in soft and hard stops						
Description: The capability to prevent/inhibit/avoid catastrophic system damage through embedded hardware and software stops within the interfaces and subsystems for real-time and safety-critical systems.						
Resiliency		Resiliency Aspects (Verbs)				
		Preempt	Withstand	React	Recover	Evolve
Resiliency Types (Nouns)	Environment					
	Human		X	X		
	System		X	X		
	Support					

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Example Total Tech Capability: Tech Capability A + Tech Capability B						
Description: This example system includes both example technical capabilities, 1) fast, efficient, and cheap dexterous robotics and 2) built in soft and hard stops.						
Resiliency		Resiliency Aspects (Verbs)				
		Preempt	Withstand	React	Recover	Evolve
Resiliency Types (Nouns)	Environment	X			X	X
	Human	X	X	X	X	
	System	X	X	X	X	X
	Support					X

6 CONCLUSION

Additional work is necessary to further demonstrate the value of the Resiliency Framework tool and apply it to architectures. Through this study process, we have characterized the need to think about resiliency along with mission objectives and system requirements. We note that while resiliency is challenging to define, it should be an aspirational goal for any design, particularly those with the potential for long-duration operations. Although there is not a clear-cut approach to guarantee resiliency, there are characteristics that are indicative of resilient systems and architectures. Thinking proactively about how these characteristics, that are enabled or enhanced by technical capabilities, can be applied to mitigate or neutralize potential stressors can assist in solidifying the role and utility of resiliency. The Resiliency Framework can thus be used as an analysis (or assessment) tool to identify gaps and dependencies in technical capabilities that must be considered (or addressed) to mature a system's resiliency for envisioned future cislunar space architectures.

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