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NASA Futures Roundtables: Exploring Challenges and Opportunities for NASA in the Emerging Environment

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Executive Summary

Today's operating environment both on Earth and in space is volatile, uncertain, complex, and ambiguous (VUCA)[1]. This VUCA environment, in which NASA operates today and will continue to operate in the coming decades, is fundamentally different than in previous periods due to the increasing and diverse use of space by commercial companies, the emergence of new space-faring countries, and the increased use of space by nations with long-established space programs. Strategic foresight is an approach for navigating this uncertainty, as it enables better decision-making under ambiguity through systematic thinking about the future. Foresighting leverages a diverse set of tools and techniques to challenge assumptions about the future. Strategic foresight helps envision potential future states, identify key events and decision points, and integrate uncertainty into planning processes. This enables organizations to drive towards preferred future states and increase resiliency to disruption. Although thinking about the future is an important piece of the process, foresight is truly about what organizations do today.

In its 2021 annual report[2] evaluating NASA's strategy, the Aerospace Safety Advisory Panel (ASAP), a federal advisory committee that reports to NASA and Congress, published the following finding:

> *NASA should develop a strategic vision for the future of space exploration and operations that encompasses at least the next twenty years, including potential alternative scenarios, that is driven by how the Agency is going to understand and manage risk in the more complex environment in which it will be operating.*[3]

The purpose of this six-month study was to support NASA's response to this finding and to inform its future strategic planning efforts by (1) developing future scenarios focused on potential future states in 2040 and beyond, (2) investigating candidate strategic options that may be most resilient to these diverse scenarios, and (3) extracting from the scenarios the key questions that NASA leadership may consider when developing resilient strategic plans today. Foresighting was chosen as the preferred method for this study. Foresighting enables informed decision-making in an environment of uncertainty by helping leaders to envision possible futures and react to them today. This study did *not* attempt to develop technological roadmaps or to provide a current state and future direction of a scientific discipline, mature processes already exist for these purposes at NASA (e.g., decadal surveys). In addition, the composition of an explicit response to the ASAP finding is out of scope for this study and shall be undertaken by NASA separately.

The foresighting process was executed in a collaborative environment, bringing together NASA-internal and external stakeholders in roundtables and interviews facilitated by Aerospace foresight experts. The Aerospace foresighting team worked with approximately 200 NASA staff and external participants. Roundtables included NASA employees from early career to senior staff and with a range of technical, managerial, and administrative roles. The interviews were conducted with NASA executive leadership. Roundtables with participants external to NASA included educators, graduate students, science fiction authors, space lawyers, social justice advocates, engineers from start-ups and Fortune 500 companies, space enthusiasts, and more. The roundtables and interviews included a series of individual and group exercises designed by the Aerospace foresighting team to elicit the participants' knowledge and perspective on multiple topics pertinent to this study, including: trends and disruptors that will affect NASA's future, whether or how NASA's vision and mission should evolve in the coming decades,

[1] Warren Bennis and Burt Nanus, "Leaders: Strategies for Taking Charge," 1985.
[2] Aerospace Safety Advisory Panel Annual Report 2021, https://www.nasa.gov/sites/default/files/atoms/files/2021_asap_report-tagged.pdf, January 1, 2022.
[3] Ibid., p. 11

potential future states of the world, fears and dreams for the future of the space enterprise, and new definitions of discovery and exploration, among others.

This study was formulated around answering four questions posed by NASA. In this executive summary, we summarize the conclusions for each question. The main body of report provides greater detail on the methodology, the step-by-step analysis, and the raw inputs from the roundtables and other sources.

Question #1: What would be significant disruptions (technological, geopolitical, environmental, cultural, etc.) to the future world that NASA should plan for?

The roundtable exercises and interview questions allowed us to investigate drivers, trends, and emerging disruptors for the future world. Drivers, trends, and emerging disruptors determine the conditions (forces) that are actively shaping the current environment. A *driver* is a significant force pushing change, a *trend* is a perceptible vector (with magnitude and direction) for which change is characterized, and an *emerging disruptor* is a tangible manifestation in the present of what is possible to come (which may or may not scale into an emerging or established trend but offers a potential window into the future)[4]. Participants in the roundtables and interviews provided a wide range of inputs on drivers, trends, and emerging disruptors that are indicating change in the areas of society, technology, economics, environment, politics, threat, and space (STEEPTS). These inputs were augmented with several additional sources including Aerospace's proprietary horizon scanning method (which leverages the ITONICS platform) for searching open literature and tracking trends and disruptors, the International Space University, and the natural language processing of approximately 50 documents, some provided by NASA on the future of space and aviation and others supplied by Aerospace on global futures.

The Aerospace team synthesized hundreds of inputs from the roundtables, interviews, and other sources into 20-30 overarching trends and disruptors in each major category (STEEPTS). Several trends and disruptors appeared in multiple categories, either directly or thematically, indicating their potential importance on the future operating environment. While all the trends and emerging disruptors are important to continue to monitor, the team identified nine significant high-level trends that merit in-depth consideration for NASA future planning:

1. *Commercial space activity*: The increasing use of space for diverse purposes by commercial companies is leading to new opportunities for NASA to source technologies, capabilities, and insights. On the other hand, the growing commercial viability for space companies may force NASA to reevaluate its mission, capabilities, and staffing portfolio.

2. *Increased focus on climate change*: The effects of climate change are becoming more apparent with the increased frequency of intense storms, droughts, and heat waves, as well as with rising sea levels, and warming oceans. These climatic effects are increasing resource competition in countries with too much or too little water, but it is also providing opportunities, such as the opening of new shipping routes in the Arctic and expansion of agricultural zones.

3. *Degree of connectivity and cybersecurity*: The population is becoming more connected due to ubiquitous sensing and internet from space, leading to new social dynamics and the rise of increased cybersecurity needs.

[4] Cunzeman, K. and Dickey, R. "Strategic Foresight for the Space Enterprise," *Center for Space Policy and Strategy*, The Aerospace Corporation, https://csps.aerospace.org/papers/strategic-foresight-space-enterprise

4. *Synthetic biology*: Genetic modification as a competitive advantage is becoming more apparent as companies like Monsanto launch new products, and synthetic biology is increasingly being used for human modification such as growing organs for humans.

5. *Greater use of autonomous systems*: Increased utilization of autonomous systems is most noticeable in attention-grabbing headlines about unmanned aerial vehicles (UAVs) and self-driving cars, but greater use of autonomous systems is greatly affecting businesses and governments.

6. *Volatility of the domestic political environment:* US domestic politics is in a period of increased polarization and volatility as compared with previous decades. One relevant impact of the resulting unpredictability is the politicization of science and research. Agencies that perform scientific research are under increasing scrutiny and their priorities may swing more readily as political administrations change.

7. *Changes in international geopolitical environment:* The international geopolitical environment is changing with respect to cooperation, competition, and conflict. For agencies that have many international partnerships, the change in geopolitical relationships (as well as the rise of new ones) can lead to large impacts and potentially put long-term projects at risk. This could also lead to a more contested mission environment as more nation-states expand into space.

8. *Workforce of the future*: The COVID-19 pandemic impacted the global workforce, with continuing ramifications in workers' rights movements; increased demand for people to work from home; and infrastructure pressure changes, including greater computing/data requirements, differing pressures on support infrastructure within cities, and less commute infrastructure.

9. *Supply chains and disruption*: COVID-19 brought to light the lack of resilience within the supply chains that keep the United States operational. The lack of resilience causes, and will continue to cause, multi-country breakdowns in supply chains.

The complexity of the present and future environments cannot be sufficiently described by nine major trends alone and thus, **the scenarios derived from the next question are critical to exploring the potential interactions between these major trends and many other emerging disruptors**. These scenarios serve as the foundation for the rest of the project's analysis.

Question #2: What are the possible scenarios for the aerospace community and the broader technology world in the 2040s?

The scenarios presented here explore the corner cases of the future, where organizational strategies will be most greatly stressed. To maximize their effectiveness for developing resilient organizational strategies, scenarios are intentionally thought-provoking and sometimes provocative, but they remain within the realm of the (future) possible. The purpose of scenario development is **not** to predict the future, nor is it fruitful to assign probabilities or qualitative assessments of likelihood to different possible futures. The study leveraged the Four Futures model[5], originally conceived by Dr. James Dator at the University of Hawaii, which uses four archetypes of future storylines: (1) *growth* (business as usual, evolve the status quo into the future); (2) *discipline* (behaviors must adapt to growing internal or environmental limits); (3) *decline* (system degradation or failure modes as a crisis emerges); and (4) *transform* (game-changing disruptions with new technology, business, and/or societal factors).

[5] Dator, J. "'New Beginnings' Within a New Normal for the Four Futures," Foresight, Vol. 16, No. 6, November 2014.

Each scenario is based on a set of critical uncertainties about the future that use the trends and disruptors identified in Question #1 as inputs. In this study, the critical uncertainties used for scenario development were: 1) commercial space viability and sustainability, 2) Earth's environmental stability, 3) domestic politics' influence on NASA, 4) the human presence in space, 5) geopolitical stability, and 6) technological capability gamechangers for NASA. Each uncertainty could resolve into one of many possible future states (e.g., commercial viability could range from boom to bust in the coming decades). The foresighting team tuned these critical uncertainties to a variety of possible combinations within the Four Futures model to create four diverse and credible scenarios. This deliberate approach ensures that the process explores corner cases of the possible future space, where strategic resilience is most needed.

The four scenarios each have a concise and evocative title and a three- or four-paragraph narrative that depicts a possible future consistent with the four archetypes. When reviewing these scenarios, the reader should resist the temptation to judge them on their likelihood. In fact, we expect that none of these scenarios will be fully realized in the future. Some parts of *all* of them are likely to occur in the coming decades, but we cannot know which parts. Consequently, the specific circumstances in the scenarios are not as important as the larger themes or challenges that emerge for NASA. These themes and their key focus questions are captured to provide NASA leadership with a starting point for vision-setting and goal prioritization in the formal strategy-development process. For the sake of brevity, the four scenarios are reproduced here in a much-abridged form with their key focus questions:

1. **Growth** – ***Commercial Space in the Driver's Seat.*** The private sector commoditizes human spaceflight between the Earth and Moon and industrializes low Earth orbit (LEO). Global mobility on Earth is on the rise thanks to the scaling of sub-orbital flights, and intermittent global conflicts extend to space, where sovereignty remains untested.

   Key focus questions for NASA: What would NASA do if commercial industry was almost fully leading and setting priorities for human spaceflight? What should NASA's role be in a world where space war, including human casualties, is normalized? Should NASA take a bigger role in ensuring flight safety?

2. **Discipline** – ***Retreat from the Final Frontier.*** The private sector fails to establish commercial viability amidst global depression, and a push for greener fuels gives rise to slower but more eco-friendly air and space transportation. The metaverse becomes fully integrated into society, reducing desire for physical exploration of space but also offering opportunity to scale the "virtual experience" to the masses.

   Key focus questions for NASA: How should NASA move forward if there's no commercial sector to leverage? How should NASA approach exploration when there's little interest for human spaceflight?

3. **Decline** – ***Blamed for the Big One.*** NASA miscalculates the risk of an approaching asteroid that causes widespread devastation, leading to the public's loss of trust in NASA and science in general. STEM degree programs see a major plummet in enrollment. Congress funds a private consortium to establish and lead settlements on Mars and orbiting platforms. A Mars colony is successfully established, but political friction quickly leads to conflict between Earth and the base on Mars.

   Key focus questions for NASA: Which NASA areas of responsibility (officially or perceived) could threaten its brand and public trust? Whose role is it to govern off-world settlements (e.g., securing property rights) when commercial is leading the effort?

4. **Transformation** – ***Children of Space.*** A breakthrough in high-speed space travel enables widespread expansion into the Solar System. The new wealthy class, borne from the profits of asteroid mining, live off-world and experiment with genetic modification to enhance their livelihood and reproductive capabilities off-world. A next wave of transformation approaches with Artificial Intelligence (AI) and quantum sensors detecting a potential techno-signature from another galaxy.

   Key focus questions for NASA: What is NASA going to do if/when life is discovered off planet? What if NASA is not the organization to discover life off Earth? What are the public expectations for the roles and responsibilities of NASA? How could NASA be viewed as a failure?

Question #3: How would these disruptions impact NASA's roles in science, space technology, human exploration, aeronautics, and its associated workforce?

Amidst a volatile and uncertain operating environment, one important element of organizational effectiveness is alignment on collective, understood, and believed vision and mission. NASA's current vision statement is "exploring the secrets of the universe for the benefit of all," and its current mission statement is "NASA explores the unknown in air and space, innovates for the benefit of humanity, and inspires the world through discovery." This study explored the enterprise-wide alignment on this vision and mission and whether NASA's staff believed they should change in the future before diving into potential ways that disruption could impact NASA.

When posed with the question, "what is NASA's *why* and does it change in the next 20-plus years?", the two roundtables of NASA executives offered at least 26 different responses. There are common elements across the statements, such as "explore," "humanity," and "discovery," but the messages were far from uniform. The statements vary in both who NASA's ultimate beneficiaries may be and how specifically those beneficiaries are described. Many participants believed that NASA is at a fundamental transition point with the rapidly changing environment (particularly with the rise of commercial space). Some went so far as to say that NASA was having an identity crisis. Many participants felt that there had been pressure for NASA to turn into a more "applied agency" (i.e., focusing on delivering services, similar to NOAA) rather than a "mission-focused" (i.e., exploration-focused) agency and that pressure was driving the lack of a clear mission statement.

Feedback from the roundtables and interviews revealed that there was no enterprise-wide consensus on today's vision and mission statements. Roughly half of the internal participants felt that the vision and mission might be different in the future. The other half thought that NASA's current vision and mission were enduring, but that change would occur in exactly *what* NASA does in pursuit of that vision. Two notable themes were: (1) a tangible shift to a more applied agency, or (2) a change in focus to enabling life outside our home planet (as opposed to thinking about Earth). Regarding human spaceflight, some believed that in twenty years, "[NASA would] focus less on *'how do we get there?'* and more *'what do we do when we get there?'*." Another theme that emerged from the roundtables was the potential shift of NASA's primary role to being a catalyzing agent for the rest of the space enterprise, with comments on NASA's role such as "catalyzing discovery for the good of humanity" and, as an aspirational future state, "NASA is the catalyst for innovation, discovery, and exploration."

These perspectives on NASA's potential future roles in science, technology, and the workforce provided a starting point for the Aerospace foresighting team in its development of candidate strategic options for NASA, which capture more formally the wide range of paths that NASA leadership could elect for the organization. The roundtables, executive interviews, a review of the scenarios for challenges, opportunities, or implications against key criteria (e.g., resourcing, organizational effectiveness, culture,

etc.), and expert analysis culminated in the development of 15 strategic options, grouped into five categories as shown in the table below.

Strategic Options		Description
Commercial	1. Maintain internal capabilities relevant to NASA's mission	Overlap exists between what NASA is doing and what commercial can do
	2. NASA transitions to an acquisition-only agency	NASA employees are not actively building, integrating, or operating in-house
	3. Skate to where commercial isn't	Fully transition commercial-viable capabilities out of NASA
Innovation	4. Focus on basic research	Rebalance portfolio to be more research focused rather than mission-execution focused
	5. Lead the frontier	Go as far and fast as possible, explore the unknown where no one else is
	6. Catalyze access for all	Enable mechanisms for a significant part of society to participate in exploration and science
Non-Commercial Partnerships	7. Master in targeted areas, partner elsewhere	Self-sufficient in small subset of core competencies, partner elsewhere because NASA cannot do it all
	8. Maximize partnerships across all efforts	Value proposition as an integrator across interagency, international, etc., not necessarily an expert everywhere
	9. DIY: don't partner	Complete vertical integration under NASA-funded efforts
Workforce / Talent	10. Be the best government option	Excel at providing the best work environment in the USG
	11. Substantial effort to increase value proposition for attracting and sustaining talent	Push government swim lanes for talent acquisition
	12. Compete with non-government for top talent	Break open new possibilities for getting talent
Policy	13. Arbiter of data not policy	NASA presents/provides data, but does not get involved in policy formulation or decisions
	14. Use NASA's voice to drive awareness for policy	NASA drives conversations on topics where it has expertise
	15. NASA as a direct influencer of policy	NASA as an explicit policy advocate through data-driven evidence

These strategic options and categories are only starting points for NASA's strategic development and are intentionally not exhaustive, but they do capture the wide range of roles that NASA could pursue in the future considering the trends and disruptors identified in Question #1. Some of these strategic options are mutually exclusive, and others are not. For example, strategic options #8 ("Maximize partnerships across all efforts") and #9 ("DIY: don't partner") cannot be pursued simultaneously, as they capture two extremes on the spectrum of possible non-commercial partnership strategies. Any single strategy cannot be considered in isolation, and NASA cannot adopt them all. Generally, organizations should also consider strategies that appear to be big leaps as well as they are critical to organizational transformation. A discussion among NASA leadership about each of these is required in the context of resilience. Question #4 addresses the assessment of which strategies have the greatest potential to provide that resilience in light of the uncertain futures captured in the scenarios.

Question #4: How can NASA be best prepared to pivot when unpredicted technological or societal disruptions occur?

The 15 candidate strategic options from Question #3 were each evaluated against two metrics: (1) the number of scenarios from Question #2 where the strategy would position NASA more strongly to survive and thrive in the possible future described by the scenario and (2) the degree of organizational transformation necessary to realize the strategy, which was inferred by inputs from the NASA executive interviews and roundtables. The strategic options populate this metric space on Pareto-like fronts, where high resilience and low transformation is the direction of preference.

The most preferred strategic options are those where the largest number of possible future scenarios are covered and where the least amount of organizational transformation is needed. **Three strategic options are in this preferred region of the metric space having high resilience and low barriers to adoption:**

- **#5 Lead the frontier (i.e., go as far and fast as possible, explore the unknown where no one else is)**
- **#6 Catalyze access for all (i.e., enable mechanisms for significant part of society to participate in exploration and science)**
- **#11 Increase the value proposition for attracting and sustaining talent**

Pursuing these three strategic options would strongly position NASA in the face of a volatile and uncertain future without the need for a major shift in culture or resources. These three strategic options differ from NASA's ostensible current practice. For example, NASA's role in exploration is undisputed, but strategic option #5 (lead the frontier) would prioritize revolutionary innovation and exploration over incremental advancements and lead to other civil or commercial organizations deliberately being encouraged to take over after each frontier has been reached. Furthermore, NASA is already well regarded for its educational and public outreach, but strategic option #6 (catalyze access for all) is a more comprehensive approach where the public would take a more direct and meaningful part in NASA's exploratory mission, as opposed to being simply a consumer of media. Lastly, strategic option #11 (increase the value proposition for attracting talent) involves not only creating direct incentives for retention (e.g., compensation) but also restructuring the organization to improve employee satisfaction (e.g., geographically distributed employees doing work for any center) and including metrics for the potential for talent attraction and retention in the projects that NASA pursues.

The main body of the report details the performance of all the strategic options, including those that are least effective (low resilience and high barrier to adoption required). Of note are two options that are resilient against three of the four future scenarios (which indicates that these options are largely applicable regardless of future state):

- #4 Focus on basic research (i.e., rebalance portfolio to be more research focused rather than mission-execution focused)
- #15 NASA is a direct influencer of policy (i.e., NASA as an explicit policy advocate through data-driven evidence)

Both strategic options are considered "big leaps" in terms of organizational transformation. In the case of strategic option #4 (focus on basic research), the dominance of commercial space in three of the four scenarios suggested that NASA may be more advantageously positioned in a more research role, for which there is little commercial appetite, and by divesting many mission-execution activities that

consume substantial resources, but that may be overtaken by commercial capabilities by mid-century. Strategic option #15 (NASA is a direct influencer of policy) is the proactive complement to option #13, however it is very different than current practice.

To complement the strategic options, the foresighting team synthesized roundtable and interview inputs into a set of "universal elements" that underlie any successful strategic implementation, irrespective of the future state or specific strategies chosen for the organization as shown in the table below.

Participants in the roundtables helped identify these universal elements and addressed their own perceptions on NASA's current performance. Their inputs indicate that NASA's performance varies widely, from excellent (e.g., NASA's worldwide branding and STEM reachback) to poor (e.g., organizational alignment on vision and fostering a collaborative cross-center environment). Even if an organization is performing favorably, these elements should be actively managed because the trend is subject to forces outside the organization's control. For example, while NASA is currently performing well with creating "an inspired workforce of top talent," the trend is growing that talent acquisition and retention is becoming more challenging. In contrast, roundtable feedback suggests that work remains to be done to improve NASA's performance in cross-center collaboration, which is among the Innovation & Business Practices universal elements. Roundtable participants expressed frustration at the deep-rooted competition between different NASA centers and the *de facto* prohibition on collaboration with geographically separated colleagues and sometimes even within centers themselves when proposal dollars are at stake. The emphasis on competition instead of cooperation across the mission and centers could be preventing NASA from seizing new opportunities.

Universal Elements for Successful Implementation			
Category	**Description**	**Current Performance** (color based on inputs from roundtables & interviews) *green- good; yellow- fair; red- concerning*	**Baseline Trend**
Leadership & Organization	Organizational alignment on a collective, understood, and believed vision & mission (the "why" for NASA)	NASA has a clear, solid vision/mission statement, however there is a lack of necessary alignment or understanding throughout the organization	➔
	An integrated strategy roadmap for the NASA enterprise to help meet the vision and mission	Roadmaps at mission/directorate level, but not integrated/refined at enterprise level	
	Stakeholder management strategy including resourcing and enduring missions	Recognition of the need to increase amount of stakeholder engagement to reduce changes from admin to admin, but improvements needed	
Workforce / Talent	An inspired workforce of top talent	NASA continues to be a top-ranking government employer and engage new talent, but workforce is at risk, no guaranteed continuation	➘
	Top talent is retained and sustained at NASA	Some generational disconnects between wants/needs of workplace and mission resonance, and their understanding across management levels	➔
	Ensure a vibrant workforce promoting diversity, equity, and inclusion	Good progress on diversity, but room to go for equity and inclusion (particularly in leadership)	➚
Future Preparedness / Resilience	Adaptability and agility of the enterprise to weather disruptions and changes to the mission environment	Need formal approach for enabling integrated organizational flexibility to address surprise/drive change	➔
	Consistent scanning of how the environment is changing and weaving these insights into decision-making	Need to identify key internal stakeholders and processes that integrate horizon scanning insights into updating strategy	
Innovation & Business Practices	NASA can do some of the biggest, most complex, highest collaborative projects in the world	Demonstrated feats few others in the world have been able to achieve and should continue to "go big"	➔
	Reach-back to public, STEM, and international collaboration	Continue to strive to be world-class in its outreach efforts	
	Government-leading organization for commercial partnerships	Continue to lead in catalyzing and partnering with commercial	
	A collaborative—not counterproductive—competitive environment between mission centers and directorates	Need to address stove-piping and counterproductive internal competition	
	Abundant cross-enterprise collaboration to drive innovative outcomes	There are examples of excellence, need to expand enterprise wide within NASA and expand interagency, international, and commercial examples	
	Ability to prioritize geographic and organizational balance in portfolio to maximize impact across the entire enterprise	Work distributed by mission and Centers, not properly balanced across the enterprise	
	Recognize when to stop doing things that no longer serve the collective NASA mission	Need to establish rigorous process to decide when to stop and/or streamline investments to ensure they are serving collective mission	
Brand	Positive worldwide brand	Continue to maintain/enhance globally recognized brand	➔
	Be a trusted source of information and wisdom worldwide	Continue to provide trusted, science-based insight to the public	

A series of key questions for NASA leadership emerged from the foresighting analysis, specifically considering the strategic-decision points evident when considering the four future scenarios. Below are the major questions relevant to NASA's vision and mission that leadership should consider in the early stages of their strategic development process, the bolded questions indicate the primary questions, with related questions below:

Key Questions for NASA	
What is the "Why" for NASA and does it change in the future? How far does NASA embrace commercial vs. in-house? What is the appropriate mix of international partnerships vs. domestic capability? What is the future of human spaceflight vs. robotic exploration?	***Does NASA have the willingness to change to meet its collective vision?*** What internal and external barriers to change exist at NASA? Is NASA poised organizationally for change? What does NASA need to start or stop doing to serve its future mission?
How does NASA define success now and in the future? What is "success" for NASA? What does it mean for NASA to survive vs. thrive? Survival of the legal entity? Survival of the brand? In an abundant world with unlimited resources and endless talent, what would NASA try to do?	***How does NASA deliver resilience?*** What happens if NASA discovers life, and what if someone else does? What if there is another global conflict? What if someone else beats NASA back to the Moon and to Mars?

Foresighting is the first step in the strategy formulation and execution process. After exploring the trends and disruptors, possible futures, critical uncertainties, and possible strategic options, the follow-on steps are strategy formulation, change management, and finally tracking implementation progress. The 2021 ASAP report recommended that "NASA should develop a strategic vision for the future of space exploration that encompasses at least the next twenty years," and that the vision "should describe the role that NASA intends to play during that period." Additionally, "all aspects of the strategic plan should be clearly and unambiguously communicated throughout the Agency." Finally, the authors of the ASAP report recommend that NASA determine "how the Agency is going to understand and manage risk in the more complex environment in which it will be operating." The findings presented in this study are a framework that NASA may consider when addressing these recommendations. Any organization risks its relevance, resilience, and ability to shape the future if it fails to adopt a collective and integrated strategy, as recommended in ASAP 2021 Annual Report. Foresighting is not a one-time event. Routine reiteration is important to ensure an organization is constantly evolving to adapt to an ever-changing environment. NASA is well positioned to shape a vibrant future for itself and the nation in the aeronautics and space fields.

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1. Introduction and Motivation

Today's operating environment both on Earth and in space is volatile, uncertain, complex, and ambiguous (VUCA). This VUCA environment, in which NASA operates today and will continue to operate for the coming decades, is fundamentally different than in previous periods due to the increasing and diverse use of space by commercial companies, the emergence of new space-faring nation-states, and the increased utilization of space by nations with long-established space programs.[6,7] These circumstances lead to new challenges and obstacles for NASA to navigate and less certainty for the future. NASA must be prepared not only to lead the world in science and exploration missions in the 2030s, 2040s, and beyond but also to pursue an organizational path forward and a vision that ensures NASA's resilience against a wide array of potential societal, economic, environmental, and political volatility.

In its 2021 annual report[8] evaluating NASA's strategy, the Aerospace Safety Advisory Panel (ASAP), a federal advisory committee that reports to NASA and Congress, published the following finding:

> *NASA should develop a strategic vision for the future of space exploration and operations that encompasses at least the next twenty years, including potential alternative scenarios, that is driven by how the Agency is going to understand and manage risk in the more complex environment in which it will be operating.*[9]

The purpose of this six-month study was to support NASA's response to this finding and to inform its future strategic planning efforts by (1) developing alternative future scenarios focused on impacts in 2040 and beyond, (2) exploring the different strategic paths that NASA may take as its future role evolves and which strategies may be most resilient to this diverse array of scenarios, and (3) extracting from the scenarios key questions that NASA leadership should consider when developing resilient strategic plans. This study does not attempt to develop technological roadmaps or to provide the current state and future direction of science disciplines, mature processes for which already exist at NASA (e.g., decadal surveys). Rather, this study combines societal, economic, environmental, political, technological, threat, and space (STEEPTS) trends to formulate scenarios that capture the holistic environment that NASA will operate in. In addition, the composition of an explicit response to the ASAP finding is out of scope for this study and shall be undertaken by NASA separately.

The guiding questions for this study were:

1. What would be significant disruptions (technological, geopolitical, environmental, cultural, etc.) to the future world that NASA should plan for?

2. What are the possible scenarios for the aerospace community and the broader technology world in the 2040s?

3. How would these disruptions impact NASA's roles in science, space technology, human exploration, aeronautics, and its associated workforce?

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[6] Satellite Industry Association's "25th Annual State of the Satellite Industry Report," September 26, 2020.
[7] Cunzeman, K. and Dickey, R. "Strategic Foresight for the Space Enterprise," *Center for Space Policy and Strategy*, The Aerospace Corporation, https://csps.aerospace.org/papers/strategic-foresight-space-enterprise
[8] Aerospace Safety Advisory Panel Annual Report 2021, https://www.nasa.gov/sites/default/files/atoms/files/2021_asap_report-tagged.pdf, January 1, 2022.
[9] Ibid., p. 11

4. How can NASA be best prepared to pivot when unpredicted technological or societal disruptions occur?

To build potential future scenarios, the study team sought input from both NASA employees and external thought leaders. The team interviewed eight senior NASA executives and facilitated a series of interactive roundtables with approximately 200 NASA staff—from early-career to senior staff—and a diverse group of external participants. The NASA-internal participants represented all NASA centers and mission directorates, and the participants spanned years of service from interns to more than 50 years of civil service. The external participants included students, educators, representatives from Fortune 500 companies, entrepreneurs, authors, space enthusiasts, and artists. The team interviewed NASA executive-level leadership, which included the Deputy Administrator, Associate Administrators, and the NASA Chief Scientist.

To address the study's guiding questions, The Aerospace Corporation (Aerospace) team designed custom foresighting activities for the roundtables to draw out the societal, technical, political, and other relevant trends that could impact NASA in the next 20 years and beyond. The information gathered during the roundtables served as inputs for the Aerospace team to develop comprehensive alternative future scenarios, cross-futures insights, strategic implications, and key questions for NASA's senior leadership team to consider when building strategic plans. The Aerospace team used their proprietary horizon scanning and natural language processing capabilities to gather additional insights.

This report is organized as follows:

- Section 2 details the overall foresighting methodology of this study, including a description of the roundtables and their associated exercises, the translation of roundtable trends and disruptors into critical uncertainties, the development of scenarios, the identification of candidate strategic options based on subject matter expert (SME) review and inputs from the NASA executive interviews, the identification of the strategic options that are most resilient against the scenarios, and the formulation of other key questions from roundtable inputs that NASA leadership should address in upcoming formal strategy development.

- Section 3 is a deep dive into the roundtables themselves, including overviews of who participated, what exercises were carried out, and the general trends of the participants' responses.

- Section 4 is a review of the trends and disruptors identified by the roundtable participants, the ongoing horizon-scanning process internal to Aerospace, and the NLP review of NASA and other global futures documentation.

- Section 5 uses the NASA-internal roundtables and interviews to probe consensus views on what NASA's role and purpose should be in the coming decades and what principles should guide NASA's path forward as an organization (i.e., its "North Stars").

- Section 6 details the development of the future scenarios and the content of the scenarios themselves. The roundtable inputs inform the construction of a "Threadable CONOPS," with which four scenarios are composed. The Aerospace foresight team created four archetype scenarios (growth, discipline, decline, and transform) that derive from the Four Futures model[10]. The scenarios culminate with key focus questions that provide NASA with a starting point for vision-setting and goal prioritization in the strategy-development process. Section 6.4 discusses

[10] Dator, J. "'New Beginnings' Within a New Normal for the Four Futures," Foresight, Vol. 16, No. 6, November 2014

the development of candidate strategic options (non-exhaustive), which are based on review from the Aerospace foresighting team and inputs from the interviews with NASA executives.

- Section 7 is a cross-scenario assessment of the strategic options developed in Section 6.4. Each strategic option is evaluated for (1) its resiliency against each scenario (i.e., how favorably the strategic option would position NASA to thrive in the scenario's VUCA environment) and (2) the amount of organizational transformation needed at NASA to execute that strategic option. Using these two variables, strategic options are identified in a Pareto-like fashion that provide the maximum resilience for the least organizational transformation.

- Section 8 extends the review of the roundtable inputs and the trends and disruptors to identify "universal elements" of a notional NASA organizational strategy, including matters related to organization, workforce, business practices, and brand management, and to document key questions for NASA leadership to consider during the strategy-development process.

2. Foresighting Approach and Methodology[11,12]

Foresight is not about prediction, but preparedness. The growing complexity of the interconnected world demands that leaders explore new approaches to ensure the resilience of organizations. Strategic foresight is useful for navigating this environment, as it enables better decision-making under uncertainty through systemic thinking about the future. Foresighting relies on a diverse set of tools and techniques to challenge assumptions about the future of a complicated world. Strategic foresight helps envision potential future states, identify key events and decision points, and integrate uncertainty into planning processes to help drive organizations towards preferred future states. Although thinking about the future is an important part of the process, foresight is largely about what organizations do today.

Foresighting is used around the world to strengthen organizations in the face of uncertain futures. Figure 1 highlights formal foresighting work that has been performed in the space ecosystem, the U.S. government, international governments, academia, and the private sector as well as examples of *ad hoc* future thinking that NASA has performed previously.

We selected foresighting as the preferred method for this study. In addition to enabling informed decision-making in an environment of uncertainty, foresighting can help leaders envision and experience the future and realize how today's decisions impact the future. The foresighting process is typically executed in a collaborative environment, bringing together internal and external stakeholders. Foresighting can generate innovative solutions and creative thinking while driving valuable transformation. Insight and action are the next steps to realizing transformation and meaningful change.

[11] Cunzeman, K. and Dickey, R. "Strategic Foresight for the Space Enterprise," *Center for Space Policy and Strategy*, The Aerospace Corporation, https://csps.aerospace.org/papers/strategic-foresight-space-enterprise

[12] Cunzeman, K. et al. "Strategic Foresight: Addressing uncertainty in Long-Term Strategic Planning." The Aerospace Corporation. https://aerospace.org/paper/strategic-foresight-addressing-uncertainty-long-term-strategic-planning. November 16, 2020.

Figure 1. State of play of foresighting and futures work for various worldwide institutions demonstrating the widespread and increasing adoption of the practice to address current world decision-making needs.[13,14,15,16]

[13] https://apps.dtic.mil/sti/citations/ADB310563
[14] https://csi.asu.edu/books/vvev/
[15] https://www.newamerica.org/international-security/reports/strategic-foresight-in-us-agencies/
[16] https://www.sciencedirect.com/science/article/pii/S0040162517302287

This study was designed to yield four outputs that address the four guiding questions of Section 1: (1) documentation of the trends and disruptors in the STEEPTS categories (that may affect NASA's future operating environment, (2) scenarios that capture corner cases of the possible future, (3) "North Stars" that envision what NASA's future roles can or should be in light of the scenarios and today's underlying trends, and (4) candidate strategic options that would provide organizational resilience in the future scenarios and other key questions and insights extracted from the analysis for NASA's consideration when its leadership begins the formal strategy-development process.

Figure 2 provides a high-level graphical depiction of the study's methodology, with greater detail on the scenario-development approach in Figure 3. The following discussion walks through this methodology step by step, documenting each step's inputs, analysis process, and outputs.

Step 1: Collect Inputs

For this study, we collected inputs from three sources: futures documentation, horizon scanning, and stakeholder inputs (through roundtables and interviews), as shown on the left of Figure 2 and the top left of Figure 3. For the futures documentation, natural language processing (NLP) was performed on a set of documents, some provided by NASA and others from global futures sources.[17] Details on the exact method used for this NLP analysis are in Section 4.3. Additionally, Aerospace's subject matter experts continuously perform horizon scanning[18] and, for this study, performed custom scanning and tagged more than 1000 signals to select ones relevant to NASA.

The roundtables and interviews were the largest undertaking for this study, involving approximately 200 NASA-internal staff and external participants. In Section 3, we provide detail on the roundtables and interviews, including who participated, the exercises we conducted, and the information we collected.

Outputs: raw roundtable and interview inputs, raw NLP data, raw signals from horizon scanning

Step 2: Identify Trends & Disruptors

This step, shown in the center of Figure 3, documents the emerging trends and disruptors that are likely to have a long-term or enduring impact on the future operating environment. The foresighting team synthesized inputs from all roundtables, interviews, horizon scanning, and document processing into a series of overall trends and disruptors organized into seven categories: societal, technological, economic, environmental, political, threat, and space (see Section 4). From the 1000+ signals captured in horizon scanning, the team identified 60 emerging disruptors that informed the future scenario development in areas that NASA may not be currently tracking (see Section 4.2 and Detailed Trends and Disruptors). The team reviewed all the signals (trends and disruptors) holistically, considered their potential impact to NASA and whether there was a clear direction to the trend or not, and eliminated signals with lower future impact. This process led to a set of major shaping trends that are likely to have a dominating impact on the future environment.

Inputs: raw roundtable and interview exercises, horizon scanning inputs, and NLP of NASA documentation and futures literature (Step 1 above)

[17] Such as the NIC global futures report (https://www.dni.gov/index.php/gt2040-home), World Economic Forum Futures Report, USSF 2060 (https://apps.dtic.mil/sti/pdfs/AD1095527.pdf), etc.

[18] Horizon scanning is a technique for detecting early signs of potentially important developments through a systematic examination of potential threats and opportunities across societal, technological, economic, environmental, political, technological, and space (STEEPTS) factors.

Outputs: lists of trends and disruptors across multiple categories (study Question #1), major shaping trends

Step 3: Identify North Stars

This step, at center bottom of Figure 2, identifies consensus views on what NASA's role and purpose should be in the coming decades and what principles should guide NASA's path forward as an organization (i.e., its "North Stars"). The foresighting team collected the perspective of roundtable and interview participants on the vision, mission, and role of NASA in 2040 and beyond with multiple exercises, including "North Stars," "Dreams and Fears," and "Defining the future of discovery" (see Table 1). When developing strategic options, it is essential to consider the question, "what is this strategy attempting to drive towards?" A mission and vision statement help answer this, and envisioning aspirational North Stars helps contextualize and actualize the vision and mission. Section 5 details the results of identifying NASA's North Stars.

Inputs: executive roundtable and interview exercises (Step 1 above)

Outputs: A set of candidate North Star statements and individual words that capture stakeholders' perspective of NASA's future vision and purpose (part of study Question #3)

Step 4: Threadable CONOPS

This step (top center of Figure 3) identifies the critical uncertainties that influence the future operating environment, documents their possible future states, and selects combinations of states to use in scenario development that conform to the archetypes of the Four Futures model. The critical uncertainties educed from the analysis of trends and disruptors (Step 2 above) are incorporated as inputs into a table, called a "Threadable CONOPS," and the range of possible future states for each is associated with it in the Threadable CONOPS. While many other factors are considered when developing the scenarios, these parameters are deemed to be the driving uncertainties for the future environment relevant to an organization. With these uncertainties and their possible states, the foresighting team selected four combinations of inputs and their states in the Threadable CONOPS, one each for the four scenario archetypes of the Four Futures model (growth, discipline, decline, and transform) plus the baseline. Section 6.2 reviews the Threadable CONOPS in detail.

Inputs: key uncertainties from trends and disruptors (Step 2 above)

Outputs: five Threadable CONOPS tables, one each for the baseline, growth, discipline, decline, and transform scenarios

Step 5: Four Future Scenarios

This step (center of Figure 2 and top right of Figure 3) composes a set of four scenarios that serve as corner cases of the future operating environment. The foresighting team used the Threadable CONOPS tables (Step 4 above) and their associated selection of future states to craft a narrative for a corner-case future scenario, one each for the growth, discipline, decline, and transform archetypes. The four scenarios provide corner cases against which possible investments, technologies, and decisions can be evaluated. This approach allows for determining how decisions could play out across different sets of assumptions (selection of different state for each input in the Threadable CONOPS). The Four Futures model challenges the analyst to rethink assumptions, consider multiple possibilities for the future, and make better decisions today.

The four scenarios each have a concise and evocative title and a three- or four-paragraph narrative that depicts a possible future consistent with the four archetypes. When reviewing these scenarios, the reader should resist the temptation to judge them on their likelihood. In fact, we expect that none of these scenarios in full will happen in the real world. Some parts of *all* of them are likely to occur in the coming decades, but we cannot know which parts. Consequently, the specific circumstances or plot in the narrative are not as important as the larger themes or challenges for NASA that emerge. These themes are captured as key focus questions, which provide NASA with a starting point for vision-setting and goal prioritization in the formal strategy-development process.

Inputs: Threadable CONOPS (Step 4 above)

Outputs: four diverse future scenarios, including the scenario narrative and key questions that capture the scenario's higher-level takeaways (study Question #2)

Step 6: Strategic Options

This step (top right of Figure 2) develops a set of candidate organizational strategies by combining a stress test of the corner-case scenarios with interview and roundtable feedback. The foresighting team evaluated challenges, opportunities, and interactions of the scenarios relative to seven criteria—mission, resourcing, organizational effectiveness, workforce, leadership, culture, and innovation—and cross-correlated with the data previously collected through NASA executive interviews and roundtables exercises to develop candidate strategic options.

The interviews and roundtables provide both the participants' visions of organizational strategies that NASA could pursue, and implied perception of which strategies may be palatable or may require substantial organizational transformation, which is important for the Cross-Scenario Assessment in Step 7 below. These strategic options span the spectrum of possibilities within each category of organizational interest (e.g., from "go-it-alone without partnerships" to "maximize partnerships across all efforts"). The strategic options developed in this analysis are not intended to be exhaustive. Instead, they provide a broad foundation for NASA executive leadership to build on in the formal strategy-formulation process.

Inputs: four scenarios (Step 5 above), internal Aerospace SME analysis, executive interview inputs (Step 1 above)

Outputs: candidate strategic options (completion of study Question #3, capturing candidate future paths and roles for NASA in light of the uncertain future environment)

Step 7: Cross-Scenario Assessment

This step (bottom right of Figure 2) identifies which candidate strategic options—in Pareto-like fashion—offer organizational resilience versus their necessary degree of organizational transformation. Each strategic option is evaluated against two metrics: (1) the number of future scenarios that the strategy offers organizational resilience against (the more, the better), which is evaluated in an internal review by the Aerospace foresighting team for their effectiveness at achieving NASA's candidate North Stars, and (2) the degree of organizational transformation necessary to realize the strategy, which is supported by inputs from the NASA executive interviews and roundtables. The most preferred strategic options are those where the largest number of possible future scenarios are covered and where the least amount of organizational transformation is needed.

Additionally, a set of "universal elements" (see Section 8) are detailed with an assessment of current NASA performance (based on discussion during roundtables and executive interviews) and the baseline

trend. The universal elements are underlying activities for an organization to achieve its North Stars and strategic goals. These elements are necessary to accomplishing any strategic vision and are areas where action can be taken now, regardless of strategy.

Inputs: strategic options (Step 6 above), four scenarios (Step 5 above), North Stars (Step 4 above)

Outputs: binned strategic options according to their resilience and necessary degree of transformation, including preferred strategic options that are high-resilience and require minimal organizational transformation, and a list of "universal enablers" that underlie a successful strategic implementation (study Question #4).

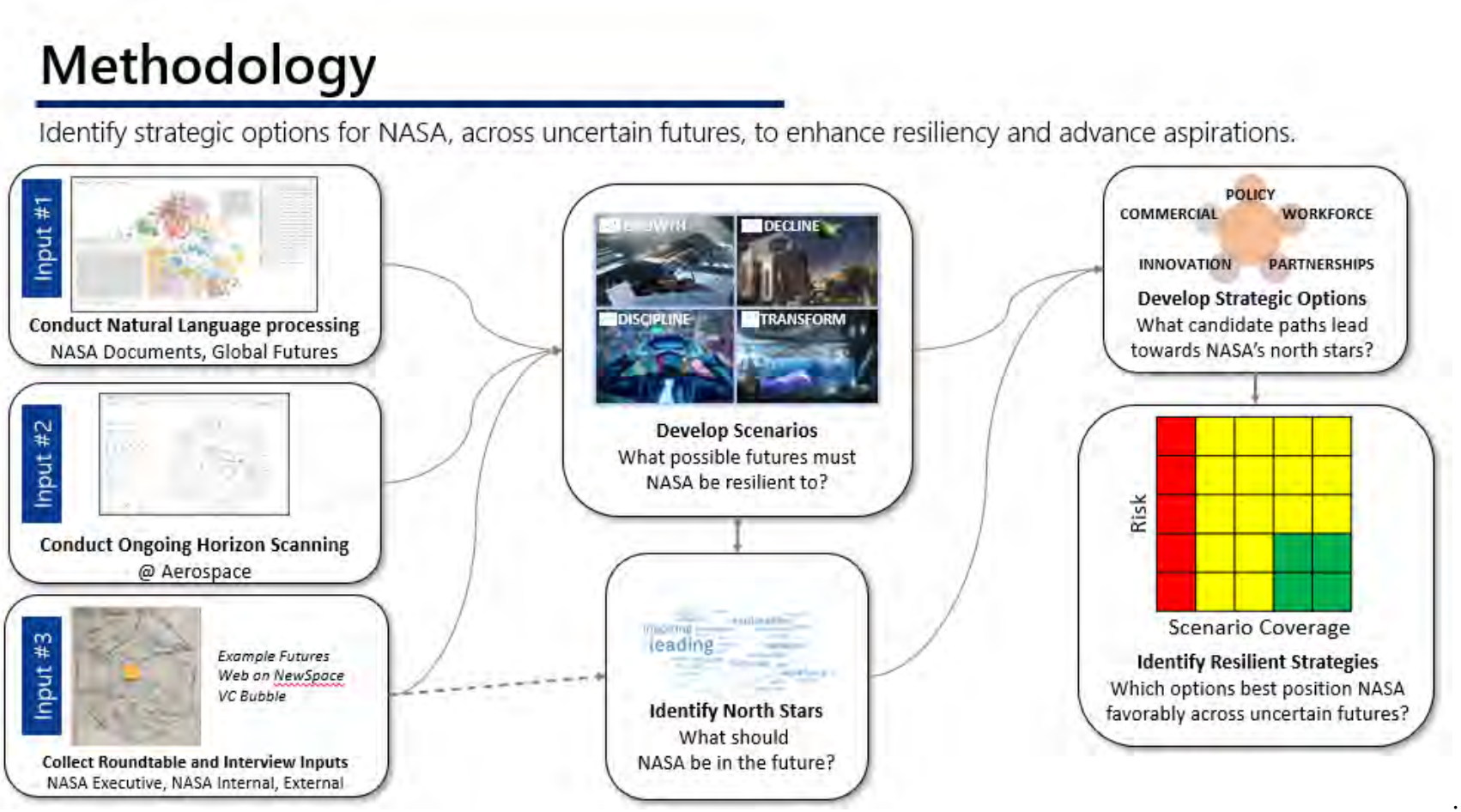

Figure 2. High-level methodological approach taken for this study.

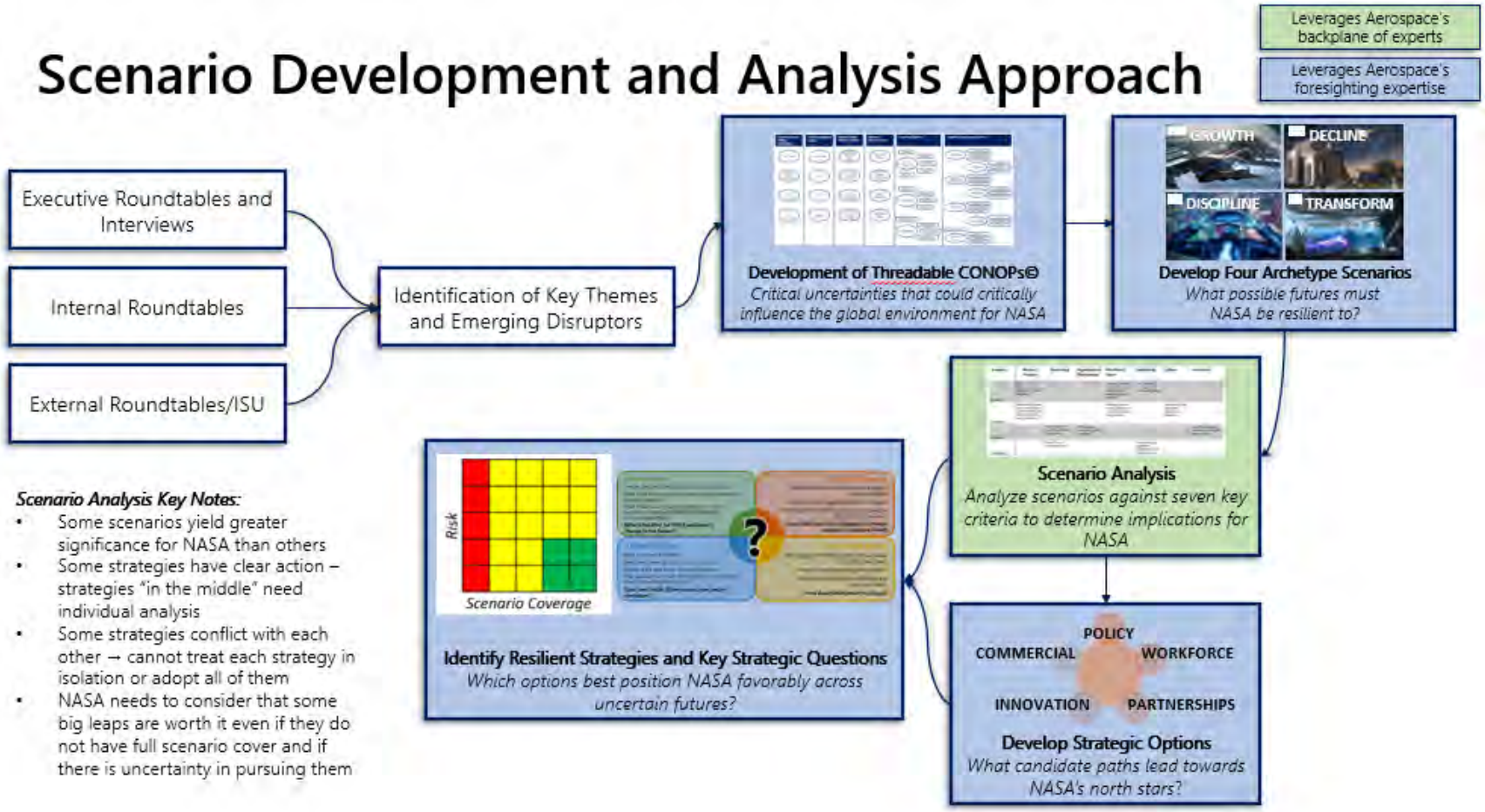

Figure 3. Detail of the scenario development and analysis process.

3. Executive Interviews and Roundtables

Here, we provide details about the executive interviews and the roundtables. For the executive interviews, we had private discussions with NASA leadership in a virtual setting. The interviewees provided candid thoughts on our questions, detailed in Section 3.1. While the topics were far reaching, ranging from technology on the cusp of usability to workforce concerns, there were common themes with both aspirations and fears for the future. One common response across most interviewees was the concern that NASA is at a juncture with respect to the business model moving forward. The interviewees recognized the uncomfortable juxtaposition between embracing growth in the commercial sector and the disappointment from current employees who do not want to see a future where NASA does not continue to build space systems in house.

In Section 3.2, we detail each of the seven roundtables. We facilitated the roundtables with a variety of participants both internal and external to NASA. The NASA-internal participants also varied with their years of experience, role, and NASA Center (for the internal-NASA participants). The external participants varied in their years of professional experience, profession, and connection to NASA. We held some roundtables virtually and some in person, driving the selection of the foresighting exercises towards those most appropriate for the respective venue and time allocated. From these roundtables with approximately 200 participants, we gleaned many diverse signals, trends, and disruptors. One common theme throughout the roundtables was a general admiration for NASA and its mission, and an excitement for the future. While the findings are too many to list in this introduction, the roundtables were a prolific source of information feeding the strategic foresighting process for this study.

3.1 Executive Interviews

Eight executive interviews were conducted to help identify North Stars, mission goals, organizational alignment, global key trends and disruptors, and the greater aerospace industry context. The executive interview questions were designed to encourage discussion and draw out insights, with relatively little preparation required by interviewees. To facilitate an open discussion, the executive interviews were not recorded, and all comments remain unattributed.

During the 45 to 60-minute executive interviews, we guided the discussion with the interviewees along the discussion points listed below (the full questions are detailed in Detailed Observations from Executive Interviews), which were provided prior to the interview:

1. In your opinion, what are the top three trends impacting the future?

2. What excites you most about the future of the broader aerospace enterprise? What emerging or adjacent applications are most exciting to you?

3. What scares you the most about the future?

4. What assumptions do you believe are being made about the future? What are the implications if these assumptions are wrong?

5. What's the single most important thing you recommend NASA act on in the near-term to best posture itself for a bright future?

6. It's 2050, describe an aspirational future state for NASA.

The interview format allowed for deviation from the discussion points based on the desires of the interviewees. The discussion began with a broad focus (note that the first four questions do not mention NASA specifically) to collect inputs from outside NASA and then narrowed on NASA-related issues more specifically. The questions on fears and assumptions about the future provided input to the potential future uncertainties/provocative future states. Responses to the interview question 5 provided a starting point for potential strategic options to analyze against the scenarios. Responses to question 6 provided inputs into NASA's preferred future state, as well as organizational alignments for this preferred future state. The interview responses were used as inputs to the development of the Threadable CONOPS, elements of the scenarios, and strategic options/enabling elements. Detailed summaries of the executive interview comments are provided in Detailed Observations from Executive Interviews.

During the interviews, the executives shared their aspirations for NASA's future including their recommendations, as well as their frustrations and concerns. For the top trends impacting the future, common topics the executives cited included commercial investment in space and how to partner/ collaborate going forward, "challenges around climate change and sustainability," internationalization of space and "peace through international partnerships like the ISS," infrastructure maintenance with "50 to 60-year old facilities," legislation and policy needs including "roads, stop signs, and driver's license" for space, political polarization with need to "stop the churn from party-to-party politics," "NASA like a JOBS program," and "train NASA people to be businesspeople."

In response to the "What excites you about the broader aerospace enterprise?" question, the interviewees indicated they were excited about the dynamic future of aerospace, commenting that this is the "most exciting time there has ever been." "Apollo was exciting, but just itself. Today, there is an explosion of different ideas and players." The interviewees were also excited by the potential of several technologies including "nuclear systems in space for continuous power and propulsion," on-orbit servicing and manufacturing (OSAM), electric propulsion, "exploitation of AI and ML at scale," NLP for larger data sets, new disruptive launch systems, "hypersonics … for small payload launches," and CubeSats. "NASA's ability to use data" is just scratching the surface of its potential, e.g., the "application of climate data to third world farmers and mining data in the right hands." The interviewees largely found the integration of the space economy and the regular economy had exciting potential, and the "pipeline of talent is exciting, almost limitless, with each class smarter than the last."

The executives also shared the concerns that keep them awake at night. These fears included shrinking budgets, "orbital debris…pollution in space is real hazard and there isn't an answer," the explosion of new ideas and players in the commercial space, "Wild West stuff going on in space" with regard to the large LEO constellations– where is the "oversight, who is liable if something goes wrong," the "scarcity of energy and resources," "not moving at scale or speed with industry," "degraded infrastructure to support our missions and partners," and how to train staff under the age of 30, while recognizing that these experts that might leave.

Areas where the executives expressed assumptions that NASA is making about the future included "continuing the status quo [despite being] in an environment where people are breaking the molds" like "SpaceX re-landing boosters and doing things we said couldn't be done…for 10% of the budget," the ability to maintain skills and talent, and leading the "long-term vision like the Moon and Mars."

When asked to provide recommendations for NASA to act upon in the near future, transformational change was a common theme including "how we travel in space," OSAM, removing "barriers to innovation like bureaucracy at all levels," partnering with commercial and other nations, affordable access to space, "failure should be an option if you aren't going to hurt anyone," looking "outside your walls and bring[ing] those folks in," creating environment for "ideas stream like the startups," getting "our institution in order," and being the "technical beacon."

The executives described NASA in 2050 with aspirations like “improves the lives of all Americans” and strives “for the benefit of all” though extensive tech transfer, affordable access to space, and inspirational leadership. The interviewees envisioned “sustained settlements on the Moon,” (possibly a national lab on the Moon), “a colony in Earth orbit,” and a “blueprint for Mars with talk of the next destination, possibly Europa.” The interviewees viewed NASA as providing “real time info for climate change,” and NASA being more dynamic “achievements in partnership with other nations and industry/commercial.”

3.2 Roundtables

Seven roundtables were designed and executed to elicit similar information as the executive interview including preferred futures (mission and vision of NASA), future opportunities, potential critical uncertainties, provocative future states, and innovative ideas. A diverse participant list and collaborative ideation approach allowed us to gain the broad insights. The roundtables ranged from several hours to a full day, depending on the format (in-person was more congenial to longer sessions as participants were all in the same time zone, breaks could be built in more logically, no screentime wear out, and data collection did not require instructions on learning new tools – pencil and paper versus a new online tool for collaboration). The goals of each of the roundtables were slightly different, depending on the participants, the format, and the amount of time available for these highly interactive sessions. The differing format and length partially lead to the selection of exercises for each roundtable. As executives drive organizational decisions, substantial time was spent on mission/vision exercises (e.g., North Stars, Dreams and Fears) in those roundtables as compared with the others. Finally, the external roundtable focused on external factors impacting NASA and the broader aerospace community, as these participants did not have the same level of personal insights into NASA as an institution.

With Figure 4, we provide a mapping of exercises to each roundtable. The specific goal of each foresighting exercise is listed in Table 1. For example, in one roundtable event, the futures web exercises explored the possibility of a “NewSpace” collapse, the potential for global conflict, and the potential for “solving” climate change. These topics were chosen based on the futures baseline and the identification of these areas as potentially impacting NASA’s future operating environment. By exploring these topics in the futures web activity, potential key elements were identified for use in the scenarios. To ensure a wide coverage of topics, we used both the futures baseline and outputs from the previous roundtables to inform the subsequent roundtable exercise selections. In Table 2, we show the number of participants by roundtable and the goal of each roundtable. Five of the roundtables contained NASA-internal participants. Of the five NASA-internal roundtables, four were virtual and one was in-person. The two non-NASA roundtables were held with one in a virtual format and one in-person. Six of these were hosted and facilitated by the Aerospace foresighting team. The intern roundtable was facilitated by NASA with Aerospace observing and gathering inputs.

EXERCISE	EXECUTIVE INTERVIEWS	NASA EXECUTIVE ROUNDTABLE	NASA INTERNAL ROUNDTABLE	EXTERNAL ROUNDTABLE (VIRTUAL)	EXTERNAL ROUNDTABLE	NASA INTERNAL EARLY CAREER AND ERG
Directed Questions	X	X			X	X
North Stars	X	X				
STEEPTS Key Trends & Disruptors		X	X	X	X	X
Mash-ups			X	X	X	X
Futures Web		X	X	X	X	
Imagine If?			X			
Dreams and Fears		X				
Defining the future of discovery and exploration					X	
Sketch the Future					X	
Discussion on implications	X	X	X	X	X	

Note: This figure does not include the NASA-designed intern roundtable workshop.

Figure 4. High-level summary of each roundtable indicating which exercises were used.

Table 1. Goal of Each Roundtable Exercise

EXERCISE	GOAL
North Stars	Determine potential North star statements for organization and identify if there is organizational alignment on North Star,
STEEPTS Key Trends & Disruptors	Identify new trends and disruptors that are relevant for organization across the entire operating environment.
Mash-ups	Illuminate potential unique/provocative future states to inform scenario development and elicit thought provoking conversations internally to an organization.
Futures Web	Identify potential future states, identify consequences of knowns today, and elicit thought provoking conversations internally to an organization.
Imagine If?	Imagine and articulate future success and desired end states to orient towards a more proactive shaping of a preferred future.
Dreams and Fears	Have stakeholders explicitly state what they fear most and what they want and aspire to most to elicit potential roadblocks and aspirational states.
Defining the future of discovery and exploration	Identify potential new definitions of discovery and exploration/unique methods for pursuing exploration.
Sketch the Future	Articulate and envision potential futures to a more tangible degree. Engage in creative visioning through drawing and hands on creation of future snapshots.
Note: This table does not include exercises used in the NASA-designed intern roundtable workshop.	

Table 2. Roundtable Formats, Number of Participants, and Goal of Roundtable

Audience (Number of Roundtables)	Number of Participants	Roundtable Goal
NASA Executive Interviews	~10	Identification of North Stars, mission, and fears for the future of NASA and organizational alignment
NASA Executive Roundtables (2)	~30	Identification of North Stars, mission, emerging trends/disruptors, and internal NASA alignment
NASA Internal Roundtables (3, including ERG and interns)	~100	Identification of global key trends, emerging trends/disruptors, and internal NASA alignment
Non-NASA Roundtables (2)	~50	Identification of a broad set of global key trends and emerging disruptors, overall context of the aerospace industry

While roundtable participants are subject to both explicit and implicit biases, we selected a diverse range of participants to ensure objectivity. By incorporating a large range of inputs (internally from executives to interns and externally from industry, academia, and international representatives), the impact of bias, although it not eliminated, is minimized in the findings.

To promote an open discussion, the roundtables were held under Chatham House Rule[19], where participants may not reveal either the name or affiliation of anyone participating but may use the information received.

Data collected from the NASA-internal roundtables can be found in Detailed Observations from Internal Roundtables. For the virtual roundtables, we used Miro[20], an online collaborative whiteboard platform that enables distributed teams to work effectively together, from brainstorming with digital sticky notes to planning and managing agile workflows. The data includes participant inputs from the online Miro boards and summarized notes from the in-person roundtables, as well as graphic recordings of the interactive sessions. The roundtable participation is summarized in Table 3.

Table 3. Futures Roundtable Summary

Futures Roundtable Events	Date	Participants (approx.)
NASA-Internal Roundtables		
In-Person Executive	10 May 2022	15
Virtual Executive	13 May 2022	25
Virtual Internal	17 May 2022	25
Virtual Early Career & ERGs	14 July 2022	35
Intern Roundtable (run by NASA)	20 July 2022	30
External Roundtables		
Virtual External	21 June 2022	40
In-Person External	23 June 2022	26

[19] "Chatham House Rule" Chatham House, Accessed 14 November 2022, https://www.chathamhouse.org/about-us/chatham-house-rule

[20] "What is Miro?" Miro, Accessed 14 November 2022, https://help.miro.com/hc/en-us/articles/360017730533-What-Is-Miro

3.2.1 In-Person Executive Roundtable

For the in-person NASA-internal executive roundtable, Aerospace facilitated a session with approximately 15 participants over four hours at NASA Headquarters in Washington D.C. with the following high-level agenda: Introductions and playing of an inspirational video, NASA's Why, Dreams and Fears activity, North star identification, Key trends and disruptors, Futures web, and Reflections for NASA. Through these selected activities, the executives focused on the future vision, mission, and potential challenges for the NASA enterprise.

The NASA executives were asked to consider NASA's "Why" statement and if it changes in the future. Some thought the mission statement would endure unchanged. Others thought the "domain will change, but the mission to explore will not change over time." A domain change could include "our approach to seeding," e.g., funding commercial launch vehicles versus NASA launch vehicles. Another executive commented, NASA will be "catalyzing discovery for the good of humanity, even if NASA doesn't do it, NASA will be the catalyst." Some executives thought the NASA mission statement would change in the future and commented, "Initial [mission] statement was about exploration, but it changes to have more intentional benefits for humanity." Others thought the statement should include an understanding of who we [NASA] are and how to make space affordable, safe, and profitable.

During the discussion of future fears, the participants recognized that some fears they believed were out of NASA's control (e.g., China, dismantled democracy, politicization of science, commercial space disasters, and commercial space monopolies) as well as listing fears they believed to be in NASA's control, listed below.

- NASA no longer maintains its brand of leading inspirational activities
- NASA becomes irrelevant
- NASA becomes an ill-informed contracting organization
- Commercial industry becomes more advanced than NASA; NASA is just a distraction in the space enterprise
- NASA gives too much leadership to private industry. NASA becomes a funding and goals-only organization with no technical expertise or building things in house. What will happen if private industry fails, and NASA no longer exists in its current form? What if this new organizational structure doesn't work?

The next prompt led to a discussion of concerns. One participant expressed their concern that they do not feel empowered to address fears even though NASA may be able to do something to prevent them. An executive questioned that since "industry is, arguably, already faster, and more capable than NASA, how can NASA maintain a unique role in the space enterprise?" "NASA has lost a lot of its agility." While another executive thought that "NASA has become very risk adverse. At some point, NASA lost its renegade approach to innovation." For example: "When a SpaceX rocket had a fire during testing on the launchpad, the SpaceX team they took it apart and quickly started testing again. If NASA had a fire on the launchpad, it would likely take a year to figure out what happened and resume testing again."

Although NASA cannot control all the root-causes of these concerns, the group expressed that NASA may be able to influence others to address these fears.

Next, participants wrote their dreams and aspirations for NASA's future and reflected on NASA's next steps. Topics discussed included the frustration of NASA's "current slow speed, red tape, and bureaucracy." "Most NASA employees still aspire to return to the culture and speed of the Apollo era where NASA was an inspirational leader." Thoughts on solving the bureaucracy problem included cycling the workforce in and out to NASA which is difficult since NASA is the "best place to work in the federal government." Another commented that a "permeable border," where employees leave and return to NASA throughout their careers, is needed to encourage agility, although salaries and the ability to participate in public-private partnerships limits this. The participant also commented that an organizational shift, where NASA is no longer beholden to Title 5 Pay and can work with colleges and the private sector, could create this more permeable border. With respect to AI and automation, the conversation was framed with the following comment, "Automation aids humans but doesn't replace them."

In the discussion of "what's next for NASA," the topics of exploration, climate change, and policy were discussed. The broader question of "who NASA is exploring with, not where or what," was brought up including the following: governments, academia, industry, shifting innovation ecosystems, and the changing NASA workforce composition. Exploring climate change and NASA's role as "the premier institution for gathering planetary and climate data" was also discussed. A participant asked, "Can NASA use its name brand to tackle these big problems by collaborating across government and industries?" Finally, NASA's role in policy advising was mentioned. "NASA is being asked to advise on policy, but NASA doesn't do policy work." A concern was expressed that if NASA starts doing prescriptive policy, it will no longer be seen as the trusted advisor/keeper of data.

Participants brainstormed potential North Star principles for NASA (detailed in Section 5) and then looked for core/universal characteristics and contradictions. Guiding principles identified by the executives included the following: agile, trusted, reliable, strategic, discovery driven, shared future, advisor, and others. Next, the participants developed key trends and disruptors for five of the seven STEEPS areas as documented in Detailed Observations from Internal Roundtables. The last activity was the creation of futures webs for three distinct topics: a venture capital/NewSpace collapse, a future where climate change is "solved," and a future where a major world conflict erupts. Potential first order, secondary, and tertiary impacts of each of these were explored across the STEEPTS, and takeaways for NASA from each group of participants were out briefed with details in Detailed Observations from Internal Roundtables. Broad takeaways from this roundtable for NASA include the potential need to 1) establish a proactive communication strategy between NASA and NewSpace with awareness of health of commercial space industry and resilient workforce, 2) establish a strategy for a slow-down or collapse of commercial space industry and its impact to innovation, 3) examine impact to NASA if commercial space leads in solving climate change, and 4) anticipate the impact of global conflicts on NASA for budget scarcity, supply chain and international partnership disruptions, and a shift to war-related technology development.

The Aerospace foresighting team hosted a virtual NASA-executive roundtable with approximately 30 participants over the course of four hours per the following agenda: Introductions, NASA's Why today and in 20 years, Dreams and Fears activity, North Star identification, Key Trends and Disruptors, Futures Web, and Reflections for NASA. Through the chosen activities, the executives focused on the future vision, mission, and potential challenges for the NASA enterprise.

The detailed roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in Detailed Observations from Internal Roundtables.

The first exercise addressed NASA's mission statement, "NASA explores the unknown in air and space, innovates for the benefit of humanity, and inspires the world through discovery."[21] Factors contributing to the participants' viewpoints included climate stability, the burgeoning cislunar economy, the peaceful use of space, the "intense push for NASA to be more like NOAA" – a monitoring agency rather than a mission-focused agency, and NASA as "a catalyst for thought leadership with youth, for inspiration, and for teaching commercial to carry the ball." One executive commented, "The word is leading. This is our chance to define where NASA will lead into the future, while other in industry may continue some of the other work."

The executive roundtable focused next on fears and aspirations for NASA and potential steps to address them. Participants were asked to write down their fears regarding the future of their organization, job expectations, competition, worst case scenario for 2040, and past failures contributing to their fears. Top level fears and concerns from this exercise included: "fear of governmental budget cuts for infrastructure at NASA," "space becomes militarized," "NASA turns into a regulatory agency," "vision gets smaller," "U.S. loses position of leadership in space exploration," "meeting expectations we have for ourselves and the public has for us with no budget," "NASA loses public trust," commercialization preventing R&D/exploration/creative edge and making NASA a "marketplace challenger versus a leader of national strategy," "competing with industry to attract talent," and "training and mentoring … next generation of leaders."

One executive commented, "Biggest fear in my role: NASA's disintegrating infrastructure is underfunded, undermaintained, and there is no real path to resolving (politics). No matter how cool the mission, if the infrastructure can't support the mission, the agency fails, and all the wonderful things it can do go down with that failure. I worry that within the missions, there isn't cohesion or sharp enough focus on few enough things to do well - and that only undermines us when we advocate for budget. Worst case scenario in 40 years is a NASA that doesn't exist. Past informing this, it's incredibly grim from a funding standpoint. We're drowning in budget gaps, immense pressure to cut personnel, and not enough people to do anything well. It's incredibly frustrating. It's like watching something rot from the inside out.... I love working here, I want so badly for the agency to transition to an inspiring, groundbreaking future, but right now I am very worried."

Another executive commented, "First thing people think when they see a new organizational strategy: 'Do I still have my job?' NASA needs to think about its people. Whatever the new vision is, everyone needs to see themselves in it. People have spent their entire careers working at the organization, so what does it mean for them if you just coming along and say, 'oops, we're going in a different direction now'?"

Takeaways from the fears exercise included a focus on "execution" since "fears are outside my control," "maintain/upgrade infrastructure to ensure future capability," overcoming NASA's "internal processes and culture that inhibit innovation at the speed of private sector", "leading international consortium" (not exploiting international partnerships), and "leveraging private sector innovation and partnerships," and being the "catalyst for innovation, discovery, and exploration."

The group also identified guiding North Stars for the what the future of NASA should be. The executives selected words including inspirational, innovation, credible, inclusive, bold, lead, collaborative, pioneering, agile, expert, disrupt, transformative, "less talk, more do," forward-thinking, industry-supporting, evolve, and others as documented in Detailed Observations from Internal Roundtables as

[21] "Our Missions and Values," NASA, Accessed 5 November 2022, https://www.nasa.gov/careers/our-mission-and-values.

potential North Star words to aspire towards. Next, key trends and disruptors were brainstormed as documented in Detailed Observations from Internal Roundtables.

The Futures Web activity focused participants on four potential future events/trends (NewSpace collapse, commercial commoditizing climate mitigation technologies, the metaverse, and life outside of Earth) and the impact they might have on NASA. Broad takeaways for NASA from this activity included the potential fragility to embracing NewSpace and commercial capabilities wholesale, benefits of exploring dual-use space technologies (for climate, etc.) and partnerships, opportunities for considering workforce of the future and potential for NASA to be left behind if not embraced, and significant opportunities for international cooperation around future exploration of universe.

Overall, the executives had positive takeaways for the future of NASA centering around themes of NASA's mission for humankind, a diverse workforce, public and private partnerships, international collaboration, climate change mitigation, NASA technology development for non-aerospace applications, and the "great, passionate people still working at NASA," but were cautioned by concerns with budget constraints, infrastructure maintenance, and political churning.

3.2.2 Virtual NASA-Internal Roundtable

The virtual NASA-internal roundtable hosted approximately 25 non-executive NASA employee participants from across the agency for four hours on Zoom with the following high-level agenda: introductions, key trends and disruptors, mash-ups, futures web, "Imagine If", and an implications discussion for NASA. The participants represented a broad range of experience levels at NASA, spanning from 18 months to 35 years, with majority of participants falling within the 10 to 15-year of service range. Throughout the roundtable exercises, the participants echoed recurring themes of the need for diversity, transformation, agility, leadership, and collaboration at NASA, including implementation ideas. One participant's biggest takeaway from the roundtable event was "[NASA has] a lack of focus on NASA's mission and vision statement with more focus on industry."

The detailed roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in Detailed Observations from Internal Roundtables. Following the introductions, the group participated in a brainstorming activity to document key trends and disruptors in the seven STEEPTS areas as shown in Detailed Observations from Internal Roundtables.

During the Mash-up activity (specific prompts detailed in Detailed Observations from Internal Roundtables), key takeaways for NASA included the following: ensure NASA remains relevant and balanced with the shift to commercial; if NASA becomes viewed as a luxury, not a necessity, tap into entrepreneurial nature of U.S. with science that has a high ROI, like the commercial efforts now on ISS; use AI to process all the data NASA is collecting in a meaningful way, focus on the unsolved problems; seize opportunities to learn from diversity of thought; and allocate time to training NASA's next generation.

Next, the group split up into three subgroups to explore possibilities of the future using the Future's Web activity. The smaller groups examined the following three scenarios and their impacts on NASA: scaling inclusivity and equity in exploration, commercial overpowering government, and a breakthrough in interstellar spaceflight. Key takeaways for NASA included exploring deeper commitments into pursuing opportunities to seed DEI in NASA's business and STEM education, examining threats to earth and space environment from unregulated commercial activity, rethinking unique leadership needs for NASA with NewSpace developments, and preparing NASA for dramatic changes due to technology breakthroughs or global developments and power shifts.

During the “Imagine If” activity, participants described the best possible future state of NASA. The following themes emerged: “advancing the NASA mission and creating a sustainable presence in space,”; focusing “on exploration and technology and [letting] go of shepherding in commercial companies to refocus on our core competencies,”; “making NASA better but maximizing the potential impact of the individuals involved with the missions,”; “pushing the boundaries of our planetary exploration capabilities,”; leading “the world in scientific exploration,”; integrating innovation “across centers and there is true diversity in decision making,”; rejecting “sunk costs as a basis for decision making,” and partnering with “anyone that shares our goals and aspirations.” Participants were asked, “What are some key differences between today’s state of NASA and the future state that will require big change?” Respondents cited the need to “diversify and become more resilient,” “to become more nimble, reduce red tape, and figure out how to collaborate across Centers,” to “transform to a yes culture, take ‘no’ out of our vocabulary,” to change from an “old boys network,” to have “transformational/inspirational leadership,” to train skilled managers rather than “fail up into management,” and add more civil servants since “NASA is stretched thin due to many external forcing functions.”

3.2.3 Virtual Early Career and Employee Resource Group (ERG) Roundtable

The Aerospace foresighting team hosted a virtual NASA early career and Employee Resource Group (ERG) roundtable with approximately 35 participants from across the agency in a 2-hour session on Zoom. The roundtable focused on aspirational views for the future per the following agenda: introductions, directed questions, key trends and disruptors (STEEPTS), mash-ups, and key takeaways for NASA.

The roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in Detailed Observations from Internal Roundtables. The first activity asked the participants to describe the most exciting thing happening today and predicted to happen in 20 years. The participants noted expanding a human presence from the moon to further out in the solar system, moving toward action on DEI and accessibility at NASA, a broader application of satellite data for farmers and climate solutions, “hyper efficient air travel,” and resource mining and advance manufacturing in space. During the exercise to identify key trends and disruptors across STEEPTS, the early career and ERG roundtable participants’ responses had a noticeable focus on quality of life and workforce concerns including “normalization of overworking and not taking vacations,” loyalty to companies with “younger generation’s willingness to leave unsatisfactory jobs,” “NASA not encouraging geographically diverse applicants,” “economic income inequality is now at 1900 levels,” “housing prices,” “exponentially expensive world relative to stagnant government pay,” “college/university debt becoming untenable,” “alignment of career with organization that share values,” and “universal paid parental leave.” This list can be found in Detailed Observations from Internal Roundtables.

The group was then divided into three breakout rooms for two rounds of mash-up exercises. Key takeaways for NASA included: “having NASA’s own house in order impacts international relations,” as “autonomy gets linked into more and more critical industries, the question of liability could have life-or-death consequences for both individuals and nation-states,” “how might NASA’s futures ethics protocol evolve for enhancing biospheres for human sustainability,” and “who’s controlling the resources will drive behavior on Earth and in space.”

Participants expressed appreciation that “Agency leadership is thinking about the big picture” and their desire to see the “outcome of these roundtables and share with the ERGs across the agency.” Notable takeaway included that was that there was a perceived lower level of loyalty from younger workforce to their employer when they “can’t afford cars or homes,” a hope for “systemic development of minority employees,” a desire for sharing of NASA’s “cool work to help the planet” with those who need the

information, and that “NASA should be constantly assessing these potential disruptors” for impact to NASA.

3.2.4 Virtual NASA Intern Roundtable (Led by NASA)

Following the format of the Aerospace-led roundtables, an intern in NASA OTPS organized and led a two-hour virtual roundtable with over 30 NASA interns in attendance and Aerospace representatives observing to gather inputs for this study. The stated goal was to “advise NASA leadership on mission priorities and studies/strategy for NASA’s future.” The data collected during the intern roundtable and summarized in Appendix C is provided courtesy of NASA and included in this report since it was used to inform the study results.

The roundtable workshop was kicked off with two polls asking, “What excites you about the future (40+ years)?” and “What scares you about the future (40+ years)?” “Exploration” / “technology” and “climate” / “instability” were the most popular responses, respectively, to the questions. When asked about what the future will look like, the interns were somewhat pessimistic in the virtual chat about the future. The interns were concerned about “knowledge transfer” at NASA and “upward mobility for people in thirties and younger.” Participants also commented on the impact of politics on the militarization of space, equity of access to space, and on the risk to Mars mission – “political climate can delay or derail us from getting to Mars.”

When asked about how NASA can act in the near-term to best posture itself for a bright future, the interns commented on education initiatives, diversity in the workplace, loss of talent to higher pay alternatives, public outreach and support, communication strategies that show importance of NASA’s mission, collaboration, international partnerships that transcend politics, and embracing “systems thinking.” When comparing NASA to industry, participants noted that NASA is more risk adverse and “not allowed to fail” whereas private industry is allowed to fail. Also, NASA can lead by example by having “realistic working conditions in the space industry” as commercial industries are “somewhat exploiting their workers.” An important impact of NASA as the “most positive government organization” is to “get young people to think about science.”

The interns were asked to write their ideal futures. They commented on early career rotational programs, cross-center transfer opportunities, and the need to rethink the future workplace. They were positive about the work at LaRC on workspace analysis and redesign, making it more of a “university feel” with collaborative spaces. Several in the group complained about the MSFC old facilities with asbestos and “bland and dated” interiors. A desire for diverse hiring, mental health and wellbeing of employees, and low cost and comprehensive healthcare was also noted.

3.2.5 Virtual External Roundtable

The virtual external roundtable hosted approximately 40 participants over the course of four hours on Zoom per the following agenda: key trends and disruptors, diving into exploration and discovery, mash-ups, futures web, and reflections for NASA. The participants included representatives from academia, military technical advisors, AI/ML and cloud technologies, writing genres, entertainment, space venture capitalists, commercial space companies, and others. Although many comments about the future were pessimistic, some participants commented that discussing the future brought about a more optimistic outlook.

The roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, and graphic recordings are included in Detailed Observations from External RoundtablesMuch of

the external roundtables were captured in the graphic recordings available in the Appendix, and thus let detail is provided here.

The first activity was to document trends and disruptors across STEEPTS as shown in Detailed Observations from External Roundtables. As a group, the external participants provided a more diverse set of trends and disruptors than the internal roundtables. The “Threat” and “Space” categories were covered within the other categories and thus these categories were not focused on during the roundtable. During the discussions, the following comments were noted:

- “NASA has an outsized role compared to other government agencies because it is the most positive brand in the U.S. government (and possibly the world). This gives NASA an outsized responsibility to think globally.”

- "’Indigenizing science’- “…indigenous groups and tribal bands [the] around [the] world getting together with allies and scientists to bring in thousands of years of inter-generational understanding to share inputs on major topics of interest (e.g., climate). Need to also incorporate into [this] space exploration.”

- “Treat space as object of appreciation and protection, not an economic narrative for exploitation of resources. Don't want space to become landfill. Troubling that most conversation about settling Mars includes terraforming and destroying its current natural beauty and turning it into a suburb of Earth. Today we have the sense of space being endless, but we're possible / probably falling prey to the same fallacy.”

- “While many comments come from an apathetic or dystopian/pessimistic standpoint, venture capitalists see lots of pitches of emerging technologies that are really inspiring. If even a small fraction of these technologies come to fruition, then the future is going to be very bright. Very optimistic. What drives the pessimism? Culture? Politics? We live in the most peaceful and equitable times that humanity has ever seen, compared to 100, 500, 1000 years in the past. Things are not great, but a lot better.”

- “Fascinating to watch the rise of non-classical actors… covering all parts of the space enterprise… Working with global space players (Rwanda, Nigeria, Angola, etc.). Nobody knew Angola was doing anything, then suddenly, they have 200 engineers.”

- “Fundamental thing that makes us human is our curiosity; hope that we can do exploration without exploitation.”

- “All the problems of the world find their way to remote places like Hawaii, so why wouldn't they also find their way to space, to a space station, to a space colony on Mars?”

- “Asteroids are for extraction; the Moon is for tourism. The Moon's advantage is time (you can get there fast, but it takes a lot of energy), near-Earth asteroids are better bets because you can get a lot more resources out of them, but it takes a long time, and you can't put people there.”

- “Government does R&D when there isn't an obvious commercial argument for investment.”

- “Should NASA be looking at second-generation propulsion instead of chemical rockets? There's plenty of commercial R&D for chemical rockets.”

Following the exercises, the external participants shared their biggest takeaways which included the following: “process is not a substitute for vision and action,” “thinking through possible future, optimism was able to emerge,” “don’t let the ‘how’ block the ‘why’,” “Africa has a lot to contribute to this conversation,” STEEPTS landscape will change, “What sustainable foundations are we building,” need to communicate how “space is deeply intertwined with plant Earth,” and what is NASA’s global responsibility since “NASA is the most positive brand in the U.S. government.”

3.2.6 In-Person External Roundtable

The Aerospace foresighting team hosted the in-person external roundtable with over 20 participants over the course of a full day in Crystal City, Virginia. A detailed listed of attendees and their biographies is available in Table 40. The participants included a wide range of space and non-space backgrounds including those from academia, public policy, science fiction, venture capital, investment banking, design innovation, space law, futurists, entertainment, cislunar, DEI education in tech, and NGOs. The roundtable had the following high-level agenda: exploring the changing broader global environment (STEEPTS), signals mash-ups, discovering the possibilities of the future of discovery and exploration, futures webs, sketch the future of discovery and exploration, and overall discussion of implications. The details are contained in Detailed Observations from External Roundtables. The external roundtables were captured through graphic recordings available in Detailed Observations from External Roundtables.

Participants brought examples of innovating exploration which included the following: robots using AI in mining, in-space manufacturing (needs customers for use in space), and augmented interspecies communication (FluentPet). Next, the participants answered questions about the meaning of space discovery and how to make it important to all people. Ideas to keep space relevant to the masses included the message that “everyone is an underdog when we’re in space,” “not everyone has to buy in … [but] non-technical people [need to] feel they fit into the bigger picture,” invest money into bringing communities in that have not been represented in the past – like a “docuseries made by HBCU students about what it’s like to be a human in space,” “use TikTok … [it] is important for education,” and storytellers (movies like *For All Mankind*) may be more impactful than NASA on people’s interest in space. At the conclusion of the roundtable, the external participants noted key takeaways:

- “What does the future of aviation look like? Brings up the question of what NASA’s role is in all of this. NASA needs to maintain the fuel of humanity. NASA has been that brand.”

- “When you’re trying to change people’s minds they go through (1) denial, (2) resistance, (3) exploration, (4) acceptance, (5) manifestation, etc. Just moving people into resistance is a step forward!”

- “It seems like some people at NASA and especially on the Hill think that space development and settlements are likely going to happen in this lifetime or perhaps in 10-20 years. A lot of us see human exploration to Mars and settlements happening more quickly than we might expect — how can we communicate that to the ‘haters’?”

- “From the activist and educator perspective, this workshop helped give insights into the future that activists need to focus on. Opportunity and the future aren’t equally distributed. Girls and communities of color need to be ready to participate and be in the room for these future leaning activities. This session was a call to action!”

4. Drivers, Trends, and Disruptors

To build the four future scenarios, we relied on the inputs as discussed in Section 2, which include: drivers, trends, and emerging disruptors. Drivers, trends, and emerging disruptors determine the conditions (forces) that are actively shaping the current environment. A *driver* is a significant force pushing change, a *trend* is a perceptible vector (with magnitude and direction) for which change is characterized, and an *emerging disruptor* is a tangible manifestation in the present of what is possible to come (which may or may not scale into an emerging or established trend but offers a potential window into the future).

4.1 Drivers

Figure 5 is a description of nine of the drivers of space activities, specifically in the context of civil activities but in many cases applicable to all space applications. These drivers are derived from "Strategic Foresight for the Space Enterprise"[22] and provided a baseline to begin the discussion about trends and disruptors during the roundtables. They also help inform the critical uncertainties going into the Threadable CONOPS.

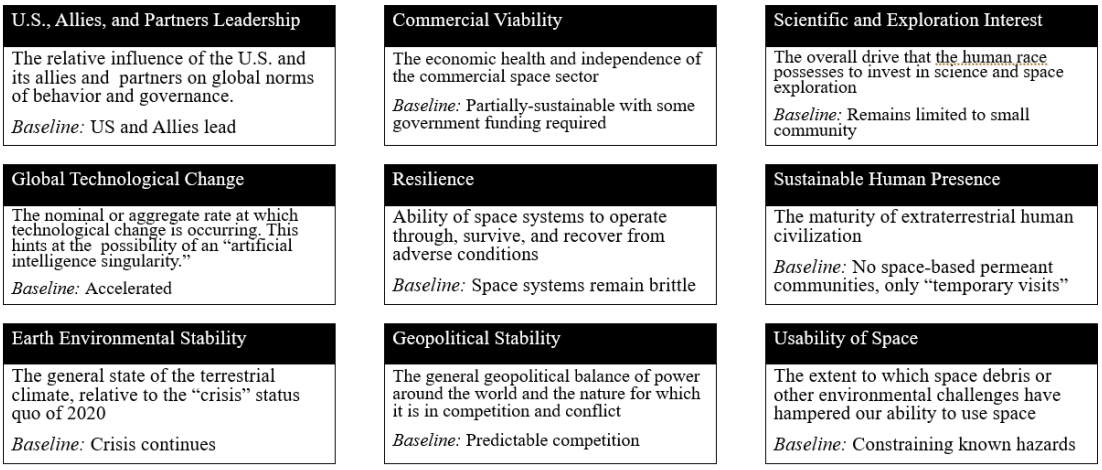

Figure 5. Detailed list of major underlying currents impacting space activities**.**

4.2 Trends and Disruptors

Trends are indicators of future change and must meet two criteria: (1) the trend must be increasing, decreasing, or changing in some fundamental way, and (2) its change must be documented by a credible source. These trends detailed here were collected both from the roundtables and ITONICS (software leveraged as part of Aerospace's proprietary horizon scanning process). We also included the emerging disruptors (i.e., current signals that may or may not result in a future trend but present the potential to substantially impact the global landscape) in this comparison. Emerging disruptors are innovations that represent upcoming change, and by identifying these signals, signposts can be defined. Signposts are indicators that can be monitored to signal that an emerging disruptor is turning into a trend or that a trend is changing in nature.

[22] Cunzeman, K. and Dickey, R. "Strategic Foresight for the Space Enterprise," *Center for Space Policy and Strategy,* The Aerospace Corporation, https://csps.aerospace.org/papers/strategic-foresight-space-enterprise

The scenarios in Section 6.3 were built upon the trends catalogued below. The Aerospace team synthesized hundreds of inputs from the roundtables, interviews, and other sources into 20-30 overarching trends and disruptors in each major category (STEEPTS). Table 4, through Table 8 show the binned categories of trends and disruptors identified in each of the Aerospace-facilitated roundtables for Societal, Technological, Economic, Environmental, and Political areas respectively. The "threat" and "space" categories in the STEEPTS framework are not called out separately here because inputs in those areas were usually already captured in the others. These tables combine the two NASA-executive roundtables (in-person and virtual) into a single column and the two external roundtables into another single column.

There are rows where no inputs are associated with roundtable input (e.g., "Integration of technology with intelligent animals" in Table 5). The absence of checkmarks in that row indicates that the trend or disruptor appeared in the ITONICS scan for trends and disruptors but was not identified in the roundtables. This outcome is reasonable and expected and highlights the value of using diverse sources of trends and disruptors. We advise the reader to take all inputs at face value regardless of which group provided it as an input. Furthermore, having an input appear in several or all the roundtables does not necessarily equate to strength or importance of the input per se; this situation could happen because the input is relatively well known to the participants (who are diverse but possess many similarities) or is a response to a recent current event.

Table 4. A Binned List of the Societal Trends and Disruptors Comparing the Inputs from the Roundtables

		Societal Trends & Disruptors	Roundtable Inputs: NASA Early-Career	NASA Internal (Senior Staff)	NASA Executive	External
TRENDS	Social Justice	Focus on DEIA initiatives	✓	✓	✓	✓
		Growing inequality		✓		✓
	Interpersonal Relationships	Prevalence / use of social media, shortening attention spans	✓	✓	✓	
		Growing self-centered attitude, personalization of everything		✓	✓	✓
		Growing divisiveness and manipulation of information	✓	✓	✓	✓
		Globalization of communication and relationships		✓		✓
	Workplace / Workforce	Challenge hiring and retaining STEM talent	✓	✓	✓	✓
		Geographic dispersion of workforce / remote work		✓	✓	✓
		Proliferation of collaborative tools		✓	✓	✓
		Demand for more benefits in workplace		✓		✓
		Alignment of job and personal values	✓			✓
	Community Trust	Loss of confidence in "expert" community or science in general	✓		✓	✓
		Anti-immigrant and anti-globalization sentiment		✓		
		Skepticism of placing trust in government, corporations, and other institutions				✓
		Global cultural homogenization				✓
		Disillusionment with higher education				✓
	Lifestyle / Quality of Life	Nomadic lifestyle ("van life")	✓		✓	
		Increasing fragility of supply chains		✓		✓
		Growing implementation and reliance on AI	✓			
		Aging population and delay of child rearing	✓			✓
		Environmentalism			✓	
		Ethical consumerism			✓	
		Ubiquitous tracking and surveillance				✓
		Intergenerational living arrangements				✓
		Uncertainty, unease, and pessimism about the future				✓
	Building Wealth	Shift in focus to short-term returns, neglect of long-term projects		✓	✓	
		End of ownership, everything on subscription model				✓
DISRUPTORS	Telehealth		✓			
	Mass automation of service industry		✓			✓
	AI in food supply chain			✓		
	AI in design			✓		
	Blockchain and digital currency			✓		
	Ubiquitous surveillance			✓		✓
	Legalization of marijuana, other pharmaceuticals			✓		
	Declining birth rates				✓	✓
	Deepfakes					✓

Table 5. A Binned List of the Technological Trends and Disruptors Comparing the Inputs from the Roundtables

		Technological Trends & Disruptors	Roundtable Inputs			
			NASA Early-Career	NASA Internal (Senior Staff)	NASA Executive	External
TRENDS	Energy and Environment	Shift to green technologies	✓	✓		
		Advanced energy storage		✓		✓
		Advanced nuclear power generation				✓
	Computing	Application of AI/ML to all aspects of life	✓	✓	✓	✓
		Cloud computing, storage of all personal and corporate data in cloud	✓	✓		✓
		Ubiquitous application of blockchain			✓	✓
	Science/Tech Culture	Shift of tech staff and big innovation from government to commercial		✓		
		Acceptance of failure			✓	
		Non-traditional education platforms (e.g., YouTube, TikTok)				✓
		Transition to subscription model of ownership for hardware				✓
	Information	Universal connectivity between people and devices, internet of things	✓	✓	✓	✓
		Balkanization of connectivity regimes, separate information ecosystems				✓
		Data management and cybersecurity	✓		✓	✓
	Space	Proliferation of new and/or smaller satellite form factors		✓		
		Diversification and proliferation of spacelift industry		✓		✓
		Expansion of commercial space applications, commercial exploitation of LEO		✓	✓	✓
		In-situ resource utilization (ISRU), in-space manufacturing (ISM)			✓	✓
		Advances in nuclear propulsion				✓
		Advanced genetics, designer medicine, and bioengineering	✓	✓	✓	✓
	Manufacturing	Additive manufacturing		✓		✓
		Design and grow organic practical articles and building materials*				
		Quantum technology (computing, communication, encryption, etc.)		✓	✓	✓
		Autonomous technologies	✓		✓	
		Miniaturization of sensors			✓	✓
	Humans and Tech	Augmented reality, life in the metaverse	✓		✓	✓
		Human-machine interfaces	✓	✓	✓	✓
		Integration of technology with intelligent animals				✓
DISRUPTORS		Augmented reality		✓		
		In-space assembly and servicing (ISAM), in-space manufacturing (ISM)		✓		
		Hyperlocal micromanufacturing		✓		
		Bioprinting		✓		✓
		Telemedicine		✓		
		Commercial mining of the Solar System		✓		
		Ubiquitous surveillance		✓		
		Self-assembling / self-replicating robots		✓		
		Crowdsourced funding of S&T		✓		✓
		Distributed power generation		✓		
		Life extension		✓	✓	✓
		AI that generates better AI		✓		
		Self-aware computers		✓		✓
		Right to repair	✓			
		Laboratory-on-a-chip biomedical devices	✓			
		Cybernetic implants	✓			
		Gene editing / CRISPR	✓		✓	✓
		Carbon capture / sequestration			✓	✓
		Metaverse				
		Therapeutics with mRNA-based technology			✓	✓
		AI-generated art				✓
		Major world powers disconnect from global Internet				✓
		Artificial wombs				✓
		Efficient and cheap desalination and water extraction				✓
		Nuclear fusion				✓
		Ultra-dense power storage*				

** Indicates this Trend/Disruptor came from a source other than the Roundtables.*

Table 6. A Binned List of the Economic Trends and Disruptors Comparing the Inputs from the Roundtables

		Economic Trends & Disruptors	Roundtable Inputs: NASA Early-Career	NASA Internal (Senior Staff)	NASA Executive	External
TRENDS	Investment	Crowdfunding		✓	✓	✓
		Increasingly aggressive or predatory investment environment		✓		✓
		Conscientious / virtuous investing		✓		
		Fads in novel investment instruments and platforms (e.g., NFTs, Robinhood)	✓			✓
		Space embraced by Silicon Valley and startup community			✓	
		On-shoring of critical industries*				
	Consumption	High housing prices, persistent / frequent bubble(s) for everything	✓	✓		
		Food insecurity		✓		
		Shift to subscription model for most/all consumption	✓			
		Taxes to offset environmental externalities			✓	✓
		Extraterrestrial resource extraction			✓	✓
		Commercial industries with state-level power and resources			✓	✓
		Brands as markers of political identity				✓
	Wealth Management	Amassing debt of all kinds	✓	✓	✓	✓
		Population not saving / unable to save for retirement	✓			
	Distribution of Wealth	Wealth concentration and inequality, socioeconomic stratification	✓	✓	✓	✓
		Continued emptying of rural communities		✓		
	Finance and Monetary Policy	Rise of digital currencies, cryptocurrency adoption by state actors	✓	✓	✓	✓
		Inflation	✓	✓	✓	✓
		Transition away from dollar as global reserve currency				✓
	Employment	Labor shortages in service industry		✓	✓	
		Workplace churn (turnover, security, recruitability)		✓		
		Stagnant real wages	✓			
		Alternative work paradigms (e.g., gig economy, 4-day work week)			✓	✓
DISRUPTORS		Shift from home ownership to universal rental / corporate ownership of housing	✓	✓		
		Gig economy becomes dominant mode of employment		✓	✓	
		Collapse of international-student attendance in US higher education		✓		
		Aging workforce		✓		✓
		Conflict over resource scarcity		✓		
		Digital dollar, elimination of cash currencies		✓		✓
		Widespread adoption of universal basic income (UBI)	✓			
		Mass automation of service industry			✓	
		Collapse of cryptocurrency system				✓
		Terrorism enters the metaverse				✓
		Asteroidal ores crash commodity markets				✓
		Real-estate transactions in metaverse exceed that in real world				✓
		Extension of human lifespan to >120 years				✓
		Nation state adopts cryptocurrency as legal tender				✓
		United States defaults on debt*				

** Indicates this Trend/Disruptor came from a source other than the Roundtables.*

Table 7. A Binned List of the Environmental Trends and Disruptors Comparing the Inputs from the Roundtables

Environmental Trends & Disruptors			Roundtable Inputs			
			NASA Early-Career	NASA Internal (Senior Staff)	NASA Executive	External
TRENDS		More destructive / less predictable weather events, other climate changes		✓	✓	✓
		Embrace of nuclear as green energy, other alternative fuels and energy sources	✓	✓	✓	
		Greenwashing	✓			✓
	Agriculture and Food	Sustainable farming, locavorism		✓		✓
		Reduction in meat consumption, rise of new meat alternatives		✓	✓	
		Loss of genetic diversity in food supply		✓		
		Corporate monopoly on agricultural gene pool				✓
	Ecology	Environmental over-exploitation and resource depletion		✓	✓	✓
		Frequent introduction of invasive species		✓	✓	✓
		Loss of biodiversity				✓
		Research into resurrection of extinct species				✓
	Personal Action	Environmental tourism / ecotourism		✓		
		Preference for public transportation, generational disinterest in owning a car	✓			
	Space Environment	Exponential growth in space population and debris	✓	✓	✓	✓
		Satellite constellations imperiling ground-based astronomy	✓		✓	
		Cooling upper atmosphere impacts LEO satellite lifetime*				
		Investment in desalination and other water-extraction tech				✓
		Bio-mimicry (learning from nature to design smarter, better tech)				✓
DISRUPTORS	Large-scale geoengineering			✓		
	Climate-induced food shortages			✓		
	Food shortages due to widespread resistance to GMOs			✓		
	Broadly palatable meat alternatives and synthetic food		✓	✓		
	"Blue Arctic" for shipping			✓		✓
	Viability of high latitudes for agriculture			✓		✓
	Gamification and crowdsourcing of climate-change solutions			✓		
	Extinction of pollinators			✓		✓
	Biological solutions to waste disposal (e.g., plastic-eating bacteria)		✓			
	New pandemic(s) emerging from melting ice and permafrost		✓			
	Massive release of methane from melting permafrost		✓			
	Asteroid impact				✓	
	Solar flares, large coronal mass ejections				✓	
	Transition to electrical vehicles, prohibition of internal combustion engines				✓	✓
	Large-scale, high-efficiency desalination					✓
	Resurrection of extinct species					✓
	Genetic modifications to tolerate climate change					✓
	Kessler Syndrome on orbit					✓

** Indicates this Trend/Disruptor came from a source other than the Roundtables.*

Table 8. A Binned List of the Political Trends and Disruptors Comparing the Inputs from the Roundtables

Political Trends & Disruptors			Roundtable Inputs			
			NASA Early-Career	NASA Internal (Senior Staff)	NASA Executive	External
TRENDS	Political Means and Ends	Focus primarily on near-term political gain		✓		
		Return to use of proxy wars for achieving geopolitical ends		✓	✓	
		Diminishing judicial deference to stare decisis	✓			
	Domestic and Global Division	Growing divisiveness and polarization		✓	✓	✓
		Domination by left and right extremes, no voices in center		✓		
		Return to geopolitical bifurcation between East and West spheres of influence				✓
		Bifurcation of space community into East vs. West spheres of influence				✓
	Political and Community Trust	Loss of confidence in "expert" community		✓	✓	
		Loss of confidence in government for solutions to big problems	✓	✓	✓	✓
		Manipulation / weaponization of information		✓	✓	
		Anti-immigrant sentiment		✓		
		Global resurgence of nationalism	✓	✓		
	Global Politics	Proliferation of space agencies around the world	✓		✓	
		Rise of African economic and geopolitical power(s)				✓
	Politicization of Everything	Belief that societal problems require political solutions				✓
		Confluence of political identity and employment				✓
	Political Science	Interest in alternative voting methodologies (e.g., ranked-choice, popular vote)				✓
		New governance models, digital communities, and societies				✓
DISRUPTORS	Universal private schooling			✓		
	Expansion of war to cyber domain			✓		
	Perpetual un-peaceful transfer of power			✓		
	Virtual Private Networks (VPNs) circumventing censorship			✓		
	Catastrophic failure of national infrastructure			✓		
	Deepfakes		✓			
	National or corporate claiming of extraterrestrial territory		✓			✓
	Modifications to US Supreme Court structure (e.g., number of justices, term limits)		✓			
	War in space		✓		✓	
	Ranked-choice voting, popular vote for US Presdent					✓
	Accession of one or more new states to the Union					✓

Through horizon scanning, the Aerospace team actively monitors trends and emerging disruptors across key areas using ITONICS. Below are nine major trends identified, many of which have significant support from the above tables:

1. *Commercial space activity*: The increasing use of space for diverse purposes by commercial companies is leading to a new opportunity for NASA to source technology, capabilities, and insights. On the other hand, the growing commercial viability for space companies may force NASA to reevaluate its mission, capabilities, and staffing portfolio.

2. *Increased impacts from and focus on climate change:* The effects of climate change are becoming more readily apparent with increased frequency of intense storms, droughts, heat waves, as well as rising sea levels, and warming oceans. This changing landscape has provided pressures and increased resource competition in countries with too much/not enough water and opportunities, such as the opening of new shipping routes in the Arctic and changing agricultural landscapes.

3. *Degree of connectivity and cybersecurity:* The population is increasingly becoming more connected, partially due to ubiquitous sensing and internet from space, leading to new social dynamics and the rise of increased cybersecurity needs.

4. *Synthetic biology:* Genetic modification as a competitive advantage is becoming more apparent as companies like Monsanto launch new products, and synthetic biology is increasingly being used for human modification such as growing organs for humans.

5. *Greater use of autonomous systems:* Increased utilization of autonomous systems is most noticeable in attention-grabbing headlines about unmanned aerial vehicles (UAVs) and self-

driving cars, but greater use of autonomous systems is greatly affecting businesses and governments.

6. *Volatility of the domestic political environment:* US domestic politics is in a period of increased polarization and volatility as compared with previous decades. One relevant impact of the resulting unpredictability is the politicization of science and research. Agencies that perform science and research are under increasing scrutiny and priorities may swing more readily as the political administration changes.

7. *Changes in international geopolitical environment:* The international geopolitical environment is changing with respect to cooperation, competition, and conflict. For agencies that have many international partnerships, the change in geopolitical relationships (as well as the rise of new ones) can lead to large impacts.

8. *Workforce of the future*: The COVID-19 pandemic caused a major shift in the global workforce, with continuing ramifications in workers' rights movements; increased demand for people to work from home; and infrastructure pressure changes, including greater computing/data requirements, differing pressures on support infrastructure within cities, and less commute infrastructure.

9. *Supply chains and disruption*: COVID-19 brought to light massive vulnerabilities within the supply chains that keep the United States operational. The lack of resilience causes, and will continue to cause, multi-country breakdowns in supply chains.

While many of the above trends may have been previously identified by NASA, it is important to continuously update and monitor the environment to proactively manage the impact of these trends and ensure an understanding of the vector of these trends. For instance, historically there have been many trends that suddenly switch direction, leading to potential resiliency gaps for those not actively monitoring these trends. Figure 6 depicts an example of the emerging disruptors identified as relevant to NASA through horizon scanning. Each emerging disruptor is graded by experts on its potential impact on the global landscape from severe to minimal.

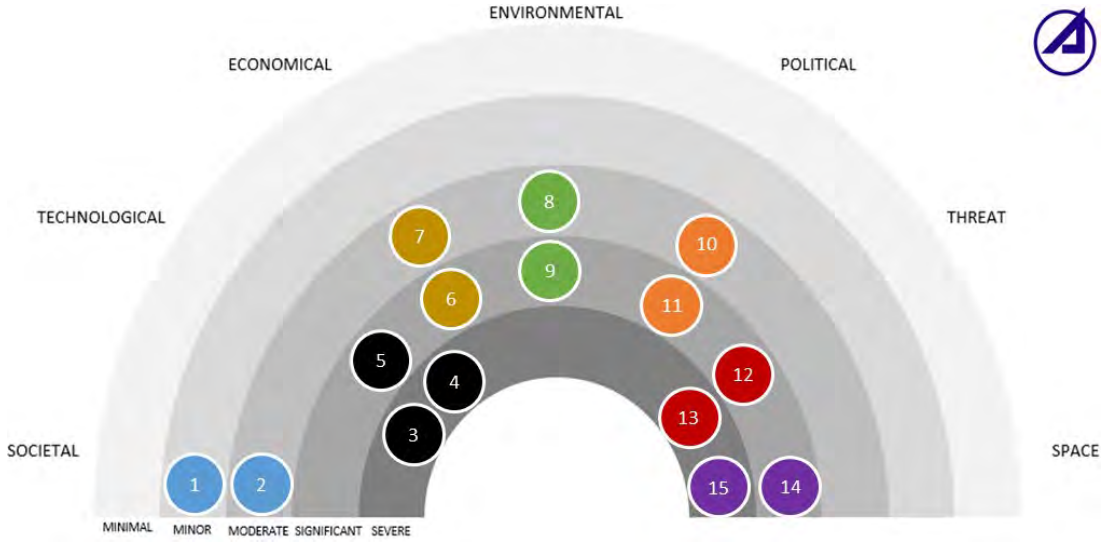

Figure 6. Custom scanning of relevant future emerging disruptors and trends with tagging of more than 1000 existing signals in the database to select ones relevant to NASA and identification of more than 60 key emerging disruptors for NASA. The colored and numbered circles represent emerging disruptors, detailed in the text below.

The 15 emerging disruptors (numbered/colored circles) shown in Figure 6 are detailed below. The full list of emerging disruptors identified through horizon scanning, as well as those identified during the roundtables, is available in Detailed Trends and Disruptors, Detailed Observations from Internal Roundtables, and Detailed Observations from External Roundtables. We selected these 15 signals to provide a sample of what was uncovered using ITONICS. These signals were not selected to be all-inclusive of the ITONICS output but to showcase findings that may not be immediately obvious to the space community at large. Trend tracking through ITONICS does not necessarily provide a comprehensive or in-depth review of each topic; the purpose is to capture signals of trends and disruptors.

1. "New Study Highlights the Link between Greater Green Space and Reduced Loneliness" [23]: Adults in urban areas where there is at least 30% green space, have a lower chance of becoming lonely compared to those with less than 10% green space. Limiting loneliness has many impacts on health, depression, heart disease, inflammation, dementia, and death.

2. "Google Toxicity-Reducing Filter Processing 500M Requests Daily: Benevolence or Thought Control" [24]: An open-source API created by Google that "uses machine learning models to score the perceived impact a comment might have on a conversation. You can use this score to give feedback to commenters, help moderators more easily review comments, allow readers to find interesting or productive comments more easily" is currently processing over 500M requests, daily. This technology can be used to reduce the "toxicity" of online content. However, the use of machine learning to process online conversations has the potential downside of steering conversations in ways that are potentially unknown (or even advantageous to specific groups). Machine learning-based content moderation has interesting implications for public discourse.

3. "X-risk: Race toward artificial superintelligence": A race may develop between major players toward artificial general intelligence (AGI) once it becomes clear that AGI's creation is possible with resources available at the time. Safety may be sacrificed at the expense of speed to maintain first mover advantage. Should an unfriendly recursively self-improving artificial general superintelligence be developed, it could represent an existential threat toward human survival. On the contrary, a beneficial superintelligence could herald a golden age for humanity and its descendants.[25]

4. "3D-printed Lung-Mimicking Air Sac Brings Functioning Bio-Printed Organs a Step Closer" [26]: Synthetic gels were once a wonder because they are light and provide structural support. However, as they were static, this signal suggests a new materials growth technique for synthetic gels that flex (a 3D-printed lung is the demonstration).

5. High-density, ultra-low-energy digital computing: "Electronic symmetry breaking by charge disproportionation results in multifaceted changes in the electronic, magnetic, and optical properties of a material, triggering ferroelectricity, metal/insulator transition, and colossal magnetoresistance. Yet, charge disproportionation lacks technological relevance because it occurs only under specific physical conditions of high or low temperature or high pressure. Here we demonstrate a voltage-triggered charge disproportionation in thin molecular films of a metal–organic complex occurring in ambient conditions. This provides a technologically

[23] "New Study Highlights the Link between Greater Green Space and Reduced Loneliness", *World Economic Forum*, June 15, 2021.
[24] "Google Toxicity-Reducing Filter Processing 500M Requests Daily: Benevolence or Thought Control," *Perspective API*, February 10, 2021.
[25] Bostrum, N., "Superintelligence: Paths, Dangers, Strategies, " *University of Oxford*, 2014.
[26] "3D-printed Lung-Mimicking Air Sac Brings Functioning Bio-Printed Organs a Step Closer," *Science Focus*, June 9, 2019.

relevant molecular route for simultaneous realization of a ternary memristor and a binary memcapacitor, scalable down to a device area of 60 nm^2. Supported by mathematical modelling, the results establish that multiple memristive states can be functionally nonvolatile, yet discrete—a combination perceived as theoretically prohibited. The device could be used as a binary or ternary memristor, a binary memcapacitor, or both concomitantly and, unlike the existing "continuous state" memristors, its discrete states are optimal for high-density, ultra-low-energy digital computing."[27]

6. "Iceland Tried a Shortened Workweek and It Was an 'Overwhelming Success'" [28]: As remote work became a roaring success for both companies and employees during the pandemic, it opened eyes to new possibilities of how we can have a better life-work balance.

7. Federal debt continues rapid increase: Federal debt is over $27T and is currently above yearly GDP of $19.5T due to the pandemic. There has been concern that if the debt reaches a point over 100% of GDP, then there could be consequences.[29]

8. National Academy of Sciences (NAS) says active climate cooling should be considered: NAS is not yet recommending geoengineering to bounce heat back into space but recommends an "emergency plan" be investigated. The report looks at three possible ways to cool the air: putting heat-reflecting particles in the stratosphere, changing the brightness of ocean clouds, and thinning high clouds. NAS says climate problem has worsened since they last evaluated it in 2015.[30]

9. "Solar-Powered System Extracts Drinkable Water from 'Dry' Air" [31]: Researchers at MIT and elsewhere have significantly boosted the output from a system that can extract drinkable water directly from the air even in dry regions, using heat from the sun or another source.

10. "Blockchain Technology in Use to Reduce Public Procurement Process Corruption" [32]: "SettleMint is exploring the use of blockchain technology to reduce corruption in the public procurement process. OECD estimates 10% to 30% of the investment in publicly funded construction projects may be lost to corruption. Blockchain technology would increase transparency in the process that should reduce the occurrence of corrupt acts."

11. "US Should Push NewSpace Treaty: Atlantic Council" [33]: "The US should push hard to overhaul the entire international legal framework for outer space — including replacing the foundational 1967 Outer Space Treaty (OST), a new report from the Atlantic Council says. As it moves to do so, the US also should more aggressively court allies with an eye to establishing a 'collective security alliance for space' among likeminded countries to 'deter aggression' and defend 'key resources and access.'"

12. Cooling upper atmosphere impacts LEO satellites: Long-term data on the mesosphere, the layer 30 to 50 miles above Earth's surface, has revealed that it is cooling and contracting.

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[27] Goswami, S. et al. "Charge disproportionate molecular redox for discrete memristive and memcapacitive switching." *Nature nanotechnology* 15.5 (2020): 380-389.
[28] "Iceland Tried a Shortened Workweek and It Was an 'Overwhelming Success'," *Forbes*, June 5, 2021.
[29] "Charting America's Debt: $27 Trillion and Counting," *Visual Capitalist*, October 30, 2020.
[30] "Science panel: Consider air cooling tech as climate backup," *Los Angeles Times*, March 25, 2021.
[31] "Solar-Powered System Extracts Drinkable Water from 'Dry' Air," *MIT News*, October 14, 2020.
[32] "Blockchain Technology in Use to Reduce Public Procurement Process Corruption," *World Economic Forum*, July 5, 2021.
[33] "US Should Push NewSpace Treaty: Atlantic Council," *Breaking Defense*, April 12, 2021.

Scientists believe this is caused by the insulating effect of a thickening lower atmosphere, a trend that will increase with time.[34]

13. "India Tests Anti-Satellite Weapon" [35]: "The Indian government announced on March 27 that it successfully fired a ground-based anti-satellite (ASAT) weapon against a satellite in low Earth orbit (LEO), a test that is likely to heighten concerns about space security and orbital debris. Indian Prime Minister Narendra Modi said that the country's military successfully demonstrated an ASAT weapon in a test known as "Mission Shakti." In that test, a ground-based missile, a version of an existing ballistic missile interceptor, hit a satellite at an altitude of about 300 kilometers."

14. "Close Calls with Starlink Account for Roughly Half of All Incidents": "The Astronautics Research Group at the University of Southampton, U.K. has found that Starlink satellites account for roughly 1,600 close encounters between resident space objects each week. A close encounter in this research is classified as two spacecraft passing within 1 km of each other. Many of these encounters are self-inflicted and lower to 500 per week when only considering encounters with non-Starlink spacecraft. As the constellation size increases, it is projected that up to 90% of all close encounters in LEO will stem from Starlink encounters. Current notification processes are not easily scalable due to their reliance on manual action, according to Kayhan Space CEO (which itself is developing a commercial autonomous space traffic management system)."

15. "Russia, China to Sign Agreement on International Lunar Research Station"[36]: Russian state space corporation Roscosmos carries on talks with China and other international partners on the creation of a joint Moon base, Roscosmos chief Dmitry Rogozin said on his Telegram channel. "We are holding talks with all international partners, first and foremost China, on establishing a Moon research base," he wrote. Rogozin reminded that the Russian Moon research program is set to begin in 2021. "We plan to begin a piloted Moon program in 2028," he stressed. Earlier, China National Space Administration (CNSA) spokesman Xu Hongliang stated that China would continue researching the Moon and it plans to unite efforts with Russia to implement the corresponding projects.

4.3 Natural Language Processing of NASA-provided Futures Documents

Natural Language Processing (NLP) is a subfield of machine learning (ML) used to pull insights from strings of text, often articles, books, and other written correspondences. For this study, NLP was used to scan both NASA-provided future documentation and global futures documents. A full list of documents is provided in List of NLP Documents Scanned This analysis helped to identify emerging disruptors and identify gaps in current NASA futures documentation and planning. For instance, are current activities not broad enough to cover areas outside current mission sets? Are there limited numbers of authoritative documents considering the broader environment? By identifying topics in the NASA-provided documents versus those in the global futures documents, gaps and/or biases can be easily assessed.

4.3.1 Data Ingest and Algorithms

For this study, NLP was used to process approximately 50 NASA-provided documents and 10 global futures and space futures (documents listed in List of NLP Documents Scanned). For each document,

[34] "NASA Satellites Find Upper Atmosphere Cooling and Contracting Due to Climate Change," *SciTechDaily*, July 4, 2021.
[35] "India Tests Anti-Satellite Weapon," *SpaceNews*, March 27, 2019.
[36] "Russia, China to Sign Agreement on International Lunar Research Station," *SpaceNews*, 17 February 2021.

paragraphs were extracted with assistance of a computer vision-based document segmentation model. A count of the paragraphs extracted per document can be seen in Figure 7. Paragraphs were soft-normalized to remove noisy characters and encoded using a pretrained NLP transformer-based language model (DistilGPT2) to make them machine interpretable. From there, customized topic models were created to parse the documents at the paragraph level to discover topics and trends. Topic clusters were generated via a Gaussian Mixture Model clustering algorithm and optimized via a hyperparameter grid search. It is important to note that an unsupervised approach (no ground truth) was implemented and thus, subject matter expert validation was required in assessing topic model content and quality. To provide additional context, keyword phrases and abstractive summaries were generated for each topic cluster. PEGASUS, an open-source NLP model fine-tuned to generated short 2-3 sentence summaries, was used to generate topic summaries.

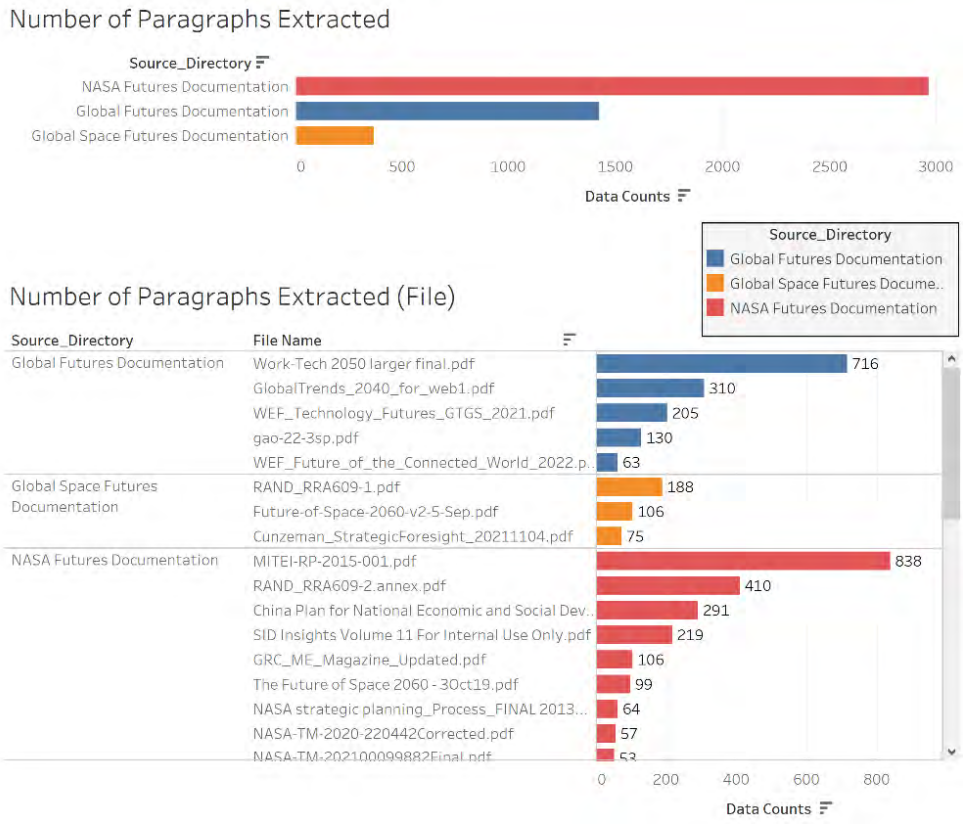

Figure 7. Snippet showcasing some data source details and paragraph counts.

For automatic timeline generation, additional components were developed for the identification and extraction of temporal entities (i.e., term or term phrases signaling periods of time, explicit dates, or other temporal adjectives). An NLP model, fine-tuned on the identification of temporal entities, was used to identify, and track temporal entities present in paragraphs. Paragraphs were then segmented based on temporal entities and those with overlapping categories had abstractive summaries generated to synthesize key points and events. For this work, the paragraphs were filtered for temporal entities corresponding to date (could be as general as year) only and excluded all other temporal terms.

Except for the use of Tableau (discussed below), all algorithms developed by Aerospace are based off open-source models fine-tuned to fit the data's domain. The algorithms are reusable, meaning data can easily be added or removed as necessary. Additionally, the algorithms are extensible, meaning new methods can be incorporated to extract data/attributes of interest.

4.3.2 Data Visualization and Insights

Identified topic clusters and temporal paragraphs were ingested into Tableau to generate various views to assist in visualization and insights. Tableau workbooks provide flexibly in sharing insights with futures analysts. Results from these Tableau visualizations can be seen in Figure 8 through Figure 11.

Some key themes (across all documents) that can be seen in the figures are sustainability (primarily from NASA-provided documents), diversification of energy sources, green fuels, green development, climate, digital mobility and enablers, future workforce, telework, telehealth, telemanufacturing, AI/ML and robotics, and the global power competition. These are areas where rapid change is expected in the future and disruptors in these areas should be closely tracked.

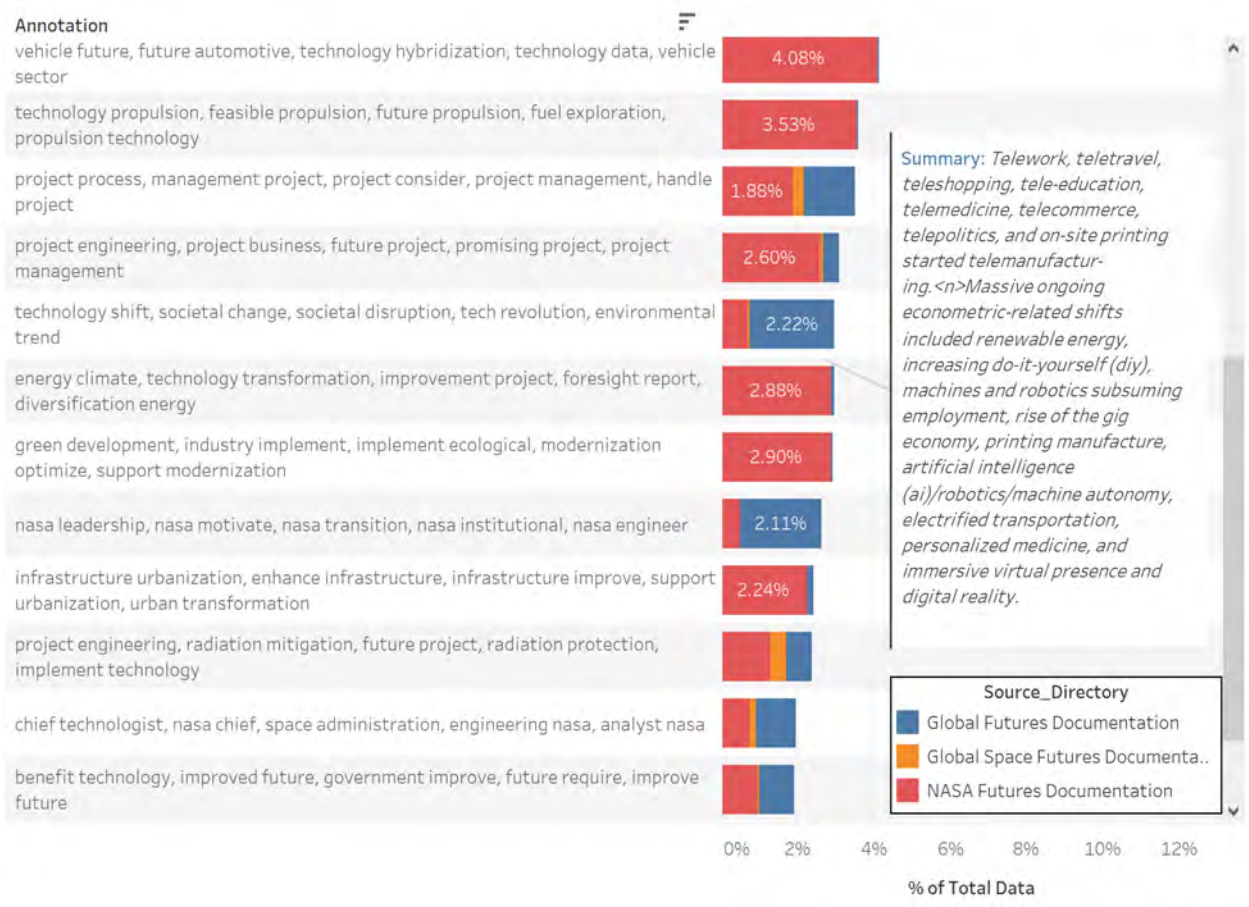

Figure 8. Sample output of selected topics (keywords shown) generated from available text.

The NASA documentation was particularly strong on many aviation themes. Some identified gaps, or rather new areas to be sure to track, within NASA's direct portfolio, were Mars and beyond, new propulsion, and tangential but relevant industry developments (additive manufacturing, autonomation, AI/ML). Overall, the NASA documentation showed gaps in the broader context in which many future technologies are happening and important factors that could be critical to their success such as emerging commercial needs, business viability, ethics, and governance models.

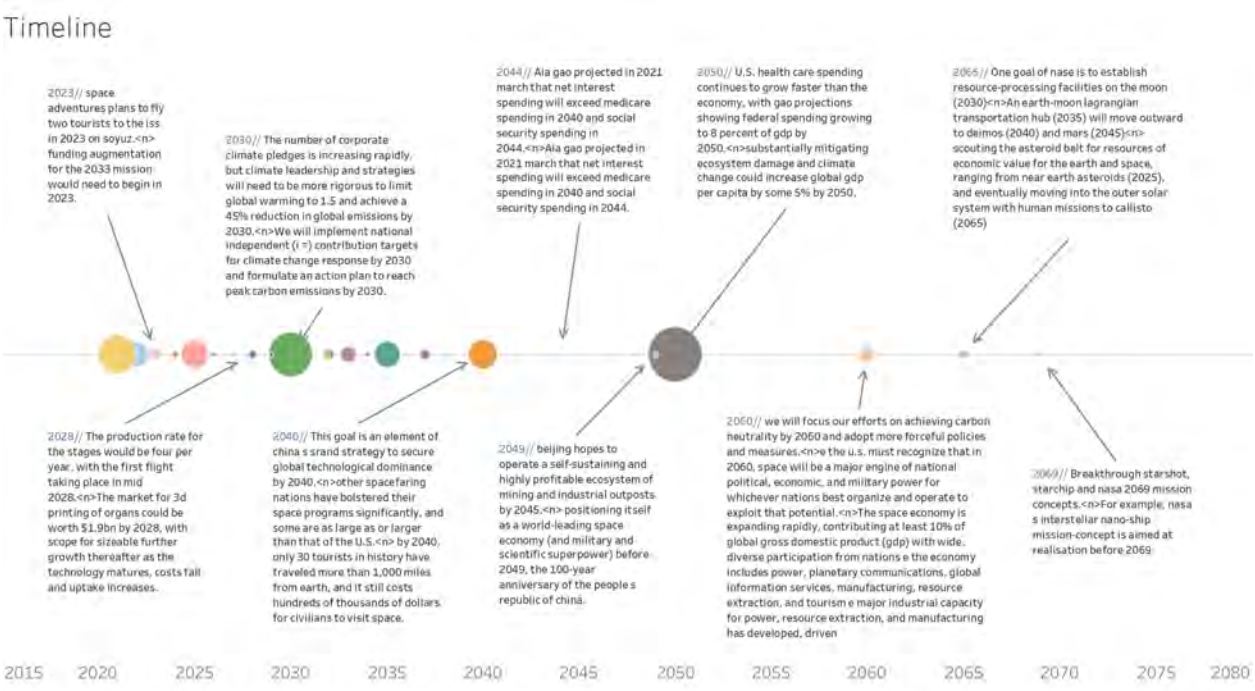

Figure 9. Example generated timeline. Timeline entries were generated using paragraphs with similar temporal entities—in this case year. Summaries were used to synthesize key themes. Frequency of topic is represented by the size of each circle on the timeline.

4.3.3 Limitations and Potential Next Steps

It is important to acknowledge some limitations of the NLP work presented here. Biases may be present in the results due to many factors, including data content (e.g., which documents are being ingested), writing style (e.g., one author many choose to refer to a specific year while others may lean towards more general terms), and extraction technique. This could lead to an increased prevalence of on certain topics (e.g., aviation). Below are ways to overcome some of these limitations.

To further extend the value of this work, there could be several key next steps. First and foremost, more data could be provided to the algorithms. Insights and themes reflect available data, and thus there is a potential for bias based on input sources. Inclusion of additional global/space futures documents would increase fidelity in future iterations. Additionally, the model could be refined through further normalization of data. Noisy artifacts (e.g., references) remain present at times within topic samples. While this has no large impact on topic clustering, improvement in the results could be seen with further processing. Next, the model could incorporate additional temporal entities. Currently, the model focuses only on entities that have a specified date (year). There are many paragraphs referring generally to "future" events that were not incorporated into this analysis. Finally, the work could be further extended with the extraction of additional metadata (e.g., government or commercial organizations). Based on feedback from end users, additional attributes of interest could be folded into the analysis.

It is recommended that NASA implement continuous NLP scanning of both internal and external documentation to focus on broader global changes and to identify emerging disruptors to assess gaps in NASA planning.

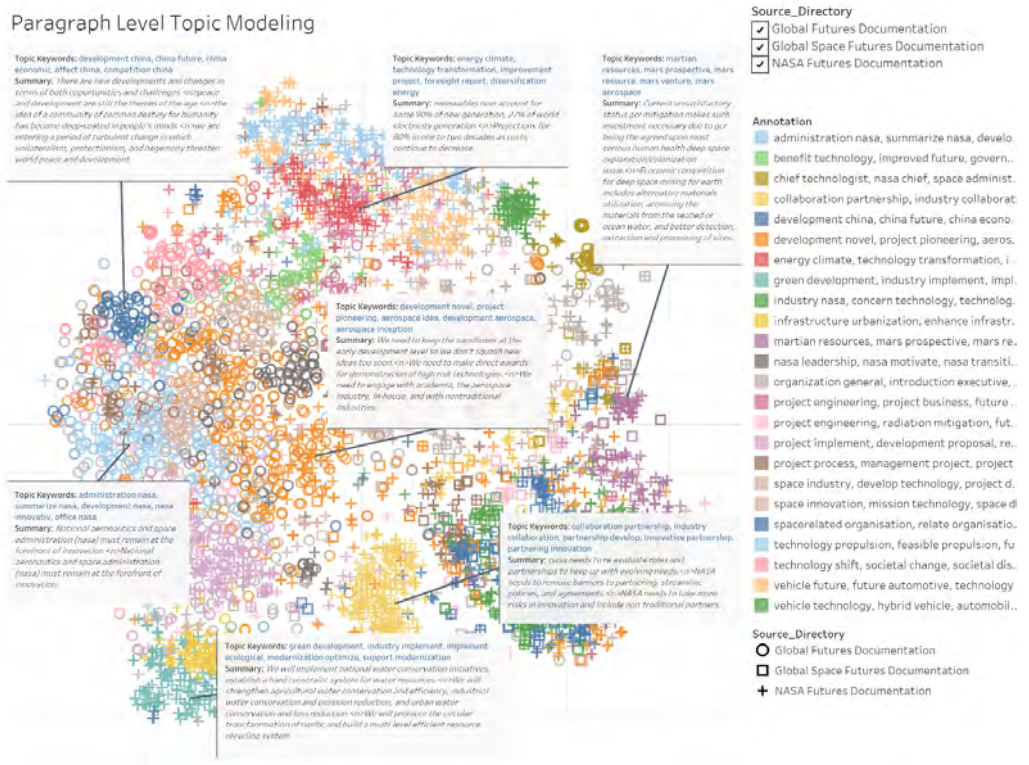

Figure 10. Example of topic cluster generated at the paragraph level. Each paragraph corresponds to a shape on the plot. Paragraphs belonging to the same topic family are color-coded accordingly.

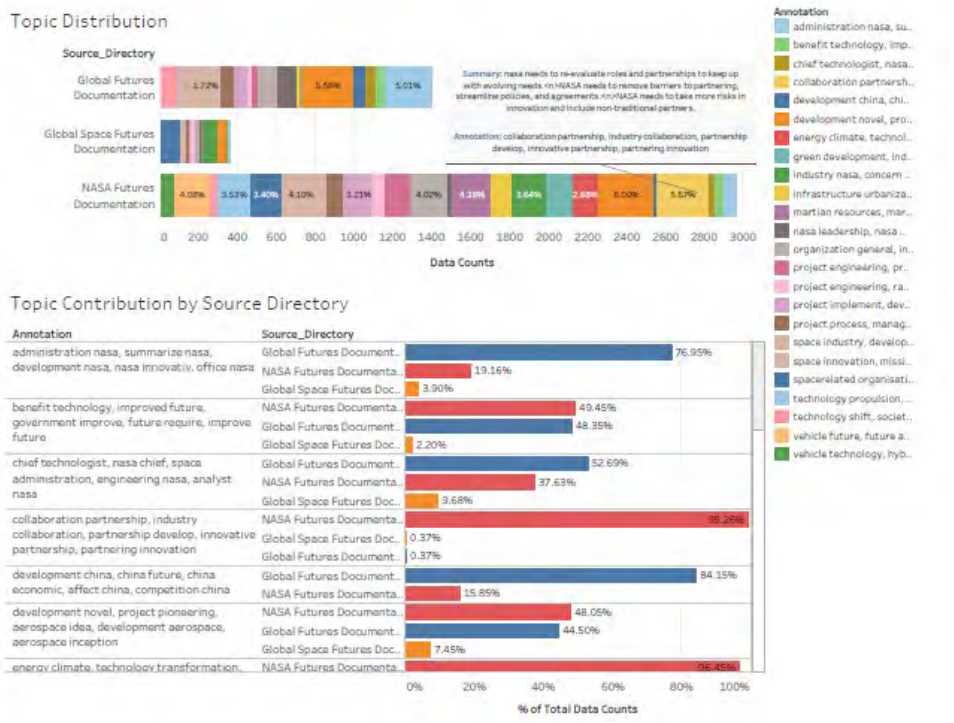

Figure 11. Graphic shows topic contribution by source directory. For example, NASA data comprises 98% of the content in the “green development” topic cluster. That is, NASA documentation is more focused on this area in contrast to other ingested documentation.

4.4 Inputs from International Space University (ISU)

The inputs from the roundtables and interviews were overwhelmingly US-centric in nature due to perspectives of the participants providing inputs. It was important for our analysts to obtain an international perspective to ensure there are no large gaps in the data. Due to limitations on the study, we were not able to hold a roundtable with international participants. An Aerospace team member was able to attend the International Space University (ISU) hosted in Oeiras/Lisbon, Portugal (30 July 2022). The overriding theme from ISU was the globalization of space. Notes from the event indicated that our international colleagues view NASA's future as being intertwined with the future global space scene, even more so than it is today. While the notes from ISU are inclusive of all international perspectives, there was an indication that the Europeans may have a more extreme perspective in the commercial versus state-government role in space. Representatives indicated that the ISS could be commercialized and that there could be a major shift from government-driven space missions to private-driven. The goal of the government (generic government, not just US) is being viewed as a shift from the prime mover in space to a "catalyst", which is consistent with our findings from the roundtable participants North Star activity.

Key trends/disruptors that international participants discussed throughout the ISU event (not a structured foresighting activity) were (all direct quotes/comments):

- "Commercialization of the ISS"
- "Need for space situational awareness"
- "Shift from govt-driven to private-driven space missions. The goal of government has shifted from prime mover to catalyst."
- "Commercial access is a two-edged sword: will people want to access ISS to do science via commercial launch, or just do science on an Axios mission?"
- "Surprised by public perception of commercial space; people think 'it's just rich people hanging out.' Companies are trying hard to be productive in space to change that perception. Blue Origin just announced first Portuguese astronaut in July"
- "Should operate from a perspective of abundance not scarcity, but at the same time the water in lunar regolith is not an unlimited resource"
- "What is the role of the private sector in creating societal resilience? E.g., is commercial GEOINT obligated to report suspected human rights violations they observe? When and to whom?"
- "The challenge is what is the role of the state? Until COVID, we embraced a metropolitan view (individualistic?) but then we went to the state for salvation from COVID. Suggestion: follow new trends of religiosity (i.e., in what ways are otherwise non-religious people behaving religiously)"
- "There have been some 1700 space startups in the last 10 years, mostly in the US, many in China, not so many in Europe; total of $260B in entrepreneurship"
- "In the last five years there have been 20 new space agencies/institutions especially in Africa. Similar story in Middle East, and a bit in Latin America"

- “Nobody attracts youth to STEM like the space sector does”
- “Most everyday people are not yet “evangelized” to the value of space”
- “Cislunar infrastructure will be key”

The participants also discussed what they wished for space by 2030:

- “Sustainable access to space open to all 195 countries”
- “Space to be inclusive for all classes, all countries”
- “Responsible use of debris environment, find solutions to debris problem”
- “The planet to be a better place because of the investments we make in space, and I can afford a trip to space”
- “Starship will change the world. You can ship a whole tractor to the moon and start building roads immediately rather than assembling things piecemeal.”
- “Need to stop talking about CubeSats; that’s old news. Talk about hotels, tractors/Caterpillars.”

The foresighting team completed a holistic review of all trends and disruptors across all sources of input. Many roundtable trends and disruptors appeared in multiple categories, either directly or thematically, indicating the outsized leverage they may wield on the evolution of the future operating environment. Furthermore, trends binned themselves into several themes from the horizon scanning and NLP activities. The team considered the signals’ potential impact to NASA and whether there was a clear direction to the trend or not and eliminated signals with lower future impact. This process led to a final set of critical uncertainties that are likely to have a dominating impact on the future environment which were fed into the Threadable CONOPS.

5. Potential North Stars for NASA

One important element of organizational effectiveness is alignment on collective, understood, and believed vision and mission statements. NASA's current vision statement is "exploring the secrets of the universe for the benefit of all," and its current mission statement is "NASA explores the unknown in air and space, innovates for the benefit of humanity, and inspires the world through discovery." This study explored the enterprise-wide alignment on this vision and mission and whether NASA's staff believed this vision and mission should change in the future.

Feedback from the roundtables and interviews revealed that there was no enterprise-wide consensus on today's vision and mission statements. Roughly half of the internal participants felt that the vision and mission might be different in the future. The other half thought that NASA's current vision and mission were enduring but that change could occur in exactly *what* NASA does in pursuit of that vision. This bifurcation of perspectives on the future "why" for NASA could be problematic in achieving cross-organizational alignment and weathering any disruption that may occur. In this section, we detail a range of possible "whys" for NASA and aspirational future states the Agency could pursue.

5.1 The Future Why for NASA

This study explored the future "Why for NASA?" by posing the question "what is NASA's why and does it change in the next 20-plus years?" to the NASA executives. The study does not attempt to drive towards alignment on a single "why" and instead highlights the (lack of) alignment on this question and presents potential options for leadership to consider during strategic planning. Answers for NASA's purpose and mission today included (ungrouped and unedited from participant responses, except for typos):

- "To advance humanity's understanding of our universe including our home planet"
- "To put people/things in space for varied reasons, successfully"
- "Explore, Discover, Understand the way humans interact with our Universe"
- "Inspire current and future generations to take on exploration and to prepare for a future in space"
- "Explore and innovate in a way that is relevant and meaningful to humankind"
- "Do what has never been done before"
- **"**Learn about our surroundings to better understand ourselves"
- "NASA explores and expands our knowledge of the universe or the benefit of all humanity"
- "Inspire through space exploration help protect Earth"
- "Exploration and leading the way; inspiration for all; taking on risk to discover"
- "Explore, Challenge and Make a Difference"
- "Solve the hardest challenges of space exploration and science"
- "Inspire stakeholders with technology, science, and consequential contributions"
- "Advance human knowledge while seeding and inspiring future aerospace opportunities"
- "Push the boundaries of science and engineering with space exploration"
- "Explore new worlds and answer questions critical to our future"
- "To give America a view into space to better understand humanity's place, purpose, and perspective"
- "To explore Earth and Universe, seek out new frontiers, & understand the unknown"
- "Explore the world, solar system, & universe around us to benefit humanity"
- "Inspire scientific learning & exploration"
- "Unlock future exploration; pursue discoveries (known & unknown); inspire individual responsibility for global challenges; change the possible"

- "To understand our origins and explore and discover our future"
- "To explore, invent, and push boundaries for the betterment of mankind"
- "Make space safe, affordable, and profitable"
- "Explore the universe(s) for the prosperity and protection of humankind"
- "Catalyzing discovery for the good of humanity"

There are common elements across the various statements, such as "explore," "humanity," and "discovery," but their messages are far from uniform. The statements vary in both who the ultimate beneficiary of NASA may be and the specificity of those beneficiaries. Many participants believed that NASA is now at a fundamental transition point with the rapidly changing environment (particularly with the rise of commercial space). Some went as far as to say NASA was having an identity crisis. Many participants felt that there had been pressure for NASA to turn into a more applied agency rather than a "mission-focused" agency and that pressure was driving the lack of a clear mission statement.

A clear consensus did emerge that "this is our chance to define where NASA will lead into the future, while others in industry may continue some of the other work." Others spoke about the importance of ensuring that NASA remains dedicated to the next generation, regardless of the mission. Some spoke about the constrained resources and budget that NASA operates with and that may limit it from driving towards its mission.

When discussing whether the NASA mission statement would or should change in the next twenty years, roughly half of all participants believed that it would not change. Most of these participants recognized that even if the "why" does not change, the "how" would. For example, as commercial industry becomes more capable, NASA could leverage the commercial sector and shift towards new destinations, or NASA could shift towards catalyzing commercial to do the impossible and seeding inspiration.

Others believed the fundamental "why" *did* change. A tangible shift to a more applied agency or a change in focus to enabling life outside our home planet (as opposed to thinking about Earth) were two notable themes. Additionally, some believed regarding human spaceflight that in twenty years, "[NASA would] focus less on how do we get there and more what do we do when we get there." For those that believed that the "why" will change in 20 years, their candidate new mission statements included:

- "Architecting the future paths and systems to explore the unknown"
- "Maintain sustainable direction and budget to fully realize the 2022 statement."
- "Doing hard things involving space to learn and explore"
- "R&D for commercial space activities"
- "Continue to do what has never been done before"
- "Inspire through space exploration help protect earth + more implementation"
- "Explore, Challenge, Innovate, Make an Impact"
- "Similar, but changed focus on technology development emphasis"
- "To enable Americans to go/experience space while continuing to push technical boundaries and observations"
- "To explore the Earth & Universe & push new frontiers to benefit all humankind"
- "Extend life into the solar system; answer are we alone?; improve life on planet"

Based on these results, a substantial challenge for NASA during its strategy formulation will be to work towards organizational alignment on the current vision and mission statements and any potential changes in the future. Failure to achieve alignment could result in an inability to execute on any strategy formulated.

5.2 Aspirational Future States of NASA

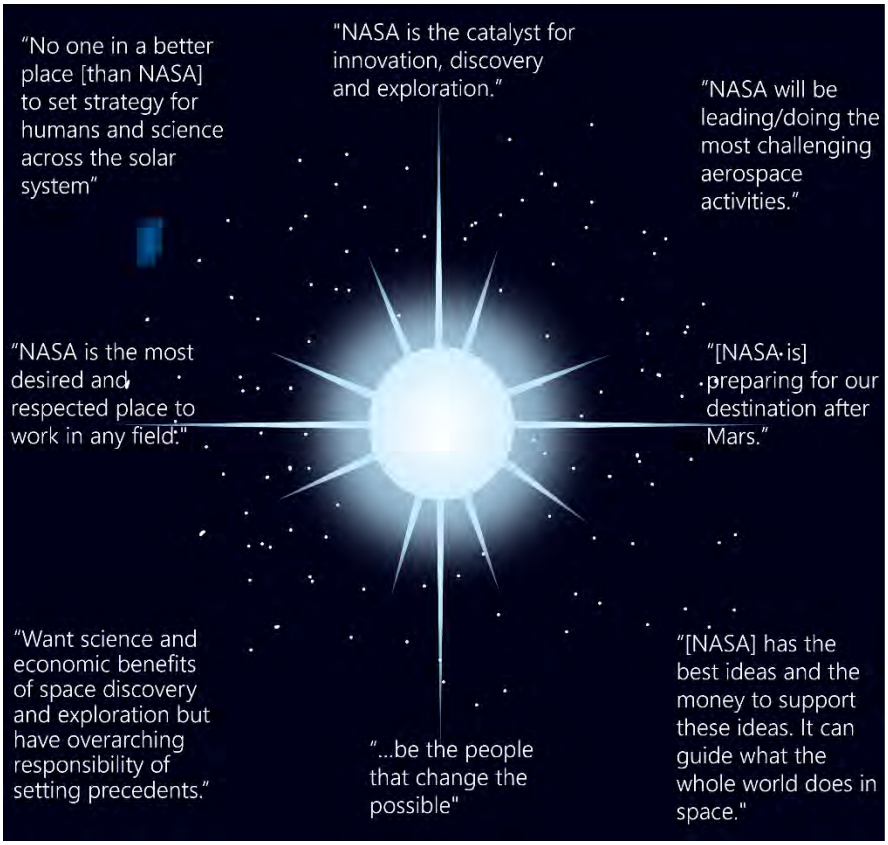

Figure 12. Aspirational future states for NASA from executive interviews.

In addition to exploring the "why" for NASA, this study explored aspirational future states and North Stars for NASA. When developing strategic options, it is essential to consider the question, "what is this strategy attempting to drive towards?" The mission and vision statement help answer this, and envisioning potential aspirational future states helps contextualize and actualize the vision and mission. Some of the aspirational future states expressed in NASA executive interviews appear in Figure 12.

Language from the NASA executive roundtables were collected as candidate North Star words in a word cloud in Figure 13, where the size of each word in the diagram corresponds to the frequency of its use in conversation and in exercises. Although they are merely an alternative depiction of a linguistic histogram, word clouds can help reveal at a glance any unexpectedly dominant sentiments from a large corpus. In the case of Figure 13, two unexpected words do stand out for their frequency: "catalyze," which was usually expressed in connection with commercial industry, and "diverse," which was raised frequently in the context of the NASA workforce and talent retention. The appearance of the former in particular influenced the formulation of an additional strategic option ("Catalyze access for all") in Section 6.4, complementing the strategic options that have heritage in the most common and expected North Star words in Figure 13.

In the next section, we focus on the development of the divergent future scenarios. It is important to contextualize these scenarios considering NASA's potential future state and mission. Additionally, each scenario must be analyzed against whether achieving the mission and vision is possible and whether each scenario might lead to a change in this statement. Thinking through the scenarios in this context helps organizations build strategic resilience in driving towards their vision.

Figure 13. Candidate North Stars derived from NASA executive roundtables (size correlated with number of instances of a word).

6. Divergent Future Scenarios and Analysis

6.1 Archetypes of the Four Futures Model

To develop scenarios that could generate actionable insights for shaping future decision-making, this project leveraged the Four Futures model, which uses four archetypes of future storylines: growth, decline, discipline, and transformation. Figure 14 provides a visual illustration of these four archetypes, complemented by a baseline scenario that corresponds to the current environment. After a baseline of trends and disruptors has been established by reviewing the present, the four futures provide corner cases across which possible investments, technologies, and decisions can be evaluated. This approach allows for determining how decisions could play out across different sets of assumptions. The Four Futures model challenges the analyst to rethink assumptions, consider multiple possibilities for the future, and make better decisions today. As noted in the methodology of Section 2, the goal of this activity is **not** to predict the future but to explore corner cases of the future and build *strategic resiliency.*

Figure 14. Archetype definitions of future corner cases, as defined by the Four Futures Model.

No future scenario is inherently good or bad. Each offers a set of opportunities and challenges. The collective set of scenarios guides insight into which strategies may be more resilient or effective in achieving preferred futures than others, even under inherent uncertainty. A decision-maker can connect these 20-50-year futures to present-day action planning by triaging his or her decisions in the present to seed desired outcomes illuminated in the scenarios.

One approach for understanding the future is in terms of waves of transformation (like design thinking)[37,38]. When discussing the future of the aerospace industry and community, we can characterize the current trajectory in terms of three waves. The first wave is the "exploration epoch," where space activity primarily occurs out to GEO (with some interplanetary crafts) including scientific missions, human space flight primarily involves temporary visits (like the ISS), there exists some sustained commercial activity (both human and non-human) ... Following this wave, society moves into the "commercial epoch," where activity (human and non-human) expands to cislunar and lunar surface, humans become space steading, and commercial activity (human and non-human) occurs independent of government funding. Finally, society moves to the "settlement epoch," where the scientific missions grow in complexity and human exploration activity expands to Mars and beyond, interplanetary societies exist, and Earth has now become dependent on off-planet commercial activities (human and non-human).

[37] Jeanne Liedtka, "Why Design Thinking Works," October 2018, Harvard Business Review, https://hbr.org/2018/09/why-design-thinking-works
[38] Kara C. Cunzeman and Paul C. Frakes, "Surfing Disruption: A Primer in Strategic Foresight," The Aerospace Corporation, May 2020. [Limited Release to USG]

Society is currently in the first wave of the transformation described above. In this work, the future scenarios primarily explore the transition from the first wave to the second, with some excursions to the third wave. These excursions are valuable because they capture events that could significantly influence NASA's choices in the present. For example, during the development of the first automobile, the Ford Model T, most of society did not consider the possibility of personally owning a car. The development of this seminal automobile can be considered an excursion beyond the next transition. By not exploring potential transformations, organizations are at risk of being consumed by the transition and miss opportunities for growth or realizing their missions. When these transitions between waves will occur is unknown – it could be in 10 years, or in 50 and the exact timing of these transitions will likely be determined by the future developments of the key uncertainties identified in this work.

6.2 Threadable CONOPS

The process of developing four corner-case futures begins with the identification of key uncertainties that could influence NASA's global operating environment. Although many factors will influence the future environment and appear in the scenarios, a review of the trends and disruptors from the roundtables combined with foresighting expert analysis identifies the driving uncertainties that are likely to play an outsized role in shaping the future operating environment. Section 4 details the process of identifying these over-arching uncertainties.

Each uncertainty may have multiple future states. A feature of scenario development is the exploration of these multiple possible future states across the scenarios. By detailing the range of possibilities for each uncertainty (e.g., future conflicts ranging from "none" to "regional" to "global"), foresight can aid in a qualitative assessment of the future environment's corner cases, which are likely to put the greatest strain on the resilience of an organizational strategy. After the critical uncertainties have been identified, the foresighting team documents a range of possible future states for each uncertainty. The uncertainties are collected in a table, called a Threadable CONOPS,[39] each with their possible states. Figure 15 shows the Threadable CONOPS developed for this project, using six inputs that provide broad coverage of potential future states. Each input is variable, which means it has multiple possible states, many of which emerged from roundtable inputs.

Commercial Space Viability / Sustainability	Not viable	Limited, commercial / government partnerships	Commercial operates independently (near-Earth)	Commercial operates independently (interplanetary)			
Earth Environmental Stability	Uninhabitable	Crisis	Stable	Healing			
Domestic Politics Influence on NASA	No political interest in space	Full priorities flip from administration to administration	Some priorities flip, others persist	Cross-administration / enduring priorities			
Human Presence in Space	No humans in space	Occasional short-term visits to space	Space steading	Interplanetary societies			
Geopolitical stability	*Conflict / turbulence*	*Competition*	*Cooperation*				
	None	Monopoly	Allies only				
	Domestic	Bifurcation	With adversaries				
	Regional	Multipolar	Ever-changing				
	Global	Distributed	Free-flowing				
	Off-world						
Capability Gamechangers for NASA	*Hypersonics*	*AI systems*	*Interplanetary transportation*	*Green flight*	*Metaverse*	*Clean Energy*	*Synthetic biology*
	R&D only	Narrow	Traditional	Incremental improvement	Sparing use	Scaled renewables	Substitution
	Government / military only	General	Transformative	Zero emission	Recreational	Fusion power	Restoration
	Commercial	Super	Revolutionary	Actively beneficial	Fully integrated	Space-based solar	Regenerative
							Augmentation

Figure 15. The Threadable CONOPS used for this project, detailing critical uncertainties for NASA futures.

[39] The Aerospace Corporation Foresight Team adapted from L. Vandergriff, "Threadable CONOPS Overview—MBSE Scenario Development," The Aerospace Corporation, El Segundo, 2020.

A complete description of each variable input to the Threadable CONOPs and its possible states follows:

1. **Commercial Space Viability / Sustainability:** the economic health and independence of the commercial space sector.

    a. *Not viable* – the commercial space industry, and particularly the NewSpace industry, fails to achieve closure on its business models.

    b. *Limited, commercial / government partnerships* – the commercial space industry depends on the government to serve as an anchor tenant to maintain viability as a going concern.

    c. *Commercial operates independently (near-Earth)* – commercial space succeeds as a profitable industry independent of the government in near-Earth space (i.e., inside the Earth-Moon system).

    d. *Commercial operates independently (interplanetary)* – commercial space success as an independent profitable industry beyond the Earth-Moon system to other planets in the Solar System and possibly beyond.

2. **Earth Environmental Stability:** the general state of the Earth's climate, relative to the "crisis" status quo of 2020.

    a. *Uninhabitable* – the Earth becomes unfit for human habitation.

    b. *Crisis* – the Earth persists at the precipice of environmental collapse, with frequent destructive weather events and their associated impacts on agriculture and human migration.

    c. *Stable* – the Earth's climate stabilizes to a "normal" level of activity and volatility.

    d. *Healing* – the Earth's climate begins to reverse the negative effects of recent climate change.

3. **Domestic Politics' Influence on NASA:** the influence of the yearly budget request, congressional appropriation process, and administration changes on NASA priorities and missions.

    a. *No political interest in space* – politicians have no desire to continue using public resources on space exploration.

    b. *Full priorities flip from administration to administration* – at every quadrennial change in administration, all of NASA's priorities are changed, preventing most or any long-term investments to bear fruit.

    c. *Some priorities flip, others persist* – each flip in administration brings some changes to NASA's priorities, but others remain untouched across administrations.

    d. *Cross-administration / enduring priorities* – NASA's priorities persist from administration to administration.

4. **Human Presence in Space:** the status of human presence off-world and whether there is intentional to return to Earth for these populations or not.

    a. *No humans in space* – Neither nation states nor commercial industry maintain any human presence in space.

    b. *Occasional short-term visits to space* – Humans go to space on a short-term basis on an individual basis (e.g., the ISS can be consistently populated but with rotating personnel), limited mostly to near-Earth space

    c. *Space steading* – NASA and commercial industry maintain a constant and robust human presence in space, including long-term habitation by a single individual in space stations and outposts on the Moon. However, there remains an intent for any long-term resident in space to return to Earth at some point.

    d. *Interplanetary societies* – Long-term human developments on the Moon and Mars have evolved into their own societies and governments independent of their originating nations on Earth.

5. **Geopolitical stability:** the general geopolitical balance of power around the world and the nature of associated competition and conflict.

    a. *Conflict / turbulence* – armed conflicts vary among none, domestic, regional, global, and off-world.

    b. *Competition* – geopolitical competition among nations varies among monopoly (unipolar), bifurcation (bipolar), multipolar, and distributed (i.e., no clear dominant powers).

    c. *Cooperation* – the level of cooperation among nations varies among with allies only, with adversaries (i.e., alliances of convenience), ever-changing (i.e., moving in and out of different alliance blocs), and free-flowing (i.e., universal cooperation without blocs).

6. **Capability Gamechangers for NASA:** technology breakthroughs that could fundamentally change NASA's capabilities or mission profile.

    a. *Hypersonics* – technology is available as R&D only, for government / military use only, or has scaled to widespread commercial use.

    b. *AI systems* – AI exists for narrow applications (e.g., image recognition), in general use (e.g., managing city infrastructure), and as super-AI (i.e., capable of creative thought and creating new AI itself).

    c. *Interplanetary transportation* – travel between the moons and planets of the Solar System occur via traditional means (i.e., months- or years-long times of flight via chemical or electrical propulsion), transformative means (i.e., up to interstellar-relevant speeds[40]), or revolutionary means.

[40] Such as those proposed in Project Orion (theorized up to 11% speed of light) or Project Daedalus (theorized up to 12% speed of light)

d. *Green flight* – Earth-bound aviation develops environmentally friendly fuels and propulsion technologies ranging among minor incremental improvements, zero emission, or actively beneficial to the environment.

e. *Metaverse* – the adoption of the metaverse varies among sparing use, recreational use, and fully integrated into day-to-day life.

f. *Clean energy* – new clean-energy technologies available for global use include widely scaled renewables (e.g., wind and ground-based solar), fusion power, or space-based solar.

g. *Synthetic biology* – advances in bioengineering vary among the following: substitution (e.g., organ transplants from animals to humans), restoration (i.e., advanced healing of damaged organs), regenerative (i.e., growing new organs *de novo*), or augmentation (i.e., development of organic or artificial implants to enhance human resilience or performance).

For the development of scenarios in the Four Futures model, the foresighting team created four Threadable CONOPS with a varying selection of the input states. These selections are designed to (1) align with the model's four archetypes (growth, discipline, decline, and transform) and (2) cover as much space as possible with diverse combinations of possible future states.

6.3 Scenarios Overview

This section reviews the four corner-case scenarios and the complementary "baseline" scenario, which captures a projection of the current environment. The purpose of this scenario development is **not** to predict the future, nor is it fruitful to assign probabilities or qualitative assessments of likelihood to different possible futures. Instead, scenarios explore corner cases of the future space, where organizational strategies are most greatly stressed. Consequently, the four scenarios are **intentionally thought-provoking** and **sometimes provocative**. But they are within the realm of the (future) possible. Incorporating these scenarios into strategy formulation helps ensure organizational resilience to a volatile and uncertain future.

Scenarios developed with the Four Futures Model take the form of narratives that conform to four archetypal themes: growth (where the future develops along trends similar to the present), discipline (where behaviors must adapt to growing internal or environmental limits), decline (the system degrades or fails as crises emerge), and transformation (new technology, business, or social factors "change the game") as shown in Figure 16. The scenarios culminate with a series of key focus questions prompted by the narrative. These focus questions provide NASA with a starting point for vision-setting and goal prioritization in the strategy-development process.

When reviewing these scenarios, the reader should resist the temptation to judge them on their likelihood. None of these scenarios in full will happen in the real world. Some parts of *all* of them are likely to occur in the coming decades, but we cannot know which parts. Consequently, the exact particulars of the scenarios are not as important as the key focus questions that emerge from them. These questions help synthesize the bottom-line implications of the scenario to NASA's future strategic direction.

Progression through the future is driven more by where in "waves of transformation" (discussed in Section 1) the future is and less by set years or time passage. References to specific years in the scenarios are there to anchor the reader. These scenarios explore the transition from the "exploration epoch" to the "commercial epoch" with brief discussions of the "settlement epoch."

Figure 16. Graphical depiction of Four Futures scenarios developed.

6.3.1 Baseline

Due to the complexity of the trade space, a separate baseline (the projected future state given current trends and trajectories) is included. The Threadable CONOPS for this baseline appears in Figure 17, where the selected future states are highlighted in green. For the baseline scenario, the following states are expected during the transition from the first to the second wave of transformation:

- **Commercial viability**: Commercial space companies will be economically viable and operate independently of the government market for near-Earth (in-orbit and lunar) applications.
- **Earth environmental stability**: The climate will continue in "crisis" relative to the status quo of 2020.
- **Domestic politics influence on NASA**: Like today, NASA will continue to see some priorities changing (leading to program stop/starts) from administration to administration with others enduring across administrations.
- **Sustained human presence**: Occasional short-term visits and continued sustained orbital (e.g., like ISS or even lunar orbit) are expected; however, there is no expectation of off-world societies/routine long-term travel outside of the Earth-moon system.
- **Geopolitical stability**: Continued regional conflict is expected to continue through the "settlement epoch" with competition happening on a multipolar basis. This leads to the possibility that a "new global power" outside of current powers may emerge with space expected to be an important consideration for nation-states. Finally, cooperation is expected to only exist among allies, similar to the current state, with the potential for even more pullback from non-ally cooperation.

- **Capability gamechangers for NASA**: Hypersonics, AI systems, interplanetary transportation, green flight, and the metaverse are expected to continue having gradual improvements with no large increase in capabilities outside of current efforts. However, it is expected that clean energy will continue to have substantial investment and renewable options (including, but not limited to, wind and solar) will have been scaled to provide a substantial fraction of the necessary worldwide energy. Additionally, large improvements in synthetic biology leading to routine "substitution" and "restorative" techniques are expected.

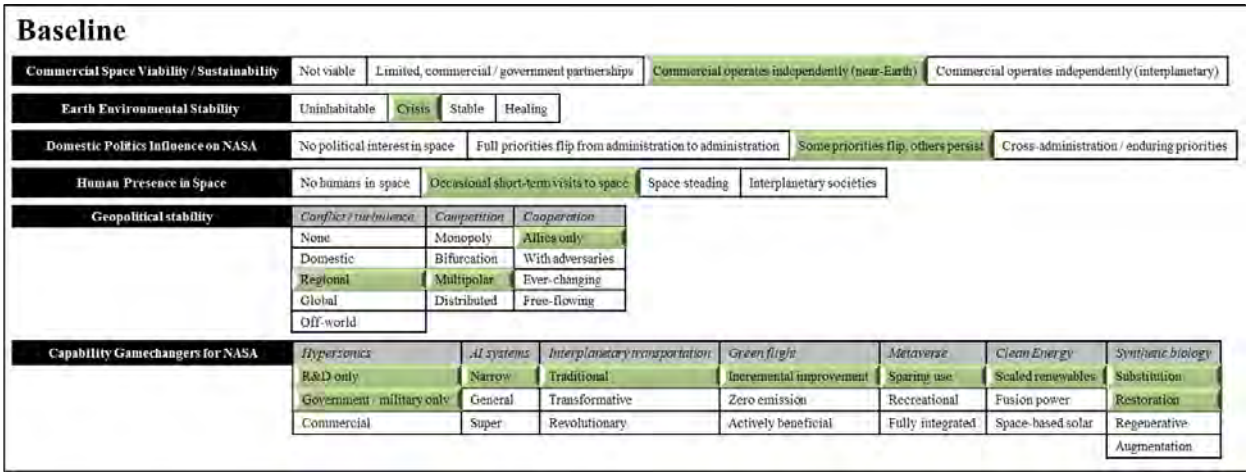

Figure 17. Baseline Threadable CONOPS.

The Baseline scenario does not include a full narrative. Rather, the Baseline Threadable CONOPS in Figure 17 provides a reference point for the corner cases in the subsequent sections.

6.3.2 Growth

A growth scenario assumes business as usual and continued development of the environment in the vein of the status quo. The growth scenario Threadable CONOPS for this project appears in Figure 18. For our growth scenario, the following input states were selected:

- **Commercial viability**: Commercial space companies will be economically viable and operate independently of the government market for near-Earth (in-orbit and lunar) applications.

- **Earth environmental stability**: The climate will continue in "crisis" relative to the status quo of 2020.

- **Domestic politics influence on NASA**: Like today, NASA will continue to see some priorities changing (leading to program stop/starts) from administration to administration with others enduring across administrations.

- **Sustained human presence**: Humans will have become a space-steading species with routine long-duration off-world and interplanetary trips; however, the intention for these humans to return to Earth remains.

- **Geopolitical stability**: A potential growth scenario involves the development of a global conflict with bifurcated and multipolar competition. Additionally, like the baseline, only cooperation with allies continues.

- **Capability gamechangers for NASA**: In the growth scenario, narrow AI systems, zero emission aviation/flight, space-based solar power, and substitutive/restorative synthetic biology are the driving capability gamechangers for NASA.

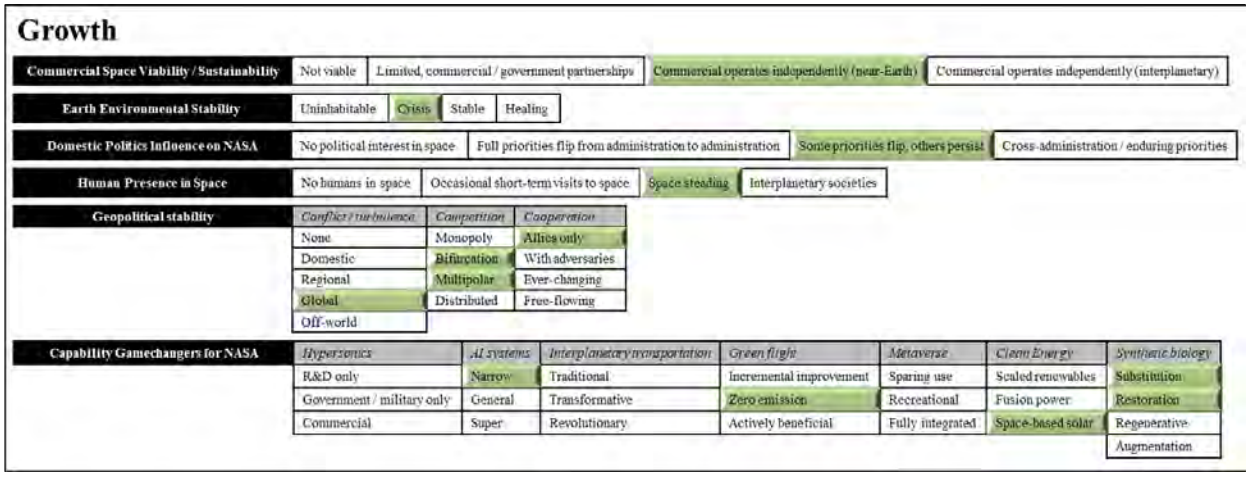

Figure 18. Growth Threadable CONOPS.

The combination of these future states led to a growth scenario titled "**Commercial Space in the Driver's Seat**" with a tagline of "Bringing space into our economic realm." The foresighting team first developed key themes for the growth scenario based on the Threadable CONOPS selections:

- The private sector has commoditized human spaceflight between Earth and the moon
- There has been an industrialization of LEO: pharmaceuticals, organs, fiber optics, and food are all economic markets that exist
- There is limited commercial interest in exploration as profitable ventures closer to Earth snag attention
- NASA has divested much of its infrastructure from previous decades and is left at disadvantage
- Global mobility on Earth is on the rise thanks to scaling of suborbital flights
- There are intermittent global conflicts that extend to space, and sovereignty remains untested

Using these themes, the growth scenario's narrative follows:

> *Spurred by immense capital investment and resilience to loss-of-life setbacks that would have crippled purely government ventures, the private sector successfully commoditized human spaceflight in the Earth-moon system by the "commercial epoch". The first boots on Mars also came from the private sector, but there was little commercial appetite to return without a substantial reduction in travel time. Commercial interest in pure exploration—even as a government contractor—dwindled in favor of profitable ventures closer to Earth. These new circumstances left NASA at a substantial disadvantage, having divested much of its exploration infrastructure to industry in the preceding decades.*

Commercial space focused primarily on the industrialization of LEO, aided by additive manufacturing of both full satellites and organic materials, and leveraged breakthroughs that made it economically viable to manufacture many goods in LEO. Manufacturing of pharmaceuticals, artificial organs, fiber optics, and some food production moved to LEO. On-orbit assembly, servicing, and refueling enabled new paradigms of architecting and sustaining large-scale infrastructure on orbit, while advances in AI and autonomy led to its increasing role in day-to-day maintenance of on-orbit facilities. The greatest limit to future expansion, still unsolved several decades in the future, is the existential risk of space debris and on-orbit collisions.

The scaling of suborbital and orbital flight paved the way for routine anywhere-to-anywhere travel at incredible speed, such as Delta Air Lines' inaugural Atlanta-to-Perth route in 2041 with a flight time of 90 minutes. Suborbital flights also led to an increase in global mobility overall, exploding the tourism industry. Smaller countries that historically relied on tourism flourished into the 2060s and expanded to space tourism as a new market to expand their GDPs, giving rise to new national space programs and additional launch sites. However, this rapid rise in nation-state space acts also triggered an expansion of the Wolf Amendment, and space became increasingly balkanized between countries aligned with China and those with the United States.

Into the 2050s, much of the global population had been impacted by disruptive climate events and socio-political turmoil, which triggered intermittent global conflicts. With so much national infrastructure moved into orbit, the expansion of these conflicts to space was inevitable. Manufacturing, space-based solar power, communications, and remote sensing satellites became regular targets, and a strike on a space hotel in 2047 led to the first human fatalities in space conflict. To protect commercial interests and their citizens both in orbit and on the Moon, China and the United States—and their respective aligned blocks—withdrew from the Outer Space Treaty in 2055. Several decades in the future, many orbital and lunar settlements are considered sovereign territory of their originating nation, but no one has yet been willing to test the integrity of that sovereignty.

From a strategic resiliency perspective, this scenario gives rise to the following key questions for NASA to consider more broadly:

- **What would NASA do if commercial industry was almost fully leading commoditized exploration and setting priorities for exploration?**
- **What should NASA's role be in a world where space war, including human casualties, is normalized?**
- **Should NASA take on a bigger role in ensuring flight safety?**

6.3.3 Discipline

A discipline scenario requires behaviors to adapt to growing internal or environmental limits. This project's discipline scenario Threadable CONOPS is in Figure 19. For the discipline scenario, the following inputs were selected:

- **Commercial viability**: There has been a commercial space bubble with no economically viable markets and the main customer for all remaining private space companies is the government.

- **Earth environmental stability**: The climate will continue in "crisis" relative to the status quo of 2020.

- **Domestic politics influence on NASA**: There has been a shift in domestic politics influence with NASA having cross-administration continuity and enduring priorities across the board.

- **Sustained human presence**: There will be no long-term or short-term visits to space.

- **Geopolitical stability**: In the discipline scenario, there will be both domestic and regional conflicts with continuing multipolar competition.

- **Capability gamechangers for NASA**: In the discipline scenario, narrow AI systems, traditional means of interplanetary transportation, regenerative green flight, and a fully integrated metaverse are the driving capability gamechangers for NASA.

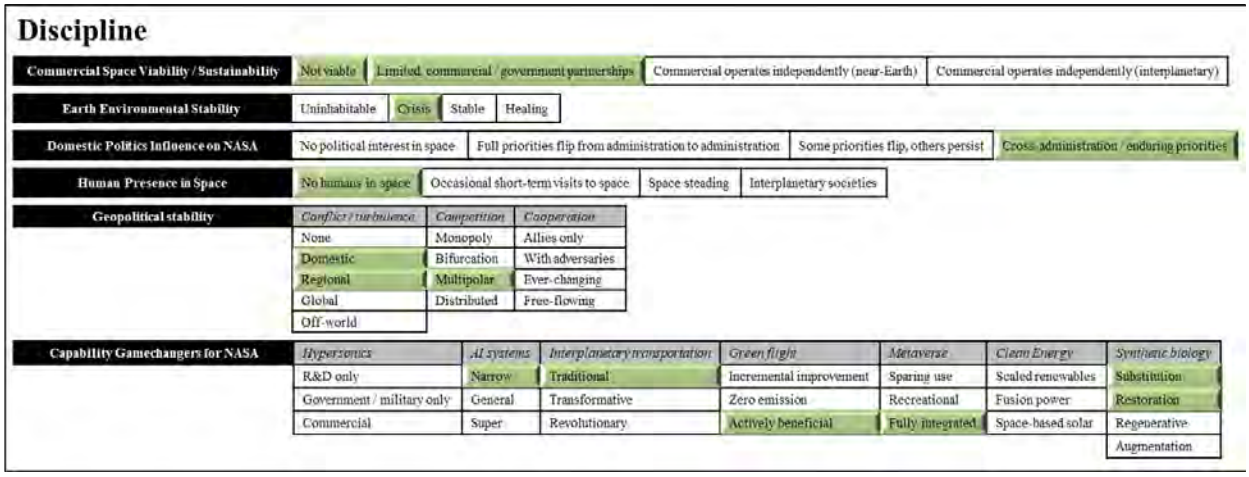

Figure 19. Discipline Threadable CONOPS.

The combination of these factors led to a discipline scenario titled "**Retreat from the Final Frontier**" with a tagline of "An impoverished and immobile population escapes into the metaverse." The key themes developed for the discipline scenario were:

- The private sector has failed to establish commercial viability amidst global depression

- A push for greener fuels gives rise to slower but more eco-friendly air and space transportation capabilities

- The metaverse becomes fully integrated into society, reducing desire for physical exploration of space, but it also offers the opportunity to scale experience to the masses

- Advanced connectivity allows for new opportunities for citizen science

- Telemedicine is delivered through the metaverse

Using these themes, the growth scenario's narrative follows:

> *A continuing global depression that began in 2023 continues through late 2027. Partially due to this recession, the private sector fails to establish a commercially viable market for any space application beyond those that existed in the late 20th century. Venture capital pulls its money out of the space industry, triggering a substantial setback for the government, which had become reliant on commercial providers for launch and had to speedily reintegrate these capabilities into its own portfolio.*
>
> *Acting on continued concern about the climate, the U.S. government sets the ambitious goal of transitioning out the use of all traditional jet and rocket fuels by 2035. This prioritization of emission control over travel speed shifts air travel time from New York to London to 40 hours using lighter-than-air aircraft, and space travel time from Earth to the moon balloons to one year via the mandated use of clean propellants with electric propulsion. Only one or two astronauts can travel per year to maintain lunar assets, while autonomous systems maintain most space assets.*
>
> *On Earth, the scaling of the metaverse accelerated the reduction in air travel. This immersive virtual environment became fully integrated into society, reducing the need and desire for human spaceflight. The workforce retreats completely into a virtual world, and human connections driven by virtual interaction is the accepted norm. Through the metaverse, children can attend Space Camp on the moon and support experiments there without leaving the couch. This gives rise to a new branch of citizen science with new visualization techniques, engaging very large audiences in science. Breakthroughs in telemedicine delivery through the metaverse only enhance the retreat from the physical world.*

From a strategic resiliency perspective, this discipline scenario gives rise to the following key questions for NASA to consider more broadly:

- **How should NASA move forward if there's no commercial sector to leverage?**
- **How should NASA approach exploration when there's little interest/need for human spaceflight?**

6.3.4 Decline

In a decline scenario, the system degrades or fails as a crisis emerges. The decline scenario's Threadable CONOPS for this project is in Figure 20. For the decline scenario, the following inputs were selected:

- **Commercial viability**: Commercial space companies will be economically viable and operate independently of the government market for both near-Earth (in-orbit and lunar) and interplanetary applications.
- **Earth environmental stability**: The climate will have stabilized such that the climate crisis is no longer worsening; however, other factors will make Earth uninhabitable.
- **Domestic politics influence on NASA**: NASA is working in a domestic political environment where priorities for the Agency are shifting completely from administration to administration.
- **Sustained human presence**: Society will be space steading with routine long-duration travel off Earth. Due to the decline of Earth's habitability, society will also quickly become interplanetary.

- **Geopolitical stability**: Conflict has moved to off-world society with competition distributed between many nation-states.

- **Capability gamechangers for NASA**: In the decline scenario, scaled commercial hypersonics, general AI systems, a fully integrated metaverse, and access to abundant clean energy are the driving capability gamechangers for NASA.

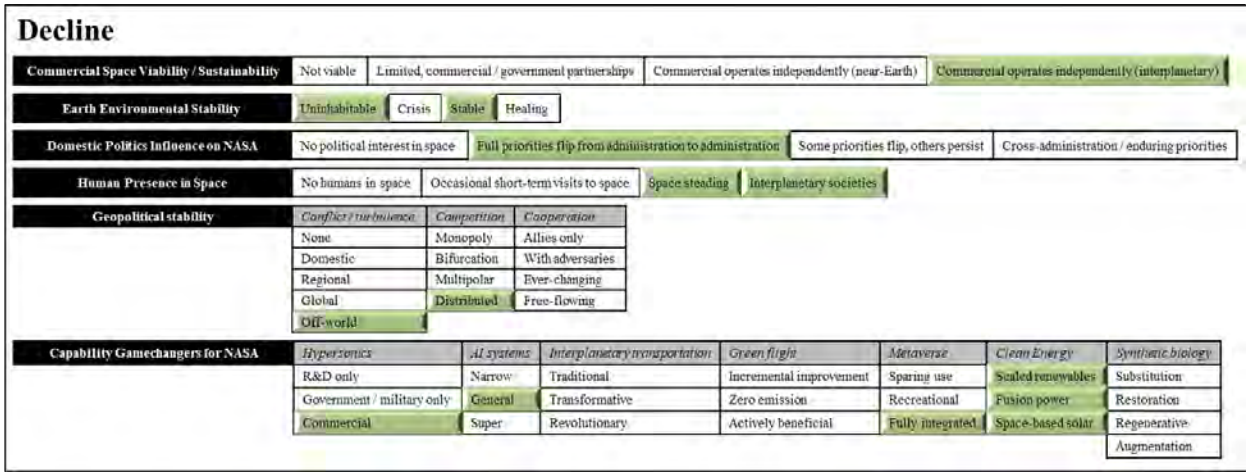

Figure 20. Decline Threadable CONOPS.

These factors led to a decline scenario titled "**Blamed for the Big One**" with a tagline of "NASA loses public trust." The key themes for the decline scenario were:

- NASA detects an asteroid that will impact Earth but believes the asteroid is not large enough to cause a disaster.

- New analysis shows the asteroid is larger than expected and hits close to the west coast, causing widespread devastation.

- NASA is immediately blamed for being wrong about the impact, not taking any action to deflect the asteroid, and actively encouraging the public not to worry.

- Congress funds a private consortium to establish and lead space settlements on Mars and orbiting platforms to "hedge our bets" against all humans living vulnerably on Earth.

- Public trust in science plummets, and STEM programs see a major reduction in enrollment.

- The commercial sector puts 10,000 people on Mars by 2055.

- Far in the future, conflict breaks out between people on Earth and orbiting waystations and the base on Mars.

Using these themes, the scenario narrative follows:

> *In the mid-2030s, NASA detects an asteroid that it believes will impact Earth in about five years. Based on analysis, NASA believes that it will hit the middle of the Pacific, and that the asteroid is not large enough to cause a tsunami or a substantial impact to civilization. NASA decides to not*

take any measures to attempt to deflect the asteroid based on this analysis and communicates aggressively with the public that there is no need for worry or action. In late 2041, about one month prior to impact, new analysis shows the asteroid is larger than originally estimated and will hit closer to the west coast than expected. The 1 km asteroid impacted the Pacific Ocean between the continental United States and Hawaii, triggering a catastrophic tsunami. NASA was immediately blamed for being wrong about the impact, not taking any action to deflect the asteroid, and actively encouraging the public not to worry. In response, Congress began to apply oppressive oversight on all NASA activities.

Fear of another surprise impact drove nations with space-faring capabilities to consider relocating parts of their population off-world. The U.S. Congress, frustrated by NASA's stagnation and focused on getting humans off the planet as quickly as possible, raided most of NASA's budget and stood up a private consortium to fund and establish new space settlements both on Mars and in orbiting platforms.

The continuing rise in lack of public trust of science reduced the overall enrollment and graduation rate in STEM education. Coupled with an unattractive government employer, the market was starved for talent. The private sector had to scale immensely to establish humanity off-world and found means to leverage talent in nontraditional ways, such as apprenticeships and rapid-certification programs. Space was no longer just for a workforce comprised of people with formal STEM degrees.

Building upon the successful proof-of-concept settlement on Mars about a decade after the impact, the commercial sector successfully transplanted 10,000 people there within a few years. The full integration of MarsNet, a digital data highway infrastructure connecting Earth and Mars, enabled those settlers to maintain their Earth-based jobs for the first three years. Slowly, the Mars settlers began to focus inwards on their community as they demonstrated self-sustainability. A key enabler of that sustainability was human-machine teaming supported by general AI. By the late 2050s, people had become desperate to get off Earth; however, the Mars settlement had not yet scaled to accommodate that large a population. Tensions rose as hundreds of thousands of settlers waited in orbiters around the moon, but the Mars colony denied landing rights. A war broke out with people still on Earth (mainly those without resources to leave) sided with those in orbiters, attacking the base on Mars.

Finally, from a strategic resiliency perspective, this scenario gives rise to the following key questions for the Agency to consider more broadly:

- **What are areas that NASA has full responsibility for and that threatens its brand and public trust?**

- **Whose role is it to govern off-world settlements and secure property rights when commercial is leading the effort?**

6.3.5 Transform

In the transform scenario, new technology, business, or social factors fundamentally "change the game." This project's transform scenario Threadable CONOPS is in Figure 21. For the decline scenario, the following inputs were selected:

- **Commercial viability**: Commercial space companies will be economically viable and operate independently of the government market for both near-Earth (in-orbit and lunar) and interplanetary applications.

- **Earth environmental stability**: The climate crisis will be in "healing" mode with a trend towards returning to historically expected levels.

- **Domestic politics influence on NASA**: There has been a shift in domestic politics influence with NASA having cross-administration continuity and enduring priorities across the board.

- **Sustained human presence**: Society will have fully established its off-world presence with societies both on- and off-world.

- **Geopolitical stability**: There will be no conflict with competition distributed between many nation-states.

- **Capability gamechangers for NASA**: In the transform scenario, revolutionary interplanetary transportation methods, a fully integrated metaverse, and fully scaled synthetic biology for all applications are the driving capability gamechangers for NASA.

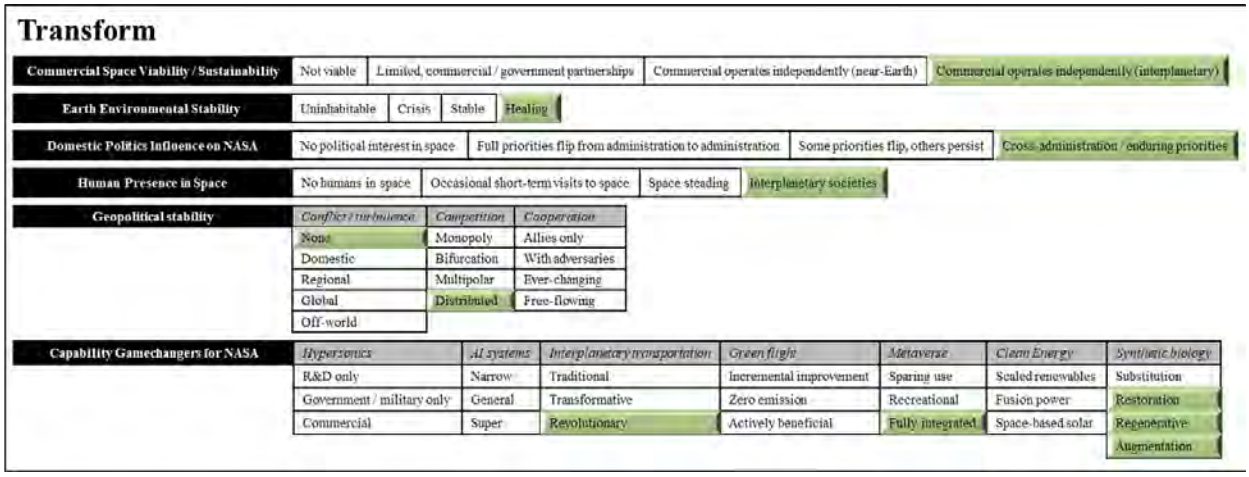

Figure 21. Transform Threadable CONOPS.

The combination of these factors led to a transform scenario titled "**Children of Space**" with a tagline of "Expansion to an interplanetary society." The key themes for the transform scenario were:

- A major breakthrough in high-speed space travel is found

- Significant profits are being made off mining platinum from an asteroid

- This leads many wealthy people to move to live off-world

- The commercial sector has experimented with DNA modification of humans to enhance their livelihood and reproductive capabilities off-world

- As humankind transitions to living off-world, the drain on Earth-based resources is reduced and the climate crisis issues begin to stabilize and eventually reverse trends

- AI and quantum sensors detect a potential AI signature from another galaxy

The discipline scenario's full narrative follows:

> *In 2030, a major breakthrough in space traveling capabilities is made and we can now travel at revolutionary speeds throughout the solar system. The first trillionaire is established when someone finds an asteroid with significant amounts of platinum and mines the resource for use on Earth. By 2035, many wealthy people choose to live off-world as it gives them access to incredibly lucrative market. To scale these new space companies, they must set up full settlements to support operations. This leads to commercial companies exploring and solving biological challenges of long-duration spaceflight and living off-world. Solutions to these issues included genetic modification to ensure effective off-world reproduction, shots that change our DNA to withstand/reverse radiation impacts, and successful demonstration of re-wiring of the brain to be resilient to new psychological environments. Additionally, companies begin to leverage AI more and more to help expand their growing space enterprises. A byproduct of the establishment of off-world companies is a substantial reduction in the strain on global infrastructure as there are fewer people to support and resources coming from other worlds. This solves the climate crisis with temperatures on average dropping to statistical 1000-year averages. This crisis-aversion leads to a new sense of global stability (if it lasts is another story).*
>
> *In 2045, a next-generation telescope is developed, equipped with AI and quantum sensors. This enables incredibly sensitive measurements and quick data analysis to determine exactly what it is finding. The settlement near Neptune, initially established by Japan, deploys the telescope, and a techno-signature from another galaxy is discovered. A mission to investigate this discovery is sent from the settlement a decade after discovery, with a goal of returning with definitive results within a decade.*

From a strategic resiliency perspective, this scenario gives rise to the following key questions for NASA to consider more broadly:

- **What is NASA going to do if/when life is discovered off planet?**
- **What if NASA is not the organization to discover life off Earth?**
- **What roles and responsibilities are NASA expected to have?**
- **What ways NASA could be viewed as a failure?**

6.4 Scenario Analysis

After the development of each scenario, these corner cases were analyzed to determine implications for NASA and potential resilient strategic options. To begin, each scenario was analyzed against seven key criteria to determine potential strategies for response to the given scenario. Challenges, opportunities, and implications were identified against each criterion and fed into the development of potential macro-strategies for NASA. The seven criteria were:

1. *Mission*: Defining the "why" behind the activities and nature behind how NASA pursues them

2. *Resourcing*: How much budget is needed for NASA activities and how is it allocated internally, particularly with respect to other key areas (e.g., workforce, culture, innovation)?

3. *Organizational effectiveness*: How impactful are the tangible outcomes of actionable intelligence and execution? How is efficiency calculated to best support agility, adaptiveness, and teaming?

How much are initiatives designed for change versus designed to last (scalable, adaptable, modular)?

4. *Workforce/talent*: How is NASA able to find the right alignment and balance of expertise when and where needed? How is NASA able to navigate the current talent market, any generational divides within the workforce, and geopolitics? How is NASA able to retain talent and able to meet the workforce needs (e.g., new way of work, DEI)?

5. *Leadership*: What broader vision and communication exists, and needs to exist, to drive the organization forward in a unified way? Is the workforce and leadership aligned and does leadership have enterprise-wide buy-in to their vision?

6. *Culture*: What are the organizational tendencies, beliefs, and approaches in how the work is done? What incentives drive the workforce and organization?

7. *Innovation*: How does NASA access innovation (e.g., internally, partnering, leveraging commercial developments)? How does NASA create an innovation ecosystem? Who has the technical advantage and available technology?

Table 9. Analysis Table of Each Scenario against Seven Key Criteria, with Potential Challenges, Opportunities, or Implications for Each Criterion

Scenario	Mission / Purpose	Resourcing	Organizational Effectiveness	Workforce / Talent	Leadership	Culture	Innovation
Growth "**Commercial Space in the Driver's Seat**"	Focus on far-flung exploration; large emphasis on science & technology			Potential opportunity to reevaluate how to retain talent with retention being a key challenge	Need leadership who is open to championing change	NASA needs to ensure culture is well known to attract talent and has opportunity to set norms for safety and governance	NASA needs to develop a better international strategy and learn how to leverage commercial
Discipline "**Retreat from the Final Frontier**"	Opportunity to engage public more in mission in non-traditional ways; what should NASA's role in climate be?		NASA has opportunity to lead government into this new metaverse and establish a new way of interacting with citizens	Challenge to attract the best and brightest—how to get people to leave metaverse		Opportunity to shift culture towards virtual engagement	
Decline "**Blamed for the Big One**"		Need to adjust to a severely constrained environment	NASA has huge opportunity to make a comeback	Ability to attract new talent will be extremely challenging—will need to take an innovative approach	Leadership must lead NASA through tough times—show workforce there is a path through		Must drive innovation internationally to help get people off Earth
Transform "**Children of Space**"	Opportunity to re-shift focus if desired	Higher focus on astrobiology likely			NASA could lead governance conversation for off-world settlements		Re-think approach to partnerships

Table 9 shows the results of this analysis, which was performed by Aerospace SMEs and the Aerospace foresighting team and serves as the foundation for the development of strategic options. For example, a loss of public trust is the core theme of the decline scenario, and the analysis team noted in Table 9 that a challenge stemming from that scenario is that the "ability to attract new talent will be extremely challenging—will need to take an innovative approach" under the workforce / talent criterion. The result is a candidate strategic option, "substantial effort to increase value proposition for attracting and sustaining talent." That strategic option is also supported by inputs from the roundtables and interviews:

- The roundtables and horizon scanning, which revealed societal trends such as challenges hiring and retaining STEM talent, demand for more benefits in the workplace, and the alignment of job and personal values, as detailed in Section 3.2, Detailed Observations from Internal Roundtables, and Detailed Observations from External Roundtables

- NASA executive interviews, which included quotes such as, "[NASA needs to] recognize experts to keep them from leaving, invest in training and development, quality of life, flexible and agile, and facilities that will attract people" and "[NASA should invest in its] infrastructure plus the people – if we can't get access to people and they aren't attracted [to work at NASA] because NASA isn't [an] awesome place to come – but people need to have a good place to come to."

The foresighting team used this analysis process to generate a total of **15 strategic options, which appear in Figure 22**. All these strategic options rest on the triad of inputs: (1) an internal review of the scenarios by Aerospace as captured in Table 9, (2) the roundtable exercises with NASA staff, and (3) interview feedback from NASA executives. Strategic Options and Supporting Roundtable Inputs includes a detailed breakdown of each strategic option's heritage from the roundtables and interviews.

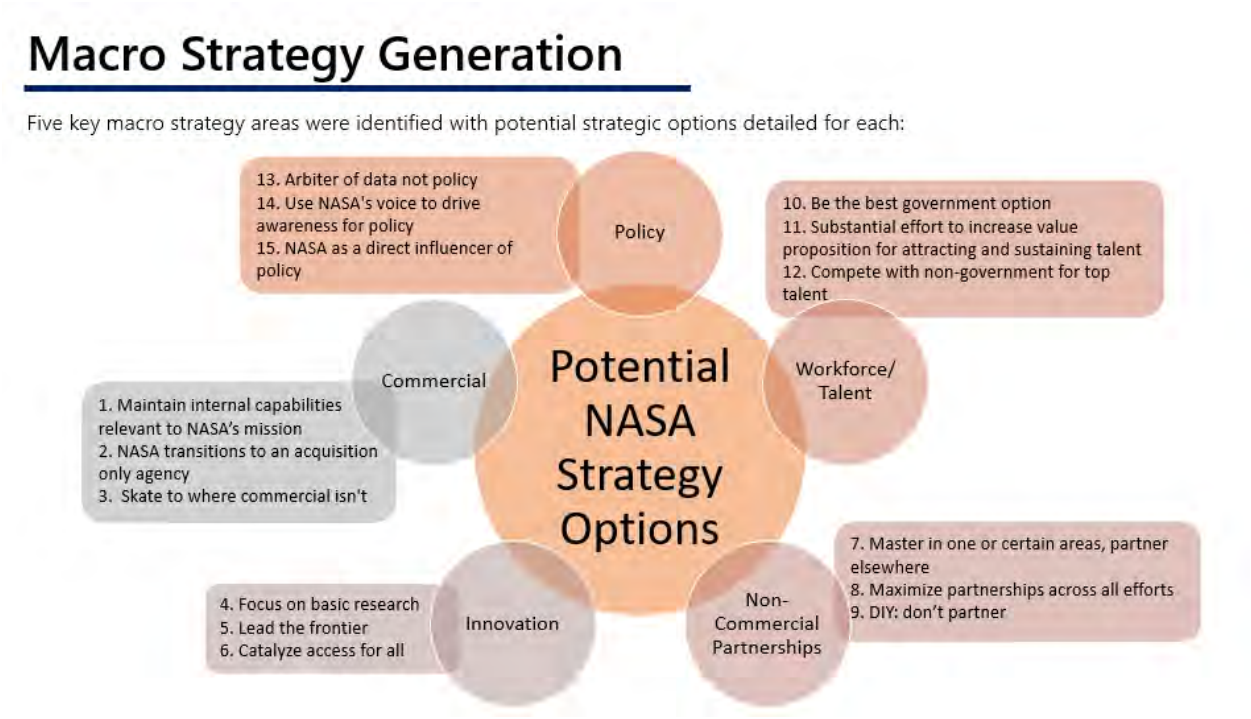

Figure 22. Possible strategic options for the five categories that NASA could pursue. These strategies are further analyzed for their resilience in the next section.

The 15 strategic options are grouped into five categories: commercial, innovation, non-commercial partnerships, workforce/talent, and policy. Some of these strategic options are mutually exclusive, and others are not. For example, strategic options #8 ("Maximize partnerships across all efforts") and #9 ("DIY: don't partner") cannot be pursued simultaneously, as they capture two extremes on the spectrum of possible non-commercial partnership strategies. Any single strategy cannot be considered in isolation, and NASA cannot adopt all of them.

The strategic options and categories in Figure 22 are only starting points for strategic development and are not exhaustive. A discussion about each of these may yield relevant information in the context of resilience. Further work remains in strategic formulation and planning activities to refine this initial list and develop larger-scale macro strategies that can be evaluated against the scenarios in this work for resiliency and efficacy. For reference, see Strategic Options and Supporting Roundtable Inputs for the strategic options parred with their supporting inputs from the roundtables and executive interviews.

After development of these strategic options, the question remains whether or how each provides resilience across the diverse futures considered in the scenario development. This question was tackled in two steps:

1. The strategic options were each analyzed for viability and resilience against each scenario.

2. The scenarios' relevance and resilience were compared against the level of organizational transformation needed to realize them (a proxy for the options' risk). This allowed strategies to be identified that provide the greatest resilience while requiring the least organizational change (or, the least risk).

The results of this analysis are presented in Section 7.

7. Cross-Futures Assessment

In this section, we present the results of the cross-scenario analysis of potential strategy options and their assessment of performance across each scenario. The strategies analyzed are not an exhaustive set of strategic options. The analysis presented here is a framework for future macro strategy formulation. By combining multiple strategies together, a high-level enterprise strategic goal can be formulated. Many of the strategies presented are not mutually exclusive (i.e., could be adopted together in a holistic NASA organizational strategy), but some are exclusive and cannot be pursued simultaneously.

Each of the 15 candidate macro strategy options was evaluated against two metrics: (1) the number of scenarios where the strategy would position NASA more strongly to survive and thrive in the possible future of the scenario and (2) the degree of transformation required of NASA to pursue that strategy. The degree of transformation was broken down into four categories:

1. Current practice: Strategies or policies that NASA follows today

2. No regrets: Strategic options that NASA could adopt with little or no downside and minimal cost

3. Middle of the road: Strategic options that would require some organizational or cultural change at NASA and may have some opportunity cost

4. Big leaps: Strategic options that would signal a substantial change in NASA organizationally or culturally, would require NASA to expend political capital, and/or would demand a large realignment of resources

Both metrics were evaluated by the team based on a review of the strategic option itself, the scenarios, and feedback from roundtable interviews that provided insight into current perceptions of NASA's risk aversion and willingness to change (see, for example, discussion of the futures baseline in Section 6.3.1). The detailed scenario coverage assessment appears in Table 10. The table lists each strategic option and, for the four corner-case future scenarios, marks those scenarios where the strategic option would provide organizational resilience and continue to guide NASA towards its desired future states, as discussed in Section 5.2. In the final column, each strategic option is binned for its degree of organizational transformation, from 1 (current practice) to 4 (big leap).

Although it may initially appear that organizations should optimize for the lowest degree of transformation, this is not advised in an ever-changing environment. Every organization needs to take some big leaps, but not every strategic decision should be a big leap. An organization will benefit from a mix of strategies across different degrees of organizational transformation, albeit with a weighting towards the lower end (i.e., current practice).

For example, Table 10 identifies strategic option #2 ("NASA transitions to an acquisition-only agency"), in which NASA employees are not actively building or integrating in house or operating spacecraft, as resilient for the growth and decline scenarios. In the growth scenario, transition to an acquisition-only strategy would free up resources from in-house build and operations to contract out to increasingly dominant commercial capabilities. In the decline scenario, an acquisition-only NASA would have been more insulated from the loss of public trust, having shifted many of its current responsibilities onto industry, and been in a stronger position after the disaster to stand up the acquisition of a large-scale off-world resettlement effort. In contrast, an acquisition-only strategy would prove highly disadvantageous in the discipline scenario, because in that scenario there was no surviving commercial space industry to contract. And in the transform scenario, the acquisition-only model would hamper NASA from pursuing an aggressive exploration regime in the newly accessible Solar System, being constrained to the set

offerings of commercial industry in this future and less capable of fielding the necessary custom capabilities for exploration. Overall, the team assessed this strategy as being a "big leap" organizationally, requiring a substantial culture change within NASA, a large-scale realignment of resources, and likely a change in political priorities for NASA from Congress.

After each strategic option was assigned values for the two metrics (i.e., scenario resilience and degree of transformation), they were assembled into the 4 × 4 grid in Figure 23, where the number of scenarios covered by the strategic option is on the horizontal axis and the degree of transformation on the vertical axis.

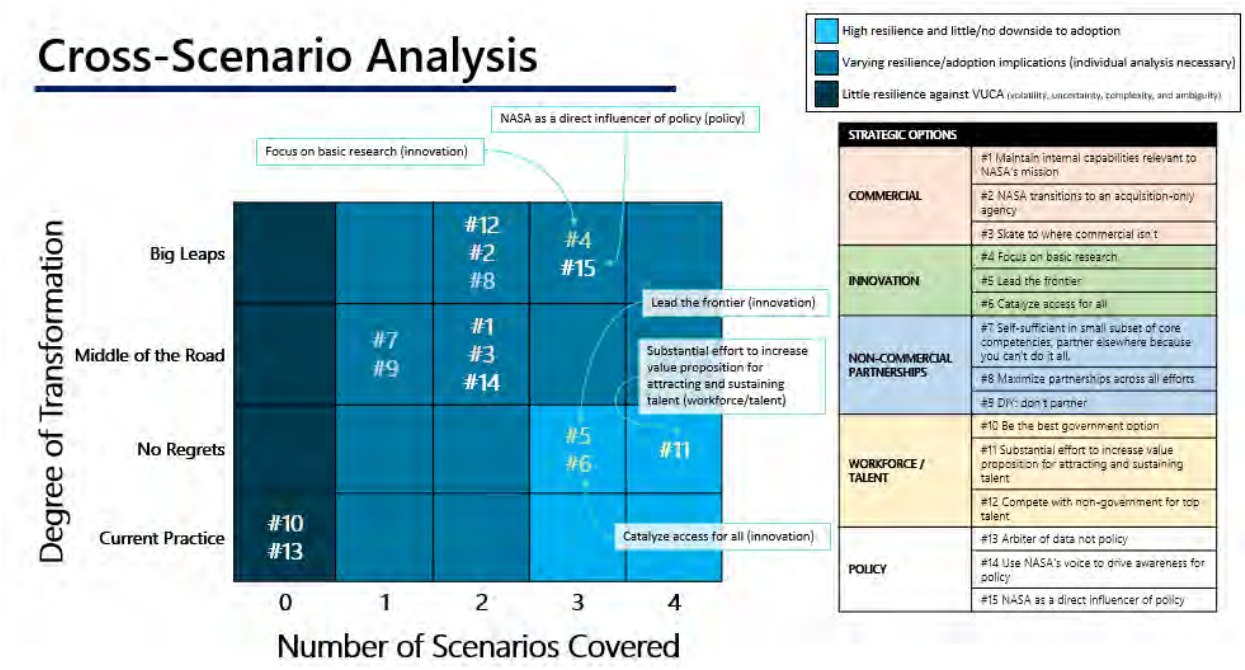

Figure 23. Scenario assessment on resiliency and degree of transformation for NASA.

The preferred strategic options are those in the lower right corner of the grid, where the largest number of possible future scenarios are covered and where the least amount of organizational transformation (i.e., current practice or "no regrets") is needed. **Three strategic options are** i**n this preferred region of the grid, being highly resilient and with little or no downside to adoption:**

- **#5 Lead the frontier (i.e., go as far and fast as possible, explore the unknown where no one else is)**
- **#6 Catalyze access for all (i.e., enable mechanisms for significant part of society to participate in exploration and science)**
- **#11 Increase the value proposition for attracting and sustaining talent**

This analysis suggests that pursuing these three strategic options could strongly position NASA in the face of a volatile and uncertain future without the need for a major shift in culture or resources. These three strategic options differ from NASA's ostensible current practice. For example, NASA's role in exploration is undisputed, but strategic option #5 (lead the frontier) envisions an approach that prioritizes revolutionary innovation and exploration over incremental advancements and where other civil or

commercial interests are deliberately encouraged to take over after each frontier has been reached. Furthermore, NASA is already well regarded for its educational and public outreach, but strategic option #6 (catalyze access for all) is a more comprehensive approach where the public would take a more direct and meaningful part in NASA's exploratory mission, as opposed to being simply a consumer of media. Lastly, strategic option #11 (increase the value proposition for attracting talent) involves not only creating direct incentives for retention (e.g., compensation) but also restructuring the organization to improve employee satisfaction (e.g., geographically distributed employees doing work for any center) and including metrics for the potential for talent attraction and retention in the projects that NASA pursues.

In contrast, two strategic options that are current practice were not resilient to any of the considered future scenarios:

- #10 Be the best government option (i.e., excel at providing the best work environment in the U.S. government)

- #13 Arbiter of data and not policy (i.e., NASA presents or provides data, but does not get involved in policy formulation or decisions)

Resilience against the considered corner-case scenarios demanded more proactive strategic approaches. NASA is widely regarded today—and reflected in the sentiments of both the internal and external roundtables—as one of the most desirable places to work in the U.S. government. However, the talent landscape is rapidly changing, and the scenarios indicate that this approach may be insufficient. Additionally, NASA is a go-to resource for large amounts of archived research data, documentation, scholarly writings, and best practices. But the scenarios suggest that unduly focusing on being only provider of data prevents NASA from positioning itself favorably in situations where NASA would have been expected (either politically or publicly) to be responsible, whether it had anything to do with shaping policy or not.

The remaining 10 strategic options offer varying levels of resilience and adoption implications and require individual analysis. Of note are two options that are resilient against three of the four future scenarios (which indicates that these options are largely applicable regardless of future state):

- #4 Focus on basic research (i.e., rebalance portfolio to be more research focused rather than mission-execution focused)

- #15 NASA is a direct influencer of policy (i.e., NASA as an explicit advocator of policies through data-driven evidence)

Both strategic options are considered "big leaps" in terms of organizational transformation. In the case of strategy #4 (focus on basic research), the dominance of commercial space in three of the four scenarios suggested that NASA may be more advantageously positioned in a pure research role, for which there is little commercial appetite, and by divesting many mission-execution activities that consume substantial resources but that may be overtaken by commercial capabilities by mid-century. Strategic option #15 (NASA is a direct influencer of policy) is the proactive complement to option #13, mentioned above as being not resilient. The scenarios explore multiple futures where humanity's place in space and interaction with technology are substantially evolved from today. Without proactive involvement in the development of policy, NASA may run the risk of being overtaken or made irrelevant if it remains a spectator to the dynamism of events.

Table 10. Strategic Options, Their Descriptions, and Their Scenario Coverage

Strategic Options		Description	Baseline	Growth	Decline	Discipline	Transform	Degree of Transformation Bin
Commercial	1. Maintain internal capabilities relevant to NASA's mission	Overlap exists between what NASA is doing and what commercial can do	x			x		3
	2. NASA transitions to an acquisition-only agency	NASA employees are not actively building, integrating, or operating in-house		x	x			2
	3. Skate to where commercial isn't	Fully transition commercial-viable capabilities out of NASA		x			x	3
Innovation	4. Focus on basic research	Rebalance portfolio to be more research focused rather than mission-execution focused		x	x		x	3
	5. Lead the frontier	Go as far and fast as possible, explore the unknown where no one else is		x	x		x	1
	6. Catalyze access for all	Enable mechanisms for a significant part of society to participate in exploration and science		x	x		x	3
Non-Commercial Partnerships	7. Master in targeted areas, partner elsewhere	Self-sufficient in small subset of core competencies, partner elsewhere because NASA cannot do it all	x	x				3
	8. Maximize partnerships across all efforts	Value proposition as an integrator across interagency, international, etc., not necessarily an expert everywhere			x		x	3
	9. DIY: don't partner	Complete vertical integration under NASA-funded efforts				x		1
Workforce/ Talent	10. Be the best government option	Excel at providing the best work environment in the USG	x					1
	11. Substantial effort to increase value proposition for attracting and sustaining talent	Push government swim lanes for talent acquisition		x	x	x	x	4
	12. Compete with non-government for top talent	Break open new possibilities for getting talent		x			x	2
Policy	13. Arbiter of data not policy	NASA presents/provides data, but does not get involved in policy formulation or decisions	x					1
	14. Use NASA's voice to drive awareness for policy	NASA drives conversations on topics where it has expertise		x		x		3
	15. NASA as a direct influencer of policy	NASA as an explicit policy advocate through data-driven evidence		x	x		x	2

8. Additional Key Insights

To complement the strategic options, the foresighting team synthesized roundtable and interview inputs and industry best practices into a set of "universal elements" that underlie a successful strategic implementation, irrespective of the future state or specific strategies chosen for the organization. Figure 24 shows the universal elements for successful implementation of any strategy selected by NASA leadership. These elements are necessary to accomplishing any strategic vision and are areas where action can be taken now, regardless of strategy. Both the current and future-ready assessment can be altered by actions through strategy. All these elements should be actively managed, even if an organization is performing favorably across them, because the future trend is subject to forces outside of an organization's control. Acknowledgment of the changing context and vigilance towards maintaining relevancy in each of these core areas is necessary to building a strong and resilient organizational foundation. Figure 24 includes a detailed description of the element, an assessment of NASA's current performance on that element, and a baseline of the projected trend for that element.

Participants in the roundtables illuminated many of these universal elements and addressed their perceptions on NASA's current performance, which indicated that performance varies widely across them, from excellent (e.g., NASA's worldwide branding, and STEM reachback) to poor (e.g., organizational alignment on vision, and fostering a collaborative cross-center environment). For example, NASA currently performs well on "an inspired workforce of top talent." Feedback from the roundtables consistently indicated that NASA remains a desired place to work within government and access to talent is not currently a challenge. However, talent attraction, particularly due to outside pressures such as the growing private sector and a known reduction in the proficiency of US STEM talent[41], will put increasing pressure on this element.

In contrast, roundtable feedback suggests that work remains to improve NASA's performance in cross-center collaboration, which is among the Innovation & Business Practices universal elements. Roundtable participants expressed frustration at the deep-rooted competition between different NASA centers and the *de facto* prohibition on collaboration with geographically separated colleagues and sometimes even within centers themselves when proposal dollars are at stake. The emphasis on competition instead of cooperation across the mission and centers could be preventing NASA from seizing new opportunities. This management decision also causes unnecessary stress and friction between the NASA centers that works against the organization's larger mission. Should such patterns continue, the work environment and the mission will be further negatively impacted.

[41] Gabrielle Athanasia and Jillian Cota, "The U.S. Should Strengthen STEM Education to Remain Globally Competitive," *Center for Strategic and International Studies,* April 1, 2022.

Universal Elements for Successful Implementation			
Category	**Description**	**Current Performance 4** (color based on inputs from roundtables & interviews) *green- good; yellow- fair; red- concerning*	**Baseline Trend**
Leadership & Organization	Organizational alignment on a collective, understood, and believed vision & mission (the "why" for NASA)	NASA has a clear, solid vision/mission statement, however there is a lack of necessary alignment or understanding throughout the organization	→
	An integrated strategy roadmap for the NASA enterprise to help meet the vision and mission	Roadmaps at mission/directorate level, but not integrated/refined at enterprise level	
	Stakeholder management strategy including resourcing and enduring missions	Recognition of the need to increase amount of stakeholder engagement to reduce changes from admin to admin, but improvements needed	
Workforce / Talent	An inspired workforce of top talent	NASA continues to be a top-ranking government employer and engage new talent, but workforce is at risk, no guaranteed continuation	↘
	Top talent is retained and sustained at NASA	Some generational disconnects between wants/needs of workplace and mission resonance, and their understanding across management levels	→
	Ensure a vibrant workforce promoting diversity, equity, and inclusion	Good progress on diversity, but room to go for equity and inclusion (particularly in leadership)	↗
Future Preparedness / Resilience	Adaptability and agility of the enterprise to weather disruptions and changes to the mission environment	Need formal approach for enabling integrated organizational flexibility to address surprise/drive change	→
	Consistent scanning of how the environment is changing and weaving these insights into decision-making	Need to identify key internal stakeholders and processes that integrate horizon scanning insights into updating strategy	
Innovation & Business Practices	NASA can do some of the biggest, most complex, highest collaborative projects in the world	Demonstrated feats few others in the world have been able to achieve and should continue to "go big"	→
	Reach-back to public, STEM, and international collaboration	Continue to strive to be world-class in its outreach efforts	
	Government-leading organization for commercial partnerships	Continue to lead in catalyzing and partnering with commercial	
	A collaborative—not counterproductive—competitive environment between mission centers and directorates	Need to address stove-piping and counterproductive internal competition	
	Abundant cross-enterprise collaboration to drive innovative outcomes	There are examples of excellence, need to expand enterprise wide within NASA and expand interagency, international, and commercial examples	
	Ability to prioritize geographic and organizational balance in portfolio to maximize impact across the entire enterprise	Work distributed by mission and Centers, not properly balanced across the enterprise	
	Recognize when to stop doing things that no longer serve the collective NASA mission	Need to establish rigorous process to decide when to stop and/or streamline investments to ensure they are serving collective mission	
Brand	Positive worldwide brand	Continue to maintain/enhance globally recognized brand	→
	Be a trusted source of information and wisdom worldwide	Continue to provide trusted, science-based insight to the public	

Figure 24. Universal elements for successful implementation grouped into categories with descriptions and current performance. It is important to also consider the projected baseline trend as current performance is not necessarily indicative of an ability to perform in the future environment.

Lastly, the team assembled a series of key questions for NASA leadership that emerged overall from the foresighting analysis, and the inputs gathered from the roundtables, interviews, and documentation review. These are major questions relevant to NASA's vision, mission, and strategic direction that leadership should consider in the earliest stages of the strategic development process. The key questions appear in Figure 25. The diverse perspectives and strategic thinking of the roundtable participants highlighted four dominant themes that NASA's leadership must grapple with:

1. *Balancing Acts*. The future will require balancing many different strategic factors that not only play into NASA's technology portfolio but also impact the "why" for NASA and its organizational vision and mission:

    a. Commercial capabilities vs. in-house development

    b. International partnerships vs. domestic capability

    c. Human spaceflight vs. robotic exploration

2. *Being Poised for Change*. NASA must be prepared to inhabit a world where change is the norm and where stopping activities may be as important as starting them to maintain alignment with the organization's collective vision.

3. *Responding to Shocks*. World events could shake NASA's foundations, and the organization should pursue a strategy as resilient as possible to weather them, from the discovery of extraterrestrial life to major global conflict to being beaten on the way to Mars.

4. *Defining Success*. Every mission at NASA must define success criteria, and leadership should also define "success" for the organization and what it means for NASA to thrive and not just survive.

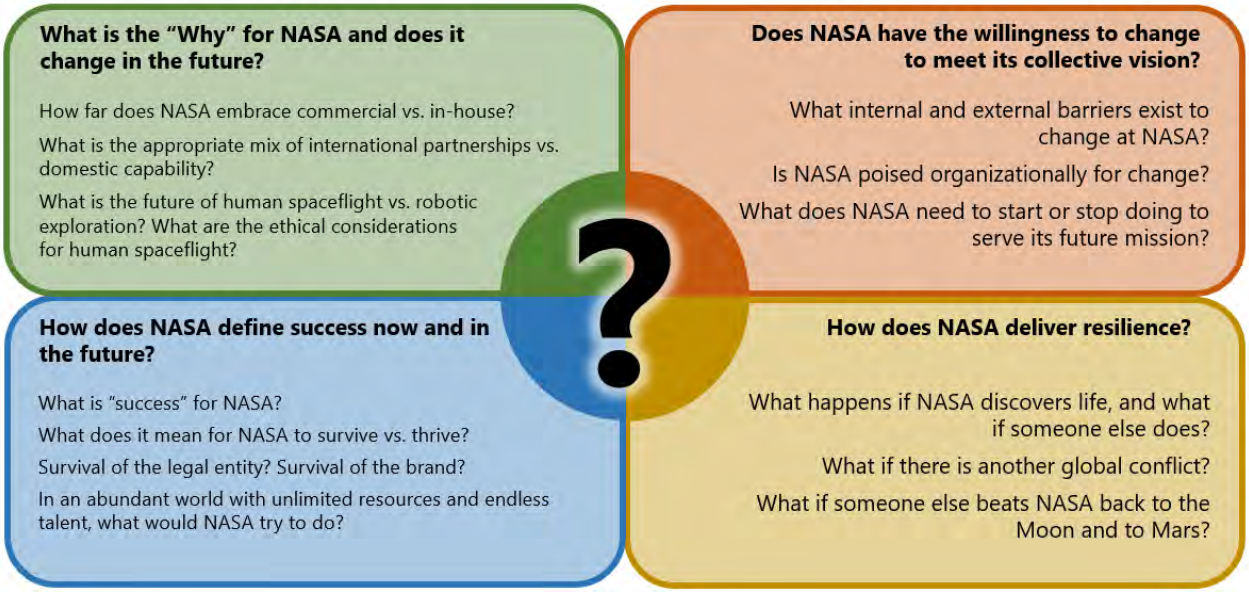

Figure 25. Key questions for NASA leadership to consider during the strategic development process. The formulation of these questions relied heavily on diversity of perspectives.

NASA leadership should work to address these key questions first, including formulating a strategy and an action plan to address their posture towards each. Identifying key signposts and decision points they can anticipate along the way is also helpful in managing high-impact issues in uncertain environments. For example, key measures NASA might consider for guiding its strategy towards its relationship with commercial companies include meeting performance metrics, maintaining business sustainability, or having multiple commercial options to deliver a capability as some signposts to monitor as it decides the pathway forward. NASA may determine that certain signposts need to emerge before they execute the next phase of its strategy. It may also set up some pilot programs to test out certain approaches before scaling across the organization. The other key questions identified in this study (including the scenarios' key focus question in Section 6 and the key questions in Figure 24, are important to triage and address in the future. While some may not be as urgent, all have the potential for significant impact for the future of NASA.

The foresighting team has compiled additional courses of action that NASA could consider as new or modified business practices that would serve to institutionalize the process of adapting to a VUCA future:

- Establish an ongoing foresighting practice by leveraging current internal efforts at the mission and center levels.
- Incorporate an enterprise-wide approach into areas such as executive strategy, visioning, technology investments, and partnerships.
- Foster a more futures-aware workforce.
- Create incentives to drive toward more enterprise-wide thinking aligned with the vision of NASA.
- Deliberately incorporate diverse perspectives from throughout the workforce in enterprise-level initiatives.

Foresighting is only the first step in the strategy formulation and execution process. After exploring the trends and disruptors, possible futures, critical uncertainties, and possible strategic options, the follow-on steps are strategy formulation, then change management, and finally tracking implementation progress. The 2021 ASAP report recommended that "NASA should develop a strategic vision for the future of space exploration that encompasses at least the next twenty years," and that the vision "should describe the role that NASA intends to play during that period." Additionally, "all aspects of the strategic plan should be clearly and unambiguously communicated throughout the Agency." Finally, it recommends that NASA determine "how the Agency is going to understand and manage risk in the more complex environment in which it will be operating." The findings presented in this study are a framework that NASA may consider when addressing these recommendations. Any organization risks its relevance, resilience, and ability to shape the future if it fails to adopt a collective and integrated strategy, as recommended in ASAP 2021 Annual Report. Foresighting is not a one-time event. Routine reiteration is important to ensure an organization is constantly evolving to adapt to an ever-changing environment.

Appendix A. Detailed Trends and Disruptors

In this appendix, we provide a full list of trends and disruptors from ITONICS (The Aerospace Corporation's horizon scanning platform). Trends and emerging disruptors from the roundtable can be found in Detailed Observations from Internal Roundtables and Detailed Observations from External Roundtables

1. *Canada Aims to Establish a New Space Division to Further its Space Capabilities*: "Canada's military will establish a new space division later this year as it further develops its capabilities and skills for space operations. The division would be responsible to the Royal Canadian Air Force commander for the generation of space capabilities for force employment missions. Canada's version would be much smaller than the US's Space Force."[42]

2. *Russia-Ukraine War Worsens Fertilizer Crunch, Risking Food Supplies*: "The Russia-Ukraine war pushes up the price of natural gas, a key ingredient in fertilizer, and has led to severe sanctions against Russia, a major exporter of fertilizer. Higher fertilizer prices are making the world's food supply more expensive and less abundant, as farmers skimp on nutrients for their crops and get lower yields. While the ripples will be felt by grocery shoppers in wealthy countries, the squeeze on food supplies will land hardest on families in poorer countries."[43]

3. *Stretchable and Printable Free-Form Lithium-Ion Batteries*: A Korean research team has developed a soft, mechanically deformable, and stretchable lithium battery that can be used in the development of wearable devices and examined the battery's feasibility by printing them on clothing surfaces. The development of a battery that is soft and stretchable like human skin and organs has been attracting interest owing to the rapidly increasing demand for high-performance wearable devices such as smart bands, implantable electronic devices such as pacemakers, and soft wearable devices for use in the realistic metaverse.[44]

4. *Wildfires Will Worsen, Warns U.N. Report:* "Fires are going to be bigger, more intense, and more frequent.…According to the report, wildfires may increase globally by 14% by the end of this decade and 50% by 2100 if no preventive actions are taken."[45]

5. *Cooling Upper Atmosphere Impacts LEO Satellites*: Long-term data on the mesosphere, the layer 30 to 50 miles above Earth's surface, has revealed that it is cooling and contracting. Scientists believe this is caused by the insulating effect of a thickening lower atmosphere, a trend that will increase with time.[46]

6. *DeepMind Has Trained an AI to Control Nuclear Fusion*: The Google-backed firm taught a reinforcement learning algorithm to control the fiery plasma inside a tokamak nuclear fusion reactor. Finding smart ways to control and confine that plasma will be key to unlocking the potential of nuclear fusion, which has been mooted as the clean energy source of the future for decades. At this point, the science underlying fusion seems sound, so what remains is an engineering challenge. An AI-controlled tokamak could be optimized to control the transfer of heat out of the reaction to the walls of the vessel and prevent damaging "plasma instabilities." The reactors themselves could be redesigned to take advantage of the tighter control offered by

[42] "Canada Aims to Establish a NewSpace Division to Further its Space Capabilities," *SpaceNews,* April 22, 2022.
[43] "Russia-Ukraine War Worsens Fertilizer Crunch, Risking Food Supplies," *NPR,* April 13, 2022.
[44] "Stretchable and Printable Free-Form Lithium-Ion Batteries," *Advanced Batteries & Energy Storage Research,* April 5, 2022.
[45] "Wildfires Will Worsen, Warns U.N. Report," *Eos,* March 31, 2022.
[46] "NASA Satellites Find Upper Atmosphere Cooling and Contracting Due to Climate Change," *SciTechDaily,* July 4, 2021.

reinforcement learning. Ultimately the collaboration with DeepMind could allow researchers to push the boundaries and accelerate the long journey toward fusion power.[47]

7. *Technology integration with intelligent life forms*: "For millennia, people have trained canines to assist with everyday activities of humans, from herding sheep to sniffing out explosives. The four URLs attached to this signal discuss (1) how primarily dolphins have been used for underwater assistance from mine clearing to surveillance, (2) advancements in robotics for more complexed tasks and delicate maneuvering, and (3) and (4) the ability to functionally communicate with other intelligent life forms on our planet. Putting these all together, what sort of ethical issues might arise? For example, in the article about the dolphins, the Soviets had armed dolphins to attack people or other dolphins that might enter one of their ports. Can these ethical issues be balanced by humankind's needs for justified intervention in international conflicts and other hazardous conditions? Could this be something that we use in spaceflight? What if we used a monkey with a robotic arm attached to climb around the outside of a spacecraft to fix problems during flight?"[48]

8. *Power for the moon and beyond*: Innovative new magnet could facilitate development of fusion and medical devices. "If we are designing a power plant that will run continuously for hours or days, then we can't use current magnets," Zhai said. "Those facilities will produce more high-energy particles than current experimental facilities do. The magnets in production today would not last long enough for future facilities like commercial fusion power plants." In this new type of magnet, metal acts as insulation and therefore would not be damaged by particles. In addition, it would operate at higher temperatures than current superconducting electromagnets do, making it easier to maintain.[49]

9. *Researchers Devise Card Game to Create a more Inclusive Experience for Awareness of Urban Planning Research for Kuwaitis*: "Urban design and planning have historically had a reputation for being technocratic and top-down, driven and guided by policy reports, academic research and data that ultimately leaves behind 'end users' or the people who actually live in these places in the process. Kuwaitscapes is a card game based around our research into public space and policymaking in Kuwait. It aims to raise awareness on how to serve diverse user groups and explore how public spaces are used at different scales of urban analysis."[50]

10. *Smart city technology and the future of policing*: "A 'smart city' is one where data collection by sensors and analytics are used to facilitate services for better performance, improved sustainability, lower costs and a decreased environmental impact. After the demands the past two years have brought on policing, smart city technologies open a window of opportunity for law enforcement that is about more than just solving and deterring crime. It can also improve contentious community relations and mend a broken identity between the protectors and the protected. By adopting smart city technology, police departments can become more effective by saving staff hours and costs and providing better service. This can build stronger relationships with the community."[51]

11. *Compressing Time-to-Decision*: As change and the need for quick decisioning become more essential, many are seeking best practices for sourcing and storing big data in different formats,

[47] "DeepMind Has Trained an AI to Control Nuclear Fusion," *Wired*, March 23, 2022.
[48] "How dolphins protect the US nuclear arsenal," *The Bulletin*, March 16, 2022.
[49] "Innovative new magnet could facilitate development of fusion and medical devices," *Phys*, March 4, 2022.
[50] "Researchers Devise Card Game to Create a more Inclusive Experience for Awareness of Urban Planning Research for Kuwaitis," *London School of Economics*, March 4, 2022.
[51] "Smart city technology and the future of policing," *Police1*, January 31, 2022.

deploying intelligent systems, monitoring their performance, and developing ethical solutions that are compliant with new regulations. Often called artificial intelligence (AI), current intelligent systems employ narrow AI to improve speed and accuracy for the multitude of structured problems they address. In fact, some vendors claim the need for customer decisions with streaming data processing, using hundreds of models to inform them in less than 200 milliseconds. This is usually achieved by leveraging data and analytics services to perform data management that discovers, describes, organizes, integrates, shares, governs, and applies data to support decisioning.[52]

12. *DIY Genetic Therapy*: A Chinese father took it upon himself to develop a cure for a rare genetic disease that his son was diagnosed with. Xu Wei, a 30-year-old online entrepreneur with no prior college education, devoted his time to learning and developing medicine at home after his one-year-old son, Haoyang, was diagnosed with Menkes disease, reported the South China Morning Post.[53]

13. *Disruptive drilling technology to help geothermal power the world*: U.S.-based technology startup Quaise Energy is looking at disrupting the geothermal sector with a completely unique drilling technology that could help tap deep supercritical resources. Geothermal energy systems have the potential to power the world and become the leading technology for reducing greenhouse gas emissions if we can drill down far enough into Earth to access the conditions necessary for economic viability and release the heat beneath our feet.[54]

14. *Sandia National Lab's psychologist notes a rise in hostile interactions between colleagues as part of rising trend of incivility*: "Ben Klein, Sandia's lead clinical psychologist, said he has seen 'a rise hostile interactions and verbal conflicts between colleagues,' which may be related to an increase in virtual work. A Portland State University study in August indicates that incivility is on the rise. Over the past two years, pandemic-driven isolation seems to have taken its toll on staff, even though Sandia offers a very positive, respectful workplace culture."[55]

15. *Hackers Can Access Pacemakers:* The core message of a new advisory from the U.S. Department of Homeland Security (DHS) warned that computer hackers can easily gain access to implanted cardiac defibrillators made by Medtronic. "An attacker with adjacent short-range access to an affected product, in situations where the product's radio is turned on, can inject, replay, modify, and/or intercept data within the telemetry communication," according to a statement from the DHS.[56]

16. *Biomanufacturing: Coming Soon to a Galaxy Near You?*: The DOD has a role in orbital and lunar missions as defined by the U.S. Space Force (USSF) Space Capstone Publication. In this document, USSF notes the "inherent value of the space domain and the tremendous influence space has on U.S. prosperity and security."" There is a critical DOD need for the continued development and future expansion of orbital manufacturing to enable and ensure supply chain resiliency, sustained technological superiority, and asset security and repair for current and future operations. To meet this unique challenge, DARPA announced that it was taking an initial step to explore and de-risk manufacturing capabilities that leverage biological processes in resource

[52] "What is real-time decisioning? 5 Key Insights," *Pega*, April 29, 2021
[53] "A Chinese father could not find drugs to treat his son's rare genetic disease, so he decided to make them himself," *South China Morning Post*, October 15, 2021.
[54] "Disruptive drilling technology to help geothermal power the world," *Think GeoEnergy*, June 18, 2021.
[55] "How do we manage an increase in workplace incivility?," *Sandia LabNews*, November 5, 2021.
[56] "Hackers Can Access Pacemakers, but Don't Panic Just Yet," *Healthline*, January 10, 2022.

limited environments with its Biomanufacturing: Survival, Utility, and Reliability beyond Earth (B-SURE) program.[57]

17. *Plans to pull CO_2 out of the air*: "The U.S. Department of Energy (DOE) announced a bold new plan to make technologies, called carbon dioxide removal (CDR) technologies, cost-effective and scalable with the launch of a new "Carbon Negative Shot" initiative. Through this initiative, the agency seeks to bring the cost of CDR down dramatically this decade — to less than $100 a ton— so that it can be deployed at a big enough scale to remove "gigatons," or billions of tons, of carbon dioxide from the atmosphere."[58]

18. *World's first living robots can now reproduce, scientists say*: The U.S. scientists who created the first living robots say the life forms, known as xenobots, can reproduce in a way not seen in plants and animals.[59]

19. *'Antiwork' movement may be long-run risk to labor force participation, Goldman Sachs*: "About 5 million Americans have exited the labor force since the pandemic began. Goldman Sachs estimates that about 3.4 million are likely gone for good due to retirements, meaning that 1.7 million people are open to returning to work. But Goldman said in a note on Nov. 11 that there is a 'long-run risk' to labor force participation: a general distaste for work. The bank's economics team pointed to the reddit thread r/Antiwork, a social media community carrying the mantra 'Unemployment for all, not just the rich!' A common theme on r/Antiwork: younger workers sharing stories about being overworked and burnt out to the point of quitting."[60]

20. *Sandia's Atomic 'Avocado' Could Allow GPS-Free PNT*: The first-of-its-kind device, a vacuum chamber for containing clouds of atomic particles that drive quantum sensors, is about the size of an avocado.[61]

21. *Chinese Censorship Is Going Global*: Beijing is not content to stop stifling free speech at the water's edge. This opinion piece suggests Western companies and institutions must put liberty before profits.[62]

22. *NASA chief says Russia leaving ISS could kick off a space race*: "The United States has for decades enjoyed a mutually beneficial relationship with Russia that has often served as a powerful symbol of cooperation between the East and West in the post-Cold War era. But that cooperation could soon dissolve, and it has NASA's new chief, Bill Nelson, concerned. Russian officials are threatening to pull out of the International Space Station, the orbiting laboratory that the US and Russia have jointly operated for two decades, as soon as 2024 in favor of operating an independent space station. Meanwhile, Nelson and the US government want to continue the ISS program through at least 2030."[63]

23. *Commonwealth Fusion Systems creates viable path to commercial fusion power with world's strongest magnet:* "The fastest path to clean, limitless fusion energy. The milestone test, conducted at MIT's Plasma Science and Fusion Center, proved that the magnet built at scale can

[57] "Biomanufacturing: Coming Soon to a Galaxy Near You?" *DARPA News,* 22 November 2021.
[58] "The US has big, new plans to pull CO2 out of the air," *The Verge,* 5 November 2021.
[59] "World's first living robots can now reproduce, scientists say," *CNN,* 29 November 2021.
[60] "'Antiwork' movement may be long-run risk to labor force participation: Goldman Sachs," *Yahoo! News,* 15 November 2021.
[61] "Sandia's Atomic 'Avocado' Could Allow GPS-Free PNT," *Breaking Defense,* 1 November 2021.
[62] "Chinese Censorship Is Going Global," *Foreign Policy,* 28 October 2021.
[63] "NASA chief says Russia leaving ISS could kick off a space race," *CNN,* 4 June 2021.

reach a sustained magnetic field of more than 20 tesla, enough to enable CFS's compact tokamak device, called SPARC, to achieve net energy from fusion, a historic first."[64]

24. *Close Calls with Starlink Account for Roughly Half of All Incidents*: "The Astronautics Research Group at the University of Southampton, U.K., has found that Starlink satellites account for roughly 1,600 close encounters every week. A close encounter in this research is classified as two spacecraft passing within 1 km of each other. Many of these encounters are self-inflicted and lower to 500 per week when only considering encounters with non-Starlink spacecraft. As the constellation size increases, it is projected that up to 90% of all close encounters in LEO will stem from Starlink encounters. Current notification processes are not easily scalable due to their reliance on manual action, according to Kayhan Space CEO (which itself is developing a commercial autonomous space traffic management system)."[65]

25. *Neural net can detect leaky pipes*: By tracking water pressure at various points and using artificial intelligence/neural nets, new research shows the ability to monitor large national infrastructures for possible hazards. With enough sensors and data, maybe roads, bridges, power lines, and traffic jams could also be monitored.[66]

26. *Nuclear power's reliability is dropping as extreme weather increases:* A comprehensive analysis shows that warmer temperatures aren't the only threat.[67]

27. *Improving air quality reduces dementia risk, multiple studies suggest*: Improving air quality may improve cognitive function and reduce dementia risk, according to several recent studies.[68]

28. *Researchers Found Telemedicine Usage in Israel during the COVID-19 Pandemic Did Not Significantly Affect Care Quality and Cost*: Prior to the COVID-19 pandemic, telemedicine saw limited use. Usage of telemedicine exploded during the COVID-19 pandemic as regulations changed and demand skyrocketed. The trend of telemedicine is unlikely to go away as the COVID-19 pandemic ends.[69]

29. *New Research Report Finds Culture Is a Bigger Driver of Human Evolution than Genetics:* Researchers found that culture helps humans adapt to their environment and overcome challenges better and faster than genetics. Tim Waring and Zach Wood found that humans are experiencing a "special evolutionary transition" in which the importance of culture is surpassing the value of genes as the primary driver of human evolution. Due to the group-orientated nature of culture, they also concluded that human evolution itself is becoming more group-oriented.[70]

30. *Foreign Investment into China Continues to Grow despite Actions of Foreign Governments to Restrict Investment*: Global economic decoupling from China or, as some call it, reshoring, is not happening. China's share of global foreign direct investment in 2020 reached an all-time high of one quarter, almost twice its share in 2019. This broad measure of foreign direct investment

[64] "Commonwealth Fusion Systems creates viable path to commercial fusion power with world's strongest magnet," *Commonwealth Fusion Systems,* September 8, 2021.
[65] "SpaceX Starlink satellites responsible for over half of close encounters in orbit, scientist says," *Space,* August 18, 2021.
[66] "This Neural Net Can Detect Leaky Pipes in Mere Seconds," *Popular Mechanics,* April 10, 2020.
[67] "Nuclear power's reliability is dropping as extreme weather increases," *Ars Technica,* July 24, 2021.
[68] "Improving air quality reduces dementia risk, multiple studies suggest," *Alzheimer's Association,* July 26, 2021.
[69] "Healthcare delivery: What the rise of telemedicine means for you," *World Economic Forum,* July 26, 2021.
[70] "Culture drives human evolution more than genetics," *University of Maine,* June 2, 2021.

inflows includes new nonfinancial investment, reinvested profits of existing nonfinancial foreign affiliates, as well as foreign investment and reinvestment in financial institutions in China.[71]

31. *OrbitFab's First Operational Gas Station in Space*: "OrbitFab reported a successful deployment of Tanker-001 Tenzing from Spaceflight's LTE-1 Orbital Transfer Vehicle on SpaceX's Transporter 2 mission launched on June 30, 2021. OrbitFab's company slogan is "Gas Stations in Space" and Tanker-001 is the first free-flying propellant depot they have launched. Tanker-001 contains high-test peroxide (HTP), a green propellant, as its "gas" commodity to dispense to other clients. The spacecraft also has the company's "gas cap," RAFTI, for the purpose of fluid coupling in the space environment. Propellant is currently a strong life-limiting commodity on spacecraft. With the introduction of refueling capabilities into new spacecraft, operational lifetimes could likely increase with new maneuvers and CONOPS open for exploration/usage."[72]

32. *'Great Resignation'—95% of workforce considering new job*: In the wake of the COVID-19 pandemic, a growing number of workers are rethinking what they want in a job and a lifestyle.[73]

33. *Blockchain Technology in Use to Reduce Public Procurement Process Corruption: "*SettleMint is exploring the use of blockchain technology to reduce corruption in the public procurement process. OECD estimates 10% to 30% of the investment in publicly funded construction projects may be lost to corruption. Blockchain technology would increase transparency in the process, which should reduce the occurrence of corrupt acts."[74]

34. *Iceland Tried a Shortened Workweek and It Was an 'Overwhelming Success'*: As remote work became a roaring success for both companies and employees during the pandemic, it opened our eyes to new possibilities of how we can have a better life-work balance.[75]

35. *New study highlights the link between greater green space and reduced loneliness:* Adults in urban areas where there's at least 30% green space have a lower chance of becoming lonely compared to those with less than 10% green space. Limiting loneliness has many impacts on health, reducing the risk of depression, heart disease, inflammation, dementia, and death.[76]

36. *United States should push new space treaty: Atlantic Council*: "The US should push hard to overhaul the entire international legal framework for outer space—including replacing the foundational 1967 Outer Space Treaty (OST), a new report from the Atlantic Council says. As it moves to do so, the US also should more aggressively court allies with an eye to establishing a 'collective security alliance for space' among likeminded countries to 'deter aggression' and defend 'key resources and access.'"[77]

37. *Public Market Further Embraces NewSpace Opportunities*: "Cathie Wood's ARK Space exchange traded fund (ETF) started trading and provides an easy way for investors to have exposure to investments in space. This is the first ETF that gives investors the ability to buy a

[71] "Foreign Investment into a re accelerating despite global economic tensions and restrictions," *Peterson Institute for International Economics,* July 22, 2021.
[72] "OrbitFab's First Operational Gas Station in Space To Launch In 2021," *SatNews,* November 16, 2020.
[73] "'Great Resignation' gains steam as return-to-work plans take effect," *CNBC,* June 29, 2021.
[74] "How blockchain can help dismantle corruption in government services," *World Economic Forum,* July 5, 2021.
[75] "Iceland Tried a Shortened Workweek and It Was an 'Overwhelming Success'," *Forbes,* July 5, 2021.
[76] "Mental health: why green spaces are vital for reducing loneliness," *World Economic Forum,* June 15, 2021.
[77] "The Future of Security in Space: A Thirty-Year US Strategy," *The Atlantic Council,* April 14, 2021.

basket of space companies in one transaction in an ETF and enough capital to make a significant impact on capital formation for companies in NewSpace."[78]

38. *Ramping Up of Politically Motivated Capital*: The Chinese government has decided to ramp up national champions and creation of clusters of critical industries rather than import products from other countries. As a result, the U.S. government should expect the Chinese government to accelerate large-scale investments in companies that will seek to compete against Western technology leaders. This competition could manifest itself in unexpected ways beyond profitability.[79]

39. *Toyota begins building Japan's first smart city*: Toyota begins building Japan's first smart city with live-in robots and automated cars, powered by solar panels and electricity from fuel cells.[80]

40. *National Academy of Sciences (NAS) says active climate cooling should be considered*: NAS is not yet recommending geoengineering to bounce heat back into space but recommends an "emergency plan" be investigated. The report looks at three possible ways to cool the air: putting heat-reflecting particles in the stratosphere, changing the brightness of ocean clouds, and thinning high clouds. NAS says climate problem has gotten worse since they last evaluated it in 2015.[81]

41. *Russia and China to sign agreement on international lunar research station*: China has had a series of successful moon mission (the Chang'e series) in recent years. Russia has ambitions to return to the moon within the decade. This signal points to potential collaboration that could have implications far beyond lunar exploration. If nothing else, the fact that Russia is publicizing the discussions surrounding a lunar research base is noteworthy. Aerospace should be aware of the potential for closer collaboration between China and Russia in civil/scientific space (at least).[82]

42. *Extrasolar Object Interceptor and Sample Return Enabled by Compact, Ultra Power Dense Radioisotope Batteries:* A 2021 Phase I NIAC winner proposed a design for an extrasolar object-intercepting space vehicle powered by a chargeable atomic battery (CAB) that boasts potential capabilities of 5 to 8 kg/kWe and delta V on the order of 100 km/s.[83]

43. *Can we eat our way to global food security for 10 billion people?*: "To feed 10 billion people in a healthy and sustainable way, we must rethink how we produce and consume food. Regenerative farming is key to healing the planet and feeding the world with healthy food. Consumers have the power to be part of this transition, by eating plant-rich and diverse diets, and slashing and repurposing waste. Informed and empowered consumers send a powerful message to producers and policymakers alike."[84]

44. *Google Toxicity-Reducing Filter Processing 500M Requests Daily: Benevolence or Thought Control?* An open-source API created by Google that "uses machine learning models to score the perceived impact a comment might have on a conversation. You can use this score to give feedback to commenters, help moderators more easily review comments, allow readers to more easily find interesting or productive comments" is currently processing over 500M requests daily.

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[78] "Cathie Wood Amasses $50 Billion and a New Nickname: 'Money Tree'," *Bloomberg*, 5 February 2021.
[79] "Top China Chipmaker Gets State Funds for $2.4 Billion Plant," *Bloomberg*, 17 March 2021.
[80] "Toyota begins building Japan's first smart city," *Unilad*, 14 April 2021.
[81] "Science panel: Consider air cooling tech as climate backup," *Los Angeles Times*, 25 March 2021.
[82] "Russia, China to Sign Agreement on International Lunar Research Station," *SpaceNews*, 17 February 2021.
[83] "Extrasolar Object Interceptor and Sample Return Enabled by Compact, Ultra Power Dense Radioisotope Batteries," *NASA*, 25 February 2021
[84] "Eat like it matters: how your food choices can clean up the planet and feed the world," *World Economic Forum*, 23 November 2020

This technology can be used to reduce the "toxicity" of online content. However, use machine learning to process online conversation has the potential downside of steering conversations in ways that are potentially unknown (or even advantageous to specific groups). Machine-learning-based content moderation has interesting implications for public discourse.[85]

45. *Pentagon Says STEM Education Deficit is Weakening America*: The United States risks losing its competitive advantage if it continues with its business-as-usual approach and fails to equip its workforce with the education and skills to develop and field complex, cutting-edge emerging technologies like artificial intelligence, autonomous systems, machine learning, and hypersonics.[86]

46. *COVID-19 Will Double Number of People Facing Food Crises*: "The number of people facing acute food insecurity (IPC/CH 3 or worse) stands to rise to 265 million in 2020, up by 130 million from the 135 million in 2019, as a result of the economic impact of COVID-19, according to a WFP projection. The estimate was announced alongside the release of the Global Report on Food Crises, produced by WFP and 15 other humanitarian and development partners."[87]

47. *X-risk: Race toward artificial superintelligence*: A race may develop between major players toward artificial general intelligence (AGI) once it becomes clear that AGI's creation is possible with resources available at the time. Safety may be sacrificed at the expense of speed to maintain first-mover advantage. Should an unfriendly recursively self-improving artificial general superintelligence be developed, it could represent an existential threat toward human survival. On the contrary, a beneficial superintelligence could herald a golden age for humanity and its descendants.[88]

48. *3D-printed Lung-Mimicking Air Sac Brings Functioning Bio-Printed Organs a Step Closer:* Synthetic gels were once a wonder because they are light and provide structural support. However, they were static, and this signal suggests a new materials growth technique for synthetic gels that flex (a 3D-printed lung is the demonstration).[89]

49. *Demand for autonomous delivery bots increases exponentially*: As the result of the unfortunate COVID-19 virus, purchase of delivery robots is increasing. Some of these lost jobs may not return when COVID-19 is over.[90]

50. *Gourd cups*: Historically, we have manufactured things by molding, shaping, and by removing matter. In rare cases, we actually "grow" structures. With the advent of biological understanding, can we grow (which is far more energy efficient) useful parts?[91]

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[85] "Google Toxicity-Reducing Filter Processing 500M Requests Daily: Benevolence or Thought Control," *Perspective API*, February 10, 2021.
[86] "Report: Pentagon Says STEM Education Deficit is Weakening America," *National Interest*, February 7, 2021.
[87] "COVID-19 Will Double Number of People Facing Food Crises Unless Swift Action Is Taken," *UN World Food Program*, April 21, 2020.
[88] Bostrum, N., "Superintelligence: Paths, Dangers, Strategies." *University of Oxford*, 2014.
[89] "3D-printed Lung-Mimicking Air Sac Brings Functioning Bio-Printed Organs a Step Closer," *Science Focus*, June 9. 2019.
[90] "Demand for autonomous delivery bots increases exponentially," *Futurism*, April 10, 2020.
[91] "Is this the disposable cup of the future?" *Fast Company*, July 25, 2018.

51. *Federal Debt Continues Rapid Increase*: Federal debt is over $27T and is currently above yearly GDP of $19.5T due to the pandemic. There has been concern that if the debt reaches a point over 100% of GDP, there could be consequences for the significant amount of debt.[92]

52. *Accelerated High-Risk Capital Availability*: The amount of capital that is available for NewSpace and other high-risk endeavors has increased. While there have been significant amounts of capital for startups from venture capitalists and mutual/hedge funds in the private market, the amount of capital has accelerated from the injection of special purpose acquisition companies (SPACs) capital into the public market.[93]

53. *Digital Government and the Crisis of Confidence*: The trend toward digital government may lead to solutions to many of the toughest problems of transparency and corruption. One example is the use of public key infrastructure to secure, yet anonymize, the voting process. The implications of improved transparency are reduced mistrust and improved likelihood that elections in democratic nations can be conducted and certified with high confidence in the results.[94]

54. *Seeing it is not enough—Space Situational Awareness in Congested Context*: In the past just seeing an object allowed one to avoid collision, but in today's congested, cluttered, contested, connected, and constrained (5 C) space environment, the number of space entities are overwhelming the ability to process and select proper courses of action to ensure mission resilience. So, what will it take to handle the ever-increasing number of objects to manage? This article implies that new processing approaches using narrow AI such as machine learning are necessary. Other articles argue for using the swarm concepts used in ant colonies, but this requires giving up top-down control that is the hallmark of today's Space Situational Awareness CONOPS. Whatever the answer is, the Department of Defense will be working with the Department of Commerce as the Space Venture becomes more commercial and less a military domain.[95]

55. *Method of charging electric cars up to 90% in 6 minutes:* Research teams have proved for the first time that when charging and discharging Li-ion battery electrode materials, high power can be produced by significantly reducing the charging and discharging time without reducing the particle size. As a result, the Li-ion battery electrodes synthesized by the research team charge up to 90% in 6 minutes and discharge 54% in 18 seconds, a promising sign for developing high-power Li-ion batteries.[96]

56. *U.K. firms plan to beam 5G signals to the public via drones*: Two U.K. firms plan to beam 5G signals to the public via drones that stay airborne for nine days at a time. Antenna-equipped aircraft powered by hydrogen would deliver high-speed connectivity to wide areas, in partnership with existing mobile operators.[97]

57. *Solar-powered system extracts drinkable water from 'dry' air*: Researchers at MIT and elsewhere have significantly boosted the output from a system that can extract drinkable water directly from the air even in dry regions, using heat from the sun or another source.[98]

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[92] "Charting America's Debt: $27 Trillion and Counting," *Visual Capitalist*, October 30, 2020.
[93] "Special Purpose Acquisition Companies, the Hottest Investment Vehicle," *Bloomberg*, December 3, 2020.
[94] "A Texas County Clerk's Bold Crusade to Transform How We Vote," *Bloomberg*, September 15, 2020.
[95] "Space surveillance technologies a top need for U.S. military," *SpaceNews*, November 22, 2020.
[96] "Charging electric cars up to 90% in 6 minutes," *ScienMag*, October 23, 2020.
[97] "5G: Using drones to beam signals from the stratosphere," *BBC*, November 3, 2020.
[98] "Solar-Powered System Extracts Drinkable Water from 'Dry' Air," *MIT News*, October 14, 2020.

58. *High-density, ultra-low-energy digital computing*: "Electronic symmetry breaking by charge disproportionation results in multifaceted changes in the electronic, magnetic, and optical properties of a material, triggering ferroelectricity, metal/insulator transition, and colossal magnetoresistance. Yet, charge disproportionation lacks technological relevance because it occurs only under specific physical conditions of high or low temperature or high pressure. Here we demonstrate a voltage-triggered charge disproportionation in thin molecular films of a metal-organic complex occurring in ambient conditions. This provides a technologically relevant molecular route for simultaneous realization of a ternary memristor and a binary memcapacitor, scalable down to a device area of 60 nm^2. Supported by mathematical modelling, our results establish that multiple memristive states can be functionally nonvolatile, yet discrete—a combination perceived as theoretically prohibited. Our device could be used as a binary or ternary memristor, a binary memcapacitor, or both concomitantly, and unlike the existing "continuous state" memristors, its discrete states are optimal for high-density, ultra-low-energy digital computing."[99]

59. *Use of AI to detect your emotion just by how you walk:* Possible start of analyzing a person's psychological state via their motion using AI and imaging, which could be a surveillance threat if not controlled.[100]

60. *India tests anti-satellite weapon*: Anti-satellite weapons are not limited to countries like Russia and China. This is a reminder that countries with missile development capability may be able to leverage that into anti-satellite missiles.[101]

[99] Goswami, S., et al. "Charge disproportionate molecular redox for discrete memristive and memcapacitive switching." *Nature nanotechnology* 15.5 (2020): 380–389.
[100] "Can AI Detect Your Emotion Just By How You Walk?" *Forbes*, March 29, 2020.
[101] "India tests Anti-Satellite Weapon," *SpaceNews*, March 27, 2019.

Appendix B. Detailed Observations from Executive Interviews

Members of Aerospace's Strategic Foresight Team conducted a series of one-on-one interviews with NASA's executive leadership to gather their perspectives on the future, which informed the key themes and activities in the roundtables. Eight executive interviews were conducted, as shown in Table 11.

Table 11. NASA Executive Interview List.

Executive	Role	Interview Date
Robert Gibbs	NASA Associate Administrator for Mission Support Directorate (MSD)	29 April 2022
Robert Pearce	NASA Associate Administrator for Aeronautics Research Mission Directorate (ARMD)	29 April 2022
Kathryn Lueders	NASA Associate Administrator for Space Operations Mission Directorate (SOMD)	2 May 2022
Jim Reuter	NASA Associate Administrator for Space Technology Mission Directorate (STMD)	3 May 2022
Dr. Bhavya Lal	NASA Associate Administrator Technology, Policy, and Strategy (OTPS)	9 June 2022
Dr. Katherine Calvin	NASA Chief Scientist and Senior Climate Advisor	10 June 2022
Emily Vansice	NASA Office Manager, Office of the Administrator	15 June 2022
Pam Melroy	NASA Deputy Administrator	4 August 2022

Prior to the interviews, a letter describing the interview process (Figure 26), including interview goals, description, and a list of 13 potential questions, was provided to the interviewees.

During the virtual one-hour interviews, the executives provided answers to questions from the provided list, as well as some follow-up questions directed by the conversation. Due to time constraints and discussion focus areas, each interviewee answered many, but not all, of the potential questions.

AEROSPACE

Executive Interviews

Description:

The Strategic Foresight Team (SFT) at The Aerospace Corporation is assisting the Office of Technology, Policy, and Strategy (OTPS) in facilitating a series of futures roundtables focused on enterprise futures aspirations, opportunities, and risks for NASA. As part of this futures roundtable series, The Strategic Foresight Team at would like to conduct a series of one-on-one pre-workshop interviews with executive leadership to hear unfiltered perspectives on the future which will guide key themes and activities conducted in the roundtables. All responses will be kept anonymous.

Goals:

- *Gain executive input and awareness/ownership in the process*
- *Gather insights on organizational blind spots*
- *Identify and coalesce potential visions and aspirations for the future of NASA*

Structure:

- 45-60 minutes

Questions:

1. Briefly describe your career history and journey at NASA.
2. In your opinion, what are the top three trends impacting the future of NASA?
3. Do you have any activities that could inform our team's collection on future trends?
4. What excites you most about the future of the broader Aerospace enterprise? What are the biggest opportunities you see for NASA?
5. It's 2050, describe an aspirational future state for NASA.
6. What scares you the most about the future?
7. Where ought NASA be considering but currently is not, or not sufficiently?
8. What assumptions do you believe NASA is making about the future? What are the implications if they are wrong?
9. What are the key challenges, if any, that NASA can't get past now and how should those be addressed going forward?
10. How might NASA's core role and function change between now and the mid (2030) and long future (2050)?
11. What's the single most important thing you recommend NASA act on in the near-term to best posture itself for a bright future?
12. Do you have any activities or key upcoming decisions that could be informed by our futures roundtables?
13. Is there anything else you'd like to share with us before the workshop?

Figure 26. Executive interview description letter.

The key takeaways from the executive interview responses are summarized in Figure 27 through Figure 33. The key takeaways from the executive interviews, along with information gathered during the roundtable events, were used by the Aerospace foresighting team to develop comprehensive alternative future scenarios, cross-futures insights, strategic implications, and the key questions for strategic planning.

Top Trends Impacting the Future?

- Commercial investment in space, "Investors not just geeks for space"
- Willingness to take risk
- Challenges around climate change and sustainability – top of the agenda
- Net-zero emission for aviation by 2050, challenging goal but make it viable
- Internationalization of space
- "For NASA to be a leader, lead toward sustainable aerospace"
- Point way for industry
- 50-60-year-old facilities have lots of challenges ahead
- NASA like a JOBS program
- Civil space contracting R&D arm of nation
- How we partner and collaborate, how we work going forward
- Space key to peace through international partnerships like ISS, next Moon and Mars
- Innovative contracting – move away from cost-plus, ok for industry to make money
- Train NASA people to be businesspeople
- Political polarization, NASA better off in a more apolitical environment, "stop the churn from party-to-party politics"
- Political pressure for projects to finish in 4 years, not always the best answer
- "Let Go", let industry solve tech problems
- "Be like Bob" – work with industry on hard problems, buy down the risk
- Need legislative and policy, "Need roads, stop signs, driver's license…who is letting these people on the road?"
- Look at rules set for partnerships, international structure and federal piece is old and constraining
- Apply advanced aviation technologies for wildfire management, "Only flying during the day is the Dark Ages"
- Transformational impact of technology, innovation possible at accelerated rate
- Challenges of globalization
- Security challenges of developing nations
- Power density, energy density to make viable aircraft is challenging

Figure 27. Executive interviews: *Top Trends Impacting the Future?*

What excites you most about the future of broader aerospace enterprise?

- "Most exciting time there has ever been"
- "Apollo was exciting, but just itself – today there is an explosion of different ideas and players:
- "Small companies excited and willing to take chances and try things
- OSAM – servicing and manufacturing in space
- Nuclear systems in space for continuous power and propulsion
- "You've got to be in the space business" space economy and regular economy now integrated
- Merging industries and eliminating silos
- Innovation cycle with industry and sharing across manufacturers – example SpaceX uses acrylic not glass for windows – incorporated on Orion and saved weight
- Recognize people as national experts and capitalize on that expertise – civil space can talk when military can't
- In 15 years, need University of NASA with chairs for missions
- Pipeline of talent is exiting – almost limitless – each class smarter than the last
- NASA ability to use data, just scratching the surface. Application of climate data to third world farmers and mining data into right hands
- Exploitation of AI and ML at scale and NLP to work through larger data sets
- Simple transactions for RPA to let humans do other things
- CubeSats are a game-changer
- New age of innovation including electric propulsion, hybrid systems, and autonomy
- New systems coming for the future as SpaceX and Blue Origin disrupting launch and others coming
- Aviation for mobility applications for short haul in urban/suburban applications to move 2-10 people efficiently
- Hypersonics will be disruptive form small payload launches

Figure 28. Executive interviews: *What excites you most about the future of the broader aerospace enterprise?*

What scares you or keeps you up at night?

- Budget is a challenge, getting the money to do everything we hope to do
- Orbital debris is a concern, "pollution in space is a real hazard and there isn't an answer"
- "Wild West stuff going on in space" – explosion of number of satellites with SpaceX and Amazon launches
- Where is the oversight; who is liable is something goes wrong? International incident just waiting to happen
- Must change organizational construct to recognize experts or will lose them because they don't feel appreciated
- Need to figure out how to build toolbox for people under 30 – like other parts of agency that transitioned – talk to Bob
- How are you going to make sure crew members going to Mars have the right balance – need AI to keep spacecraft going
- Need to keep development skills through partnerships
- Degraded infrastructure to support our missions and partners since much is beyond useful life and 60+ years old
- We are not moving at scale or speed from our benchmarking with industry
- Ability to launch scare me – difficult to sustain with declining support from Congress
- Our Type A personalities that overcome challenges and budget deficits make us a victims of our own success. You did it for less, get even less next time
- Our culture – mission come first but massive disconnect between budget and expectations
- Scarcity of energy and resources, hopefully scarcity will drive future vectors to solve problems

Figure 29. Executive interviews: *What scares you or keeps you up at night?*

What assumptions do you believe NASA is making about the future?

- Can't continue status quo. "Now, we are in an environment where people are breaking molds"
- "Acquisition constraints are impeding us, will become irrelevant"
- We must understand the external market – no longer the dominant voice
- SpaceX re-landing boosters and doing something we said couldn't be done and for 10% of the budget
- Having the right skills to support the partnerships
- People assuming status quo which is dangerous at best
- Only absolute is our place in the market will change dramatically every 5-10 years
- If we are in an acquisition role, will talent still be attracted to NASA?
- Need to live within set limitations on energy front
- Vibrant aerospace industry with private investment and new entries and access to large amounts of money
- NASA will continue to lead and have sustained support for long-term vision like Moon and Mars

Figure 30. Executive interviews: *What assumptions do you believe NASA is making about the future?*

What's the single most important thing you recommend NASA act on in the near-term to best posture itself for a bright future?

- "Pursue things that are transformational in nature, that we can develop and make a huge difference for us downstream."
- Transformational potential for how we travel in space – get to the Moon and Mars faster.
- Manufacturing and assembling in space could be transformational
- Buy the things that are repeatable, and we can get for a service.
- NASA should be the technical beacon
- Push beyond your boundaries, look outside your walls and bring those folks in
- Differentiator is our people – invest in people with agility and flexibility
- Remove barriers to innovation like bureaucracy at all levels including all the paper pushing from Columbia days
- Generate requirements with gold, silver and bronze levels to understand risk tolerance
- Failure should be an option if you aren't going to hurt anyone
- Perfect is the enemy of good enough
- Be willing to listen – best idea wins no matter where the idea comes from
- Create environment where people submit ideas – ideas stream like the startups
- Commercial sector group with lawyers and others to help open doors to new players and startups
- Get our institution in order! Aging facilities, underinvestment, no priority or money for role of facilities in advancements
- Re-energized, can do! Push for new age of exploration on small and large scale
- Do thing in partnership with commercial and other nations – more dynamic than NASA of the past
- Make dream of access to space more affordable and make dream possible for more of humanity

Figure 31. Executive interviews: *What's the single most important thing you recommend NASA act on in the near-term to best posture itself for a bright future?*

What are the inhibitors?

- "Political environment is main inhibitor" – focused on larger programs, hard to sustain across administrations
- Interest in NASA could wane due to concerns over our planet
- Bureaucracy is a barrier to innovation – remove to enable change
- "Institutional arrogance, when you are successful for a long time, if you don't look outside your walls, you develop a blind spot. NASA is not immune to this"
- People's inability to accept risk is so low, institutionally it's a problem.
- NASA needs to do more with less resources, it gets things done too slowly
- "Facilities need to match the mission." NASA won't be seen as awesome place to work due to outdated facilities

Figure 32. Executive interviews: *What are the inhibitors?*

What is working/not working?

- Centers and directorates – plenty of places where we talk past each other, centers not feeling as comfortable and lost control and flexibility with no control of funding for IR&D.
- In past, centers could keep savings from one area and apply it to another, now they don't control funds.
- Smaller centers hurting
- Centers can get competitive with toxic relationships fighting for resources
- Strongest where mission directorates and centers act in partnership – Goddard and JPL manage to work across those pieces
- Aeronautics is working well
- STMD spread across everyone is tough
- Ames and Glenn need to figure out alignment and who is paying for them
- KSC in perfect world is performing 50% of job as a spaceport, but no funding for this to support infrastructure
- Each center director out there for themselves since resource constrained
- HQ no straight answer on how managing infrastructure
- Run NASA as a corporation – what is the overhead
- Centers have the big goals on staffing and skill alignment for future work
- "Our business core is rotten, and we need to call it out. It's fundamental."
- Showcases cross-enterprise success stories – innovation at Marshall and Red Stone Arsenal, JSC 8 partnership agreements
- KSC should be recognized as a spaceport
- NASA is a great investment for 24 billion/year. In past NASA money spent was 1:1 economic benefit, now benefit is 10:1

Figure 33. Executive interviews: *What is working/not working?*

Appendix C. Detailed Observations from Internal Roundtables

Seven roundtable exercises were held to gather inputs. Six of these were hosted and facilitated by the Aerospace foresighting team, and the intern roundtable was facilitated by NASA interns with Aerospace in attendance to observe. To increase the openness of discussion, the roundtables were held per Chatham House Rule where no one is allowed to reveal or attribute comments to individuals. In this appendix, we detail the internal roundtables (five total), providing data of any online Miro boards (virtual platform used during the roundtables) or summarized notes (in-person roundtable) as well as graphic recordings. The data presented in this appendix is directly from participants and not the opinions/views of The Aerospace Corporation.

C.1 In-Person Executive Roundtable

The in-person executive roundtable hosted about 15 participants over the course of 4 hours, with the following high-level agenda:

- Inspirational video
- NASA's Why (Section 5.1)
- Dreams and fears activity (Section 5.2)
- North star identification (Section 5)
- Trends and disruptors (see Trends and Disruptors in Table 12)
- Futures web (Section 3.2.1)

The following are summarized notes and any graphics for exercises not marked as previously discussed.

C.1.1 Fears

We previously presented the dreams portion of the dreams and fears exercise, so here we detail the future fears and current concerns collected from the participants.

- Future fears:
    - Determined five key categories of fears: (1) China, (2) dismantled democracy, (3) politicization of science, (4) commercial space disasters, (5) commercial space monopolies
    - NASA no longer maintains its brand of leading inspirational activities
    - NASA becomes irrelevant
    - NASA becomes an ill-informed contracting organization
    - Commercial industry becomes more advanced than NASA, and NASA is just a distraction in the space enterprise
    - Worried we give too much leadership to private industry and NASA becomes a funding and goals-only organization with no technical expertise or building things in house. What will happen if private industry fails, and NASA no longer exists in its current form? What if this new organizational structure doesn't work?

- Current concern:
    - Many people may not feel empowered to address these fears even though NASA may be able to do something to prevent them.
    - Industry is, arguably, already faster and more capable than NASA. How can NASA maintain a unique role in the space enterprise?
    - NASA has become very risk adverse. At some point, NASA lost its renegade approach to innovation.
    - NASA has lost a lot of its agility
    - When a SpaceX rocket had a fire during testing on the launchpad, the SpaceX team took it apart and quickly started testing again. If NASA had a fire on the launchpad, it would likely take a year to figure out what happened and resume testing again.
- NASA cannot directly control all these fears, but NASA may be able to influence others to address these fears

C.1.2 Futures Web

During this roundtable, the participants explored the following three future possibilities in breakouts during the futures web discussion:

- VC/NewSpace collapse/bubble pop
- Climate change has been "solved"
- A major world conflict erupts

While many primary, secondary, and tertiary impacts of each of these were explored across the STEEPTS, below are the takeaways each group of participants out briefed:

VC/NewSpace collapse/bubble pop

- "If it were to collapse, pace of innovation could slow down"
- "What would happen to intellectual property?"
- "There is more diversity in startup workforces and those workforces would be first to get laid off"
- "NewSpace provides a lot of public awareness of the importance of space, which could shift perception of NASA in positive or negative ways"
- "This could lead to the loss of U.S. space superiority"
- "NASA needs to be aware agile and strategic about NewSpace"
- "Need a proactive communication strategy between NASA and NewSpace"
- "NASA needs better visibility into health of NewSpace economy—what does NASA do with that information?"
- "NASA would need to protect resilient workforce, so we don't lose the technical experts that are laid off in collapse"
- "Maybe NASA may support academic training"
- "NASA could find opportunities out of something that could be generally perceived as a bad thing"

Climate change has been "solved"

- "Assume that climate would have to be prioritized over other issues to make this happen"
- "Society becomes more active in climate issues, which implies there is more individual agency and trust in science"
- "We could apply our solution to climate change to terraform other planets"
- "Society may be more willing to focus on off-world exploration knowing that we are taking good care of our own planet"
- "There would likely be temporary global unification"
- "Whoever led the solving of climate change will have a political power advantage moving forward"
- "Other problems won't disappear while we're solving climate change and will still exist after it is solved"
- "If we don't solve other problems and only focus on climate change then we'll still be doing poorly as a world"
- "Seems like commercial space will be very involved in solving climate change. How will that impact NASA?"
- "NASA can be a leader in building trust, education, and agency"
- "NASA will always need to look at Earth"

A major world conflict erupts

- "What is the long term? Are there baby booms? Are more engineers pulled into war?"
- "Is there a growth in biases?"
- "Are there more families missing members and in need of infrastructure/support?"
- "There could be a shift to war-related tech (might be bad for NASA)"
- "Budget scarcity could occur for NASA"
- "There could be major supply-chain disruption"
- "Commercial space companies would likely focus more on military"
- "There would likely be more nationalistic than globalist economies"
- "There could be the development of green weapons"
- "There would likely be less privacy but more bipartisanism"
- "Different people often get elected after a war"
- "We could lose diversity in certain segments, closed borders, impacted trade"
- "More things might be made in the United States, maybe especially space things"
- "We could lose diversity in certain segments, closed borders, impacted trade"
- "Space related: less trade and lose funding, spur space development in other countries (friends or foes?)"
- "If the conflict takes place in space, the implications in space will be bigger in the long run"
- "Military technology can often be spun into NASA programs"

Table 12. In-Person Executive Roundtable Trends and Disruptors.

Societal	Technological	Economic	Environmental	Political
Trends • Voter fraud • Roe v. wade • French and Slovenian election results • Trend towards authoritarianism • Gender roles and identities • Superficiality • Influencers • Work life balance, working remotely, hybrid workforce • #DearWhiteStaffers • Recent unionization movements • Divisive, polarized, trolling is everywhere • Elon acquiring twitter and backlash against billionaires • Multigenerational homes • Teenage suicide rate • Metaverse • Ethical consumerism • Covid and its impact on society • Social media algorithms and their impact on trends *Disruptors* • Social media • Ranked-choice voting in Alaska and other U.S. states • Censorship and misinformation • Anonymity and privacy • Metaverse	*Trends* • Tele — everything • ML/AI — everything • Crypto • Covid-driven innovation • Mars roundtrip in 200 days • Smaller batteries? • Green energy • Broadband internet for all using satellite constellations • LEO commercialization • Dual-use and spin-in technologies • Cyborgs • RNA-based vaccines • CRISPR • Digital twins for everything • NFTs • Trusted autonomy • Life extension headed to one year per year *Disruptors* • Advanced manufacturing • Material science • Sensor technology • Air-vehicles replaces cars • Knowledge sharing • Bio-manufacturing	*Trends* • Gig-economy • Individuals with state-level resources • Billionaires • Wealth disparity (1% vs. 99%) • Crypto • Crowd funding • Sports gambling • New space economy • DIY • Universal basic income • Advanced market commitments • Scalar manufacturing • What will happen to VC in the next 5 years as we enter a recession? • More companies incorporating as b-corps • Cyber criminals • Block chain • Buying and selling personal data • Student loans (rates are influenced by what the fed is doing and can prevent young people from going to college) • Growing cost of education (trend to lower job qualifications in response to this, someone earlier today mentioned that maybe NASA may hire less PhDs, NASA currently has a 2.95 GPA requirement for new hires) • The Great Resignation • Democratizing Wall Street *Disruptors* • Space VC money could dry up (might accelerate monopolies because only large companies that don't need VC) • Lower educational requirements for jobs • Machines replacing jobs • Automation • Global GDP shifting as non-US economies becomes more powerful and influential • Growing potential for geo-political conflict	*Trends* • Cis-lunar space • Space debris, congestion, traffic management • Virtual/metaverse • Climate change • Ocean circulation, temperature, acidification changes • Landfills, waste management • Meat alternatives, bio-engineered foods, • Circular economy • Resource limitations (including fresh water) • Wet bulb temperature (where you have health issues due to temperature) • Pollution • Extreme weather events • Geological events • Species extinction, birds going away • Ozone problems • Microplastics • Stocks crashing • Climate refugees • Green energy/moving away from fossil fuels • CO2 products • Geoengineering • Trends towards lower waster or zero waste living *Disruptors* • Space solar power • Space nuclear power • NEP • Population growth (we are currently asking too much of the ecosystem) • Electric vehicles • Solar panels on rooftops	*Trends* • War on the truth • Dignity • Adversarial • New(er) world order • Social media • Book banning • Socialism • Extremism • Anti-vaxers • Requirement's growth • Corruption • Voting technology • Distrust of the government • Roe v. wade • Authoritarian • Do-nothing congress • Immigration • Artemis accords and treaties • Increase in weapon ownership • Voting restrictions • Police reform • Politization of science • Texas (secede stickers) • Science on the politization of science • More minority groups in positions of power • DEI • Tension between globalization and isolationism • Wokeness • Cancel culture • Unwillingness to compromise • Fragility of democracy • Automation and social media • Freedom • Normalizing hypocrisy • Cognitive dissonance *Disruptors* • Intrusion privacy (from data collection/targeted ads to abortion rights) • Texas (seceding) • No more compromise • Conflict • Religious extremism • Social credit score

C.2 Virtual Executive Roundtable

The Aerospace foresighting team hosted a virtual executive roundtable of approximately 30 participants over the course of 4 hours, with a focus on aspirational views for the future per the following agenda:

- Introductions
- NASA's Why in 2022 and in 2042? (Section 5.1 and Figure 34)
- Dreams and fears activity (Section 5.2 and Figure 35)
- North star identification (Section 5 and Figure 36)
- Trends and disruptors (see and Table 13 and Table 14)
- Futures web (see Figure 37 through Figure 40)
- Reflections for NASA

The roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in this section.

Figure 34 contains the executives' response to NASA mission, "What is the NASA's Why in 2022 and in 2042?" etails of this discussion were presented in Section 5.1, and the visual Miro board are included here.

Figure 35 documents the executives' biggest fears/concerns with respect to the next 20-plus years of their roles, organizations, and NASA in general, along with the worst-case scenarios they foresee in 2040. Representative comments include "fear of governmental budget cuts for infrastructure at NASA," "space becomes militarized," "NASA turns into a regulatory agency," "vision gets smaller," "U.S. loses position of leadership in space exploration," and "NASA loses public trust."

Guiding North Stars for the future of NASA were identified as shown in Figure 36. The trends and disruptors across societal, technological, economic, environmental, political, threat, and science (STEEPTS) factors were identified as shown in Table 13 and Table 14.

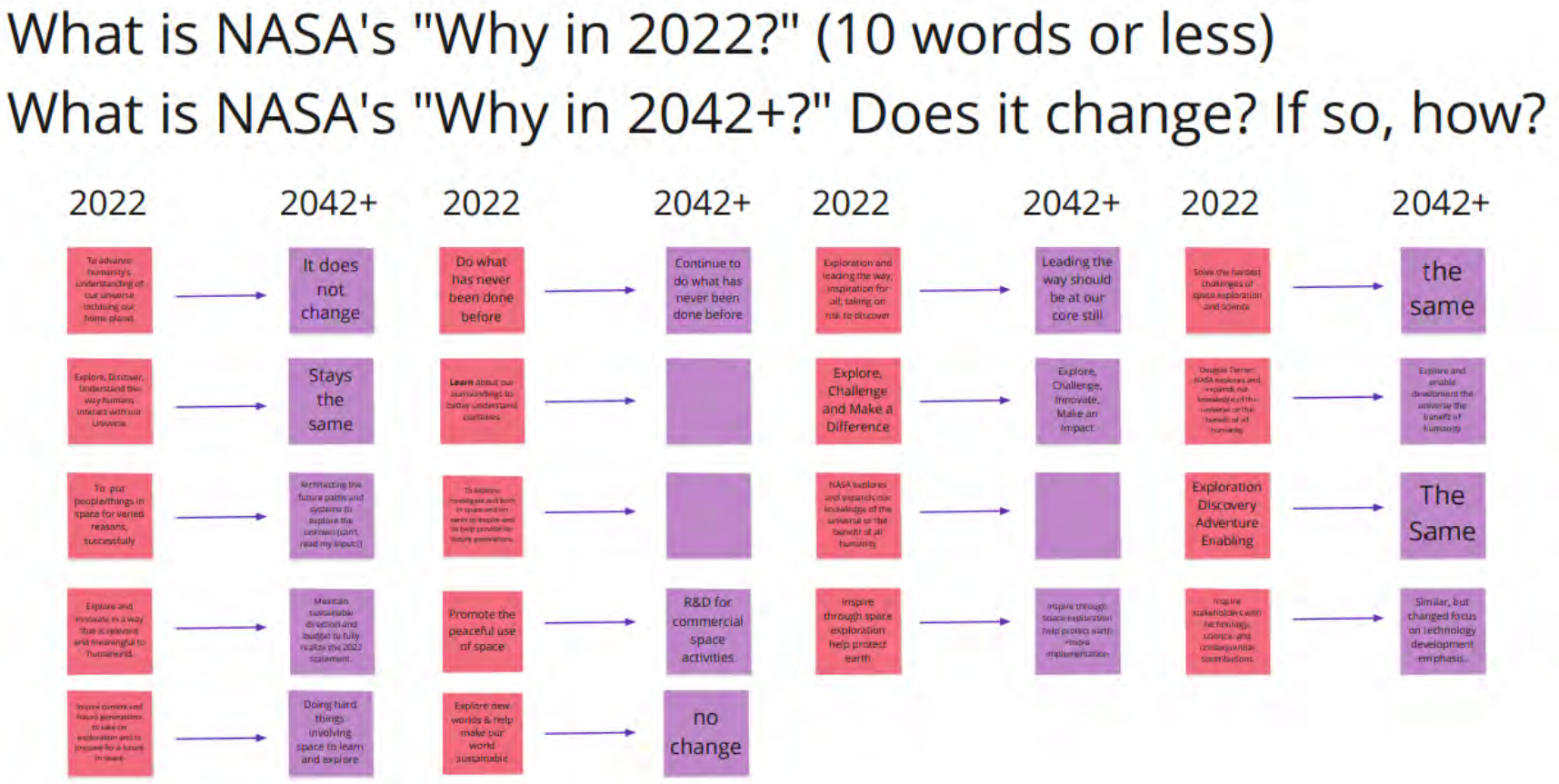


Figure 34. Virtual executive roundtable answers to NASA's "Why in 2022 and 2042?" Miro board.

Part 1 Directions:

- Take 5 minutes to free write (don't hesitate, stop, or think too much!) around the following questions:
  - What are you most afraid of with respect to the future of your role, your organization, and NASA writ large over the next 20+ years?
  - Are there worries if you don't meet certain expectations/requirements/job duties or if the environment changes?
  - Who's the competition? How might they win and you lose?
  - What's the worse case scenario you can imagine for 2040?
  - Was there something in the past or a failure that is heightening this fear?

Figure 35. Virtual executive roundtable biggest fears Miro board.

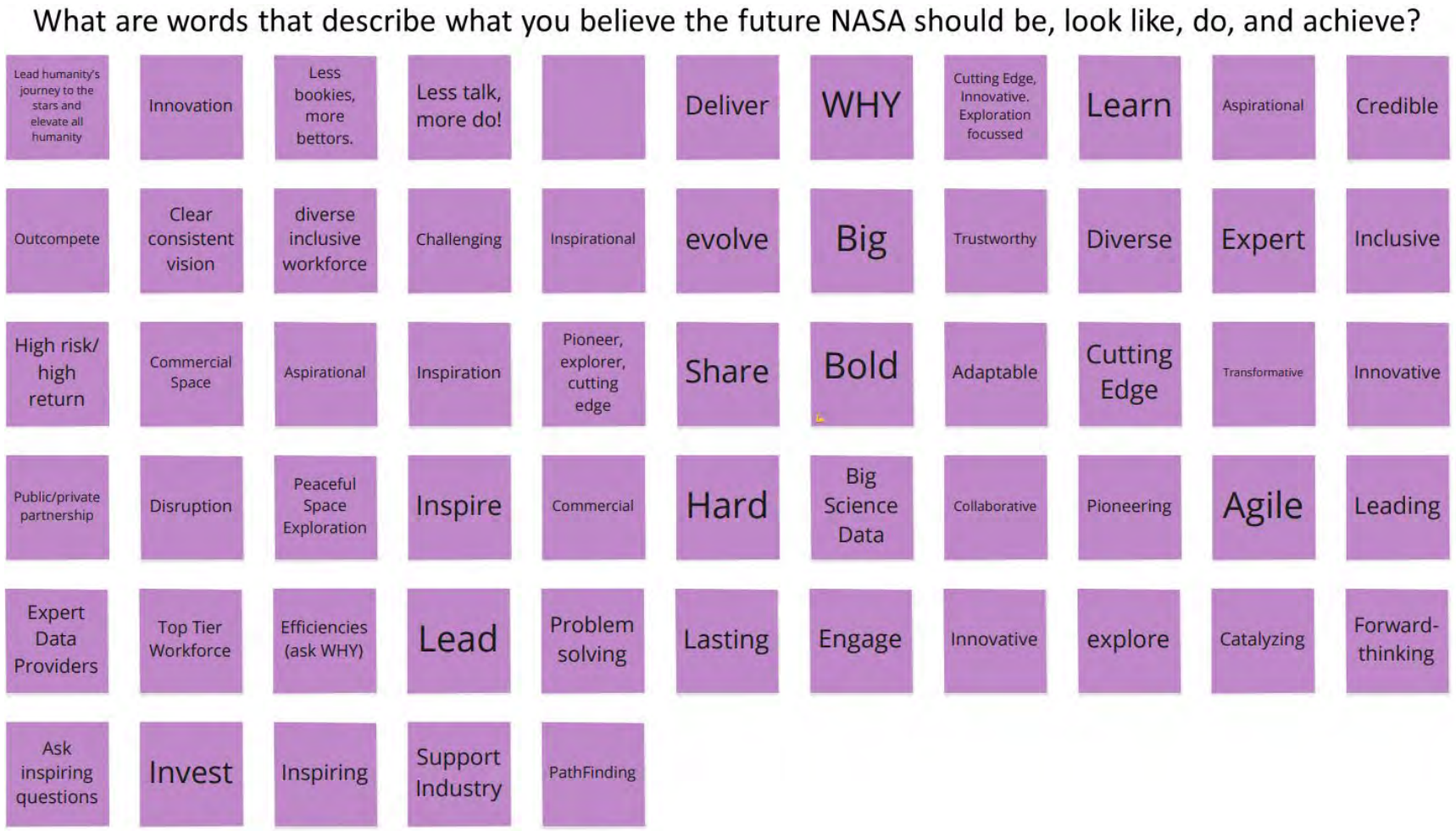


Figure 36. Virtual executive roundtable North Stars.

Table 13. Virtual NASA Executive Roundtable Trends and Disruptors (1 of 2)

Societal	Technological	Economic	Environmental
Trends	***Trends***	***Trends***	***Trends***
• short attention span • valuing science • understanding the mission and vision • reduced focus on privacy • near term focused • equity • identity fluidity • interconnectedness across geographical/geopolitical boundaries • short term employment vs. careers • polarization • distrust experts • diversity • objective facts • how does it impact me? • poor education • distrust of experts • complacent • avatar (anonymity online) • evolution of human consciousness (clearly diverging paths) • lack of critical thinking • disinformation • diversity and inclusion • youth connection • environmentalism • diversity, inclusion and equity • scientific literacy • polarized groups	• cheap sensors • massive amounts of data • virtual engagement (+ and -) • AI/Machine Learning • Artificial Intelligence • social media • ISRU • autonomy • hybrid engagement and exploration • social media - use to engage public • hackers/cybersecurity • bioengineering • BCI (Brain Computer Interface) • VR/AR enabling virtual engagement and collaboration • merging data with different fidelity/uncertainty • hacking • on-board processing • ISM • emphasis on cost vs. reliability • quantum • synthetic biology • cybersecurity & hacking • brain-inspired neuromorphic computing • crypto • integrated photonics • acceptability of failure	• space start ups • significant private space programs - in human spaceflight • increased income stratification • expanded concept of core infrastructure (pandemic fragility and strength: internet, supply chain) • space based economy • hydrogen economy • in-space servicing • visible linking aerospace technologies to terrestrial application • inflation • national debt • cislunar economy • commercial exploration of moon/mars? • commercial space • carbon tax • emphasis on attribution capability • space tourism • concentration of resources into too few hands • asteroid mining • in-space manufacturing • monetizing climate response efforts • Contract Types (fixed price vs. cost plus) • evolving currency forms and transfers	• drought • climate change • disproportionate environmental impacts on groups of people • population and growth of consumption • "Not my problem" mentality • Many NASA personnel don't believe in anthropologic climate impacts • Space tech to help curb carbon use on Earth • satellite constellations • fires • conflict (e.g., over resources) • space debris • climate change • struck in triage mode • disasters more comment • commercial space environmental impacts • attempts to politicize data • new job opportunity; expert witness • risk of overleveraging credibility to try to be all things to all stakeholders • freshwater availability • need to evaluate and call out snake oil solutions • sustainability • need an honest broker
Disruptors	***Disruptors***	***Disruptors***	***Disruptors***
• social media rumors vs. objective facts • technical workforce works elsewhere • gaming • digital engineering and collaboration • war • pandemic • stereotypes • reliability & maintainability • discovery of life elsewhere • NASA embraces DEI and is committed to diversity (connected to more international players, effective partners) • WWIII • racial inequalities	• carbon capture technologists • biomimicry • unexplored quantum capabilities • alien life • hydrogen economy • augmentation to humans • new energy source • metaverse • AI breakthrough • extensive remote presence capability • use of commercial electronics • interstellar travel • metaverse • quantum technologies • crypto • autonomy • reliability	• significant private space programs - in human space flight • economic distortions due to authoritarianism • legal considerations/machinations consume all attention and resources • economic distortions due to extreme climate change • economic disparity • war-economic implications • space commerce • gov shutdowns • international pressure on debt • pandemic 2.0 (or 11.0 or whatever we're at as a species) • policy creates commercial pull for data (verification, attribution) • bad economic policy = mass resignation	• sea-level rise • asteroid impact • apathy • rapid damaging climate change • disasters • changes to NASA's charter that directly impacts role(s) in Earth science an applications • NASA Mars ISRU tech dev is discovered as useful to mitigating Earth's climate change • ecosystem collapse • solar flares

Table 14. Virtual NASA Executive Roundtable Trends and Disruptors (2 of 2)

Political	Threat	Space
Trends • polarized • globalization • conflicts • fragmentation, loss of trust • social media rumor overcomes scientific literacy • disdain for experts and expertise • space race • uncivil • international competition • idiocrasy - politics trump engineering • authoritarianism versus inclusive democracy • loss of trust in leaders • relationship between lobbyists for commercial orgs & acquisition process • Artemis Accords • digital have-nots • changes in political impacts international partnerships • NASA as a political tool • Politics as a NASA funding tool • lack of link between leadership role and competency for specific position • restrictions on women's rights • rise of theocracy • international cooperation	***Trends*** • war • asteroid impact • international IP theft • orbital debris • another pandemic • fear • extreme climate effects • space debris	***Trends*** • expanded exploration • orbital debris • more small companies • living in space • cyber threats
Disruptors • war impacts space • working together to solve big problems results in less international conflict • 7 Eves: Neil Stephenson • Globalization - all in or on the way out? (Collapsing Empire) • Authoritarianism transforms space exploration into militarized space • space war • commercial lobbying • Artemis Accords = increased international collaboration? • NASA collectively figures out how to describe a technology development and mission future that transcends changing Executive Branch transitions. • Humans form tribes based on choosing to adapt to world as it is vs. what they want it to be. global reordering based on views.	***Disruptors*** • discovery of life - unifies humanity or the opposite • Mechanisms to communicate based on content of ideas vs. volume (some cool tech way to counter propaganda) • bioweapons • loss of life • aliens • industry and academia figure out how to make money mitigating climate change	***Disruptors*** • commercial space access transition from NASAA/Roscosmos • discoveries (ALIENS??) • transformative prop system • transition from US-Russia dominance to include other countries and private business • use as infrastructure • space land rush • accident in space - loss of assets or life • Mechanisms to communicate based on content of ideas vs. volume (some cool tech way to counter propaganda)

The group broke into four breakout rooms for the futures web activity. Team 1 looked at the possible implications of a collapse of commercial NewSpace in the future as shown in Figure 37. Their key takeaways for NASA were the potential fragility to embracing NewSpace wholesale and that NASA can't neglect NewSpace, or international competitors will fill the void.

Team 2 looked at the possible implications of commercial NewSpace figuring out how to profit from climate mitigation as shown in Figure 38 and include the following: (1) NASA could focus more concerted efforts on dual use for climate mitigation technologies and partnerships; (2) NASA could help evaluating the "snake oil" and highlight benefits that the private sector wouldn't normally gravitate to or recognize; (3) NASA could help bring large-scale new infrastructure together on AI, modeling, wind tunnels, amount of data, etc.; and (4) NASA could give the private sector more bandwidth in their needs, not just NASA's cost and low-risk requirements.

Team 3 looked at the implications of the metaverse on NASA as shown in Figure 39 and included the following: (1) are people needed in person unless they are building something; (2) can people work from the metaverse, assuming security concerns are met; (3) the metaverse could be an opportunistic space to gamify things they are trying to use citizen science for; (4) NASA should partner with the commercial sector that's building the metaverse; and (5) there is potential for NASA to be left behind/lose relevance if NASA ignores the metaverse.

Team 4 looked at the implications of aliens on the future of NASA as shown in Figure 40. Team 4 key takeaways included the following: (1) redirection for NASA in face of a significant discovery in history, (2) international cooperation and opportunity for collaboration, (3) opportunity to learn about surviving in harsh environments, and (4) a key discovery will take long-term mobilization to address.

The Futures Web, depicted in Figures 37, 38, 39, 40, 50, 51, 52, 53, 75, 76, and 77, is a tool that has been developed by The Aerospace Corporation, is subject to copyright, and requires permission or citation prior to publication.

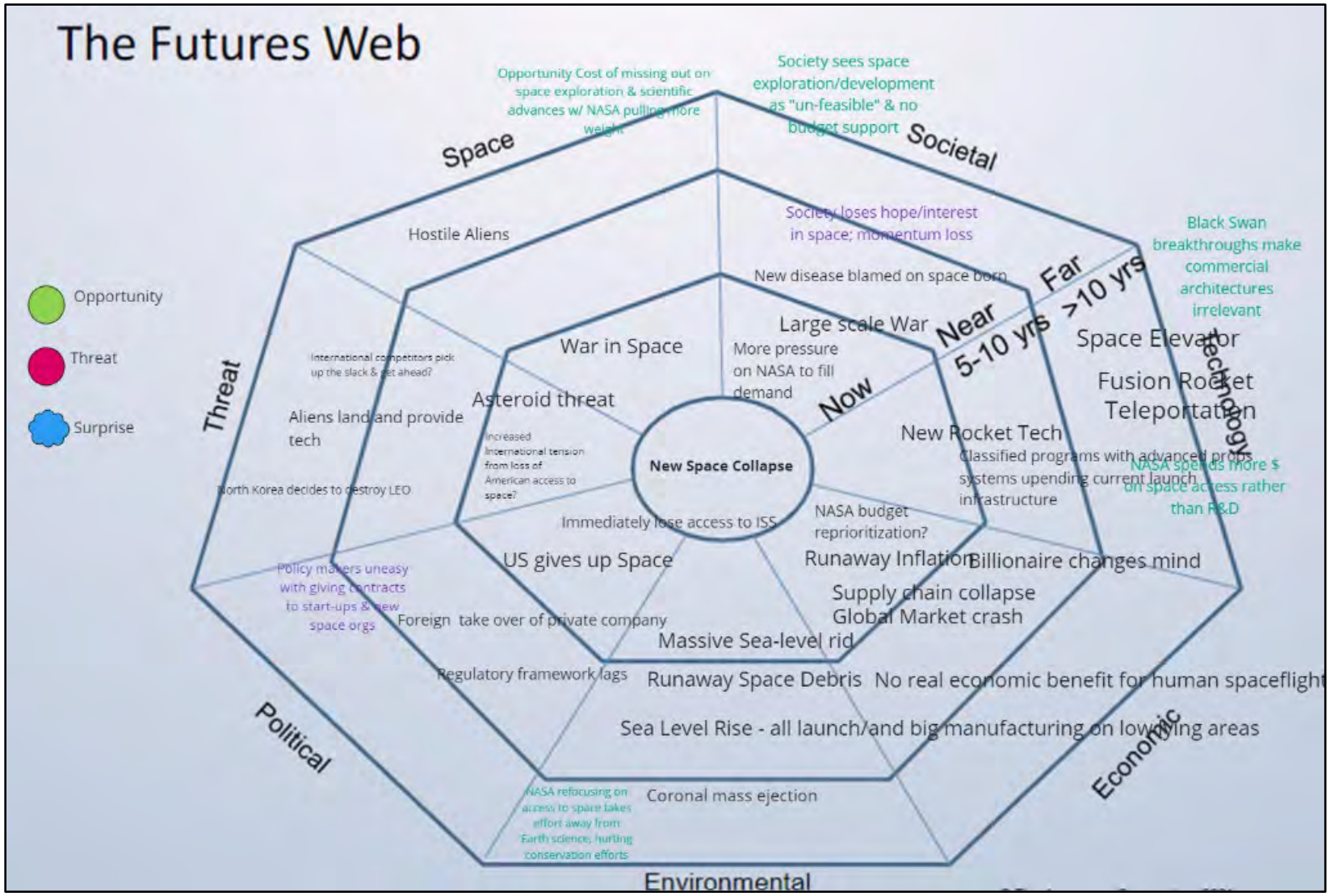


Figure 37. Virtual executive roundtable futures web - Team 1.

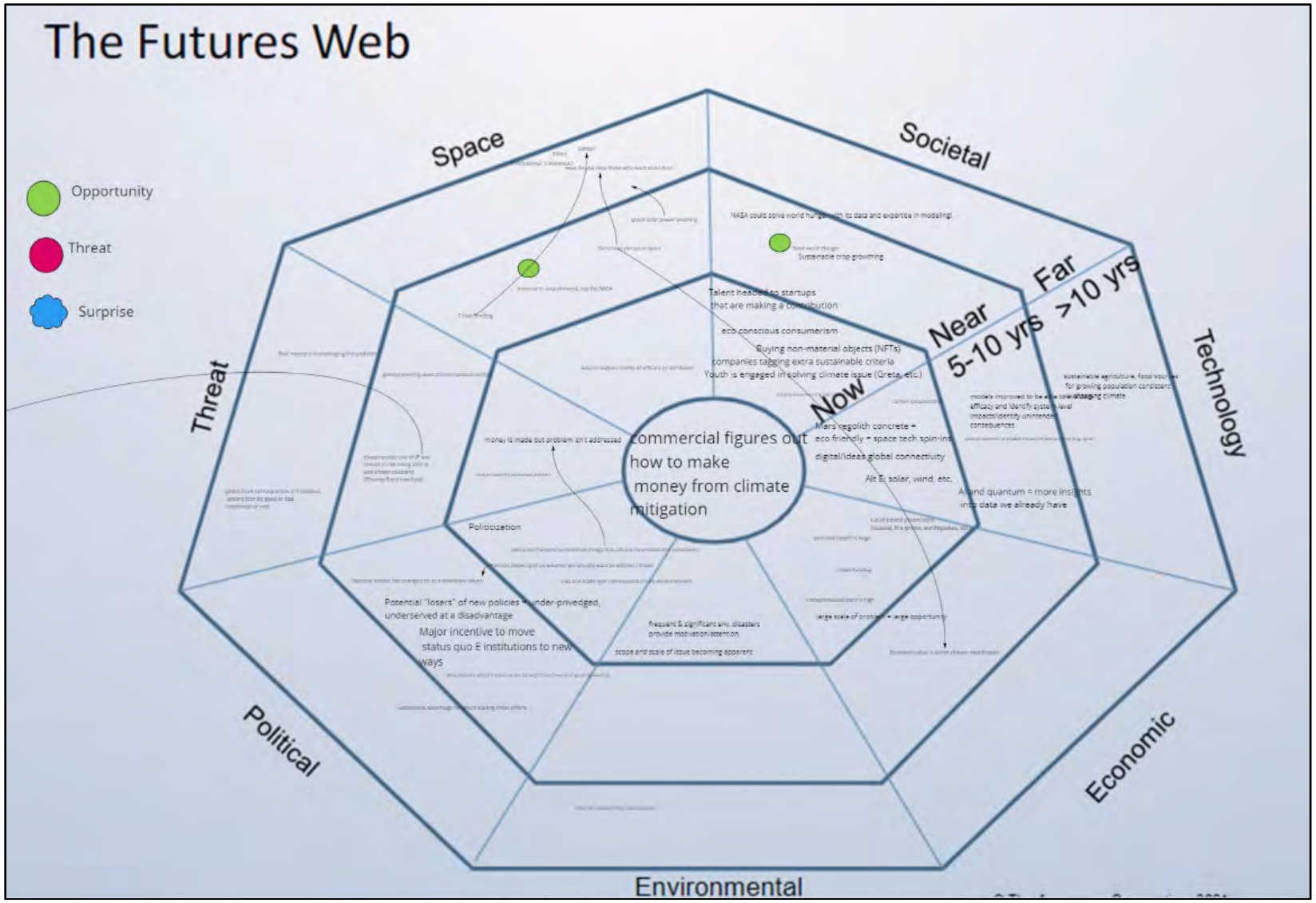


Figure 38. Virtual executive roundtable futures web - Team 2.

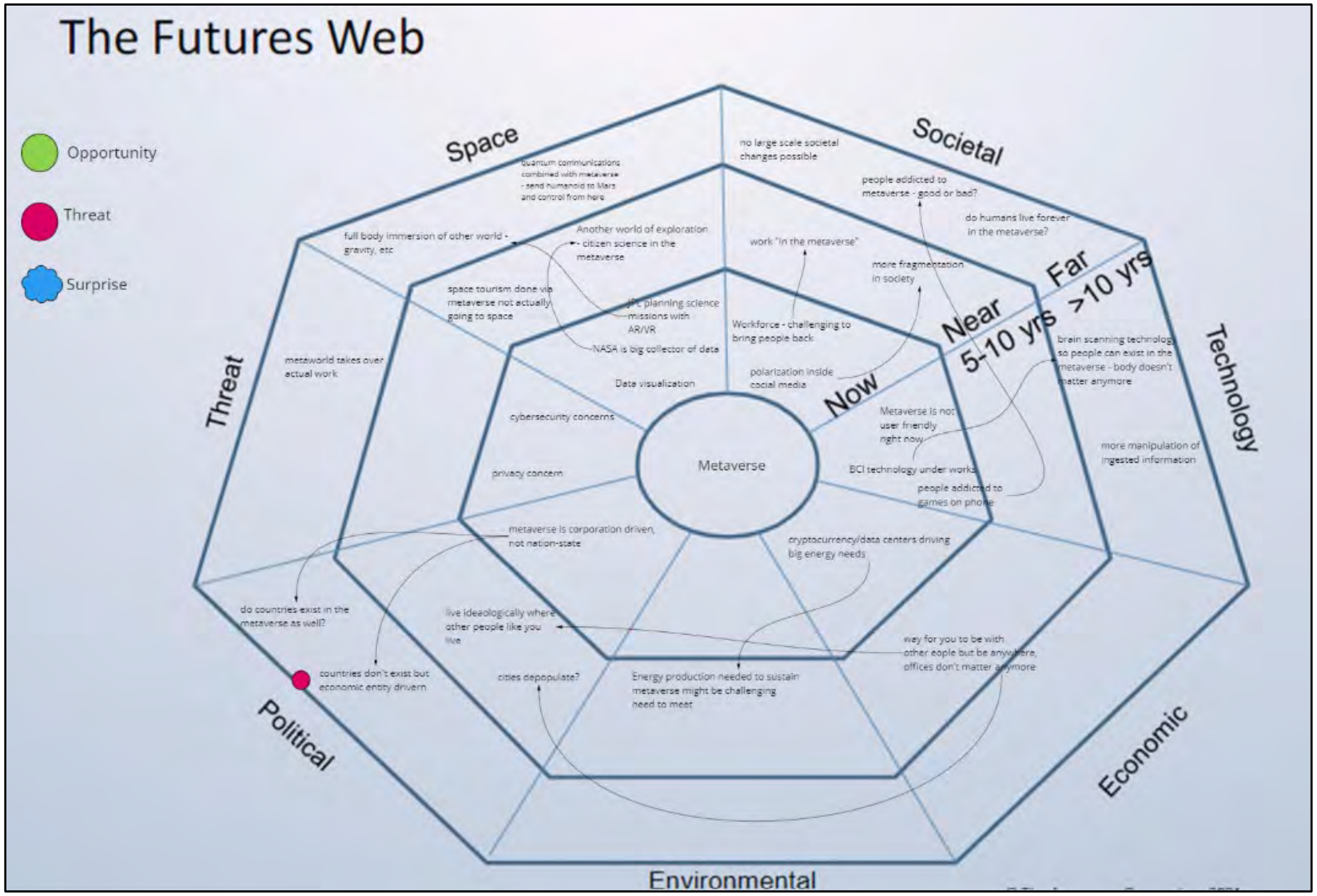


Figure 39. Virtual executive roundtable futures web - Team 3.

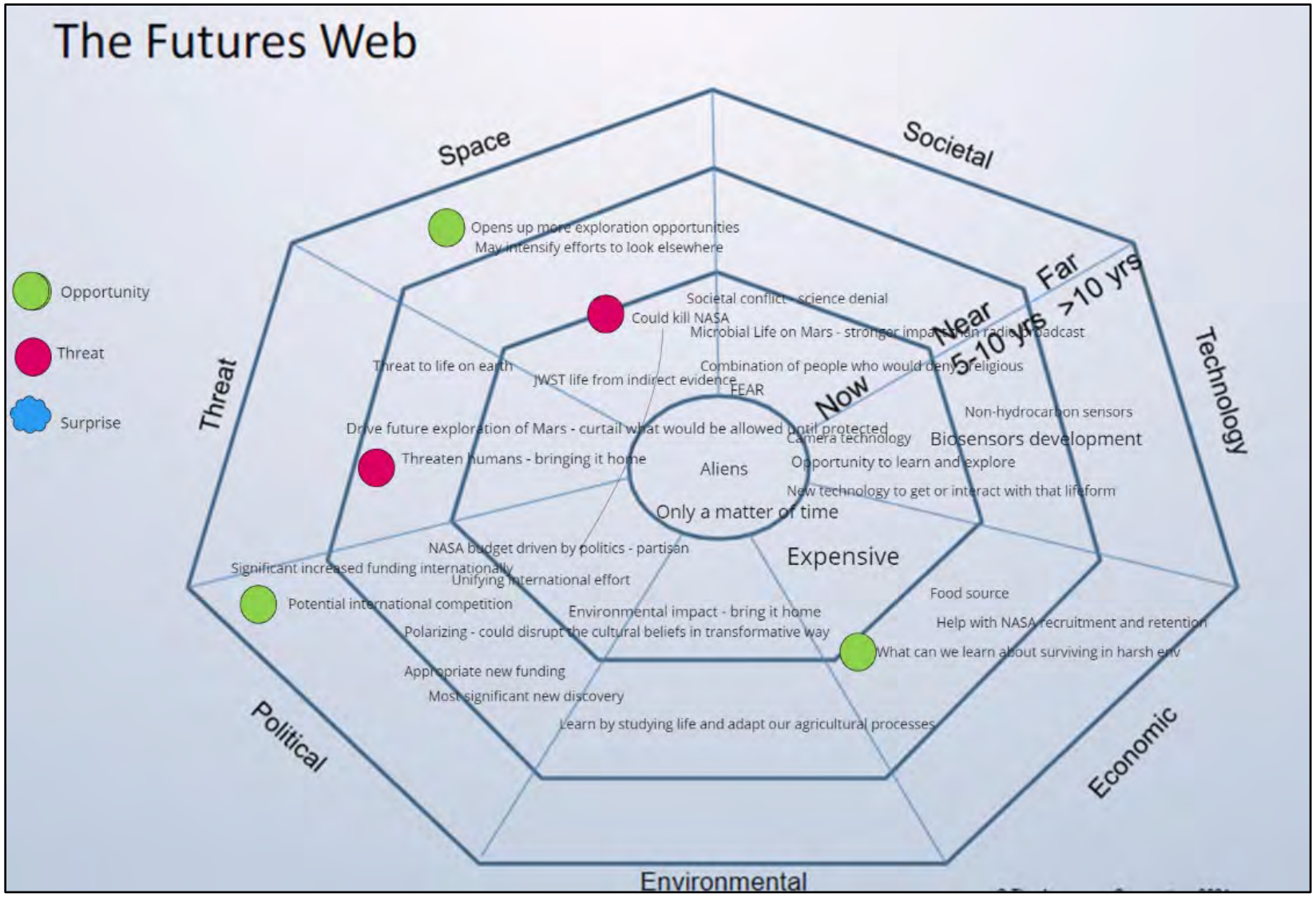


Figure 40. Virtual executive roundtable futures web - Team 4.

The executives' biggest takeaways from the roundtable event are shown in Figure 41.

Figure 41. Virtual executive roundtable event final takeaways.

C.3 Virtual Internal Roundtable

The Aerospace foresighting team hosted a virtual internal NASA roundtable with approximately 25 non-executive participants from across the agency over the course of 4 hours, including a focus on aspirational views for the future per the following agenda:

- Introductions
- Trends and disruptors (see Table 15 through Table 21)
- Mash-ups (see Table 22 and Table 23, Figure 42 through Figure 50)
- Futures web
- Imagine If?
- Implication discussion for NASA

The roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in this section.

The activity identifying trends and disruptors in the seven STEEPTS areas are shown in Table 16 through Table 21.

Table 15. Virtual NASA Internal Roundtable Trends and Disruptors (1 of 7)

Societal
Trends
• De-urbanization - move of <25% digital workers to rural, suburbs
• Two-body problem and difficulty for couples within STEM to find jobs
• Remote work and repurposing of office spaces
• Inequality is more dominant due to conflicts
• Growing divide between highly educated and not.
• Overwhelmed with collaborative tools
• Me first attitude
• Globalization of connection / communication
• Personalization
• Lack of U.S. STEM talent being educated and hirable within government
• Space access for all
• Entitled mindset
• Increased focus on righting racial/ gender-based inequalities
• Food supply chain is fragile
• People differentiating themselves in new ways - Maslow's
• Difficulty for immigrants to gain visas and U.S. citizenship"
• Demand for more benefits in the workplace
• Effective altruism vs personal altruism
• Blurring between fact/ fiction (misinformation)
• Increased cost of living
• More middle class increases
• Demands for goods and hence impacting earth health
• Increasing detrimental impact from social media
• Digital divide becomes more crippling
• Lack of ability to use collaboration tools which can be used quickly by all agencies and areas
• Increasing global conflicts and anti-globalization
• Increased focused on DEIA
• Overexposure to news and misinformation / "propaganda"
• Roe vs Wade overturned
• Addressing the healthcare crisis of long- term diseases
• Working in a "hybrid" environment
• Fewer people trained in trades/practical skills
• Climate change impacts
• Fear of open science approaches
• Lack of sufficient funding for science & eng., focus on short term projects (1 - 5 years) and lack of long-term projects
• Increased social media use
• Increasing polarization of views and political divisiveness
• Lack of embracing of diversity within the workspace
• Science as a gig economy - leading to lack of financial stability thus people leaving the field"
• Increasing virtual/decreasing in-person connections
• Virtual relationships in place of face-to-face
• Rise in disinformation, fringe views in popular culture, and populism
• Increased commercial space economy
• Flexibility - work/other
Disruptors
• AI for farming and food supply chain
• More personal interaction and less social media and people skills in a virtual environment
• Competition for scarce essential resources
• Consolidation of power into political and commercial monopolies
• AI-driven generative design
• Focus on commercialization vs. need for research not driven by profit
• Blockchain / digital currency
• Loss of accessibility for helium
• Will Elon Musk turn activist at Twitter?
• Wealth concentration amplifies idiosyncrasies and unintended consequences
• Surveillance
• Increase in collisions in LEO -> loss of access to space
• Legalization of Marijuana and other potential pharmaceuticals
• Increase access and acceptance of open science practices
• Backlash on social media/reduced use
• Urbanization leading to increased sanitation, urban heat maps, widening income inequality
• Wealth concentration
• Ubiquitous surveillance + effects on personal interactions
• Lack of acknowledgement of risks and need for regulations for commercial spaceflight
• Declining birth rates in developed countries
• Reduced investment in science/research given disinformation campaigns/ sowing distrust in scientific experts
• Impact of change in reproductive choices on workforce
• Commercial companies with power equivalent to governments
• China/North Korea
• Climate change disruption to society – coastal population centers

Table 16. Virtual NASA Internal Roundtable Trends and Disruptors (2 of 7)

Technological
Trends
• The rise of the cell phone
• Hollideck for immersion teamwork
• Push for green
• Addressing climate change with lesson from Mars and Venus
• Consolidation of platform technologies
• Deep space exploration
• AI-driven generative design
• Biomining
• Need for better communications with increase data collections
• Advanced manufacturing, additive manufacturing with new materials in new environments
• Quantum Technologies
• Dependance on the cloud
• Largescale 3D printing
• Mobility of work force
• Open-source h/w & s/w design
• Tech experts leaving Gov't for private industry
• High efficiency batteries
• IoT – everything connected to everything
• Synthetic biology and gene editing
• Constellations of SmallSats and CubeSats
• Lab-on-a-chip diagnostic/medical sensors and designer vaccines
• Nuclear systems for deep space/lunar night
• New launch vehicles
• AI/ML - long way to go yet with it and increase in new methodologies
• Biostructures
• Increasing application-specific CPU/GPU design – hardware accelerators
• Most emerging investments in healthcare are around Mental health, Life extension, gene editing/therapies, AI drug
• discovery, Nanomed
• Software engineers being poached into industry
• Bioprinting
• Commercialization of space
• LEO commercialization that enables lunar and mars
• New AI/ML techniques that don't require enormous electrical power
• Getting lost in collaboration tool alternatives
• Point-to-point travel without TSA?
• Classiq Announces $25k Classiq Coding Competition to Build the World’s Best Quantum Circuits
• Superpowered Chinese Lasers Could Soon Rip Open Raw Vacuum | Space
• Neuralink / Brain on a Chip
• Space tourism advances
• Commerce drives exploration and science – to enable more commerce
• Companies better at innovating than NASA
Disruptors
• Elon Musk to buy Twitter
• Ubiquitous augmented reality
• In-space assembly, in-space refueling, and on-orbit robotic satellite building
• Hyper- local, micromanufacturing
• Success of bioprinting
• Space junk in low earth orbit
• Quantum sensing and communication
• Virtual assistant for medical and emergency response
• Commercial mining of lunar/asteroid/etc. resources
• Limited access to fuel given geopolitical conflicts
• Growing body parts in the lab
• Fusion technology/"Free" energy
• Persistent surveillance of populations
• Increase in bias due to AI/ML and the implicit biases included in the input data
• Servicing of old satellites to increase their lifetime
• Singapore's Meta Bosses launches NFTs raising antibullying awareness - Fibre2Fashion
• Distributed, diversified power generation
• Self-assembling/ self-replicating robots and autonomous everything
• Commercialization of science technology leading to increase cost, decrease in reliability, & loss of in-house expertise
• Philanthropic funding of future science and technology and climate engineering
• New work environments - need to embrace of remote work and asynchronous work
• Life extension - immortality projects and private investments
• Air Taxi Startup, Vertiport Developer Define Aircraft- Ground Ops – IoT World Today - Online EV
• Economic Disruptions due to space mining
• AI that generates the better AI
• ZipCharge announces strategic partnerships with ICEE & Graphite, two British businesses, to develop the GoHub
• Self-aware Computer (SkyNet)
• Retirements and deaths of those who create specific tech before their knowledge has been transferred
• Catastrophic orbit debris event

Table 17. Virtual NASA Internal Roundtable Trends and Disruptors (3 of 7)

ECONOMIC
Trends
• DeFi - Decentralized finance
• Community owned real estate platforms
• Bull market
• China investing in social connections and infrastructure
• Seller's housing market
• Student loan debt
• Large companies crushing start ups
• Decrease in funding for science with respect to GDP
• Platforms for crowdfunding/tokenization - can be used for good or bad
• Concentrated wealth, inequality
• Growing shortage of "menial" labor
• Blackrock, Vanguard, State Street manage combined $22T (more than half of S&P500)
• SPACs – Special Purpose Acquisition Companies
• Focus on profits vs. long term innovation (this is where gov. can really help)
• Is Roofstock Reputable? An Investor's Information – My Blog (newsconquest.com)
• Unsustainable inflation in higher ed costs
• Russia/Ukraine conflict impacts
• Inflation and inflation's impact on cost of food
• Conscientious investing (ESG funds)
• Border crisis
• Crypto currency
• Drones everywhere
• Protection of resources and markets
• Dual-Impact investing
• Food security and food waste coexisting with food insecurity
• Rampant theft of IP
• Increasing debt - personal and government
• Housing market bubble (unsustainable increase in prices)
• Supply chain choke points
• Vertical integration
• Shortages of high-tech workforce, battle for talent
• Lack of stability for industry - turnover in companies to maintain specific needed tech and expertise
• Reduced tenure at jobs
• Automation eliminates an increasing number of jobs
• Inability to retire due to inflation or cost of essential services
• COVID pandemic continuation rises in outbreaks
• Financial literacy (decreasing?)
• Cost of education as a driver of change in postsecondary education infrastructure
• China one belt
• Cap of Civil Servant pay not keeping up with industry standard -> brain drain out of government labs
• Focus on sustainable farming
Disruptors
• Average family unable to purchase home – everyone rents?
• China's growing dominance, and China leverage over U.S. due to U.S. debt held
• Nomad employees
• Innovation in currencies, digital dollar, proliferation of incompatible cryptocurrencies
• Collapse of housing market/stock, market/crypto currencies etc.
• Funding/creation of Space Force leads to pushback of open science practices (72 hour delay)
• Removal of tenure within public universities (e.g., Florida)
• Family planning later in life
• Death of rural communities and associated brain drain
• Congress getting most of their income not from their representative duties -> this leads to the pay cap for government employees and loss of competitiveness with industry
• Inclusive work practices for people with children & family care responsibilities, need for paid maternity/paternity leave
• Gap between developing and developed nations
• China belt and road initiative - https://en.wikipedia.org/wiki/Belt_and_Road_Initiative
• Remote work, Telemedicine
• Resource Scarcity (water, minerals) vis-a-vis growing world population
• Fewer international students coming to U.S, and fewer international student staying in the U.S.
• Aging population, working population unable to support retirees (e.g., Japan)
• Restructuring of higher education to include more of the population
• Aging workforce within STEM - the lost generation
• Broad availability of broadband
• Decline in value of specialization – nurse practitioners, educators coincide with job movement to health sector
• Global conflict over resource scarcity
• Rise of influence of corporations in global interdependence
• Lack of highspeed rural internet (compared to mail, electricity, and phone)
• Complete shift in home "ownership" model to rental/corporate ownership of housing
• Shift away from traditional university education to more practical/trade education offerings
• UN SDG awareness mapping with decision making leads to supply chain uncertainties
• U.S. can't hire enough tech experts domestically

Table 18. Virtual NASA Internal Roundtable Trends and Disruptors (4 of 7)

ENVIRONMENTAL
Trends
• Farm to Table, localization of food
• Real science versus science driven by politics
• Pollution of near-earth space environment
• Lessen corporate pull in environmental policy
• Minimalism
• Reduced meat consumption - effects on human diet
• Increase of extreme weather, drought. and water shortages
• Oil eating bacteria, solar ponds, geoengineering, and unintended consequences
• Environmental justice
• Increasingly destructive weather events
• Lack of sufficient space weather data collection sites (both in space & on ground - Russia & oceans hard to cover)
• Overfishing, ocean acidification, and invasive species
• Urban regeneration and “water wars”
• Destruction of forests and wetlands
• Expansion of human occupancy in bio-diverse land
• Radiation environment within atmosphere/ionosphere as space tourism expands
• Overdevelopment without consideration of future water needs
• Species collapse
• Renewables causing landfill and end-of-life issues
• Poor infrastructure for clean water and foods
• Environment on Moon and Mars -> need to learn more about as humans start to explore these regions
• Developers without stake in environmental/societal impact of their development
• Focus on sustainable farming
• Lack of genetic diversity in food supply
• Pandemics
• Lack of available Helium
• Growing gaps in housing options
• Sustainable production of meat
• Misguided reforestation leading to soil erosion, decrease in biodiversity
• Recycling – is it commercially viable?
• Trash - where to put it and how to remove it, both in general and nuclear
• Environmental tourism
• Transition from oil to alternate forms of energy
• Greater interest in hybrid/electric cars
• Realization of our impact on environment without willingness to take actions needed to address that impact
• Greater unpredictability in weather
• Species extinction or relocation to new environments
• Increased acceptance of plant-based foods
• Increased mining of rare materials needed for green technologies
Disruptors
• Stock investments in farmland
• Community supported agriculture
• Organic farming and local farming
• Carbon capture
• Saturation frequency in certain bands
• Flora and fauna zone changes due to climate change
• Genetically modified foodstuffs
• Scandinavian (Sweden?) law for right to repair
• Geo- engineering
• SCoPEx (Aerosols in the atmosphere)
• Lack of ability to grow enough food
• Politics misusing science
• Syn Bio and unintended consequences - White House report on ethics
• Massive refugee crisis due to climate change
• Reduced interest in outdoor sports due to harsh conditions
• Free public transit
• Shift to geothermal energy generation
• Diversified food production to provide food security
• Video-gaming medical issues
• More synthetic foods
• Do artificial meats reduce emissions or create different problems in the supply chain?"
• Famine, diseases, sanitation, increased inequity due to climate change
• Plant-based food alternatives
• Push back against GMO -> leads to inability to grow enough food for population
• Long ago removal of rail lines in US lead to dependance on cars and gas – need the reverse to now happen
• "Blue Arctic" for shipping
• Opening up of northern latitudes for agriculture
• Gamification and crowdsourcing climate change solutions in the metaverse
• Extinction of pollinators (Collapse of food supply)
• New transportation technologies (Hyperloop)
• Great pacific gyre (plastics gone amok)

Table 19. Virtual NASA Internal Roundtable Trends and Disruptors (5 of 7)

POLITICAL
Trends
• Popular vote vs electoral
• Government increasingly resistant to change and reactive
• Balkanization
• U.S. anti-science sentiment
• Accountability of government funds
• Lack of support for infrastructure development
• Rise of authoritarianism
• Harder to get VISAs, green cards, and citizenship
• Gerrymandering
• Term limitations being avoided
• Increase in line items pushing science in one direction vs. another
• Lack of bipartisanship
• Wars
• Polarization
• US military wants nuclear rocket ideas for missions near the moon | Space - kick start new cold war in space?
• Prevalence of misinformation drives poor decisions
• Extreme divisiveness
• Increase in conflict between "left" and "right" (people can no longer be "center")
• Group think due to politics
• Lack of public understanding of how important responsible gov't leaders are to our well- being
• Return to Cold War style environment
• Elected leaders opposed to compromise
• Discriminatory refugee policies
• Funding of politicians coming not from their jobs
• Another cold war signal – removing buffers is bad – Are Sweden and Finland going from neutral to NATO? - BBC News
• No elected leaders looking at investing in long- term future (20+years)
• Increasing proxy wars in "3rd world" countries (Ukraine/Syria)
• Drones make people apathetic to war impacts
• Alternative facts
• Growing acceptance of biowarfare / nuclear warfare
• Decreased decorum in political discourse, driven largely by examples set by media and social media
• Inability for civil servants to lobby, thus don't get a voice with their representatives and for the budgets
• Serious issues going to public vote instead of "expert input"
• Public schools being discussed as option to get rid of
• Funding social programs rather than areas that progress mankind
Disruptors
• Refugees from war, famine, environment
• Cyber war
• Abolishing public schools
• User-centered design in govt
• Development of Space Force and the commercialization of space
• Punishing people for speaking out against unscientific work in the name of free speech
• Banning books
• Wars fought with corporate armies (Blackwater)
• Hackers attacking
• Increased effectiveness of propaganda
• Alternative facts
• Push to have all government agencies create and help develop industries/profits instead of long-term thinking and having a source of specific expertise
• Civil war
• Jan 6th
• The media not reporting both sides of a story
• Disappearance of peaceful transition of power
• Political strongmen seizing power
• Chinese growing influence on global politics
• “Bothsiderism” when one side is small compared to the other (e.g., climate change is real and not man made)
• Autocracy growing
• VPNs enable populace to circumvent censorship
• Eradication of two-party system
• Corpocratic governance
• Political correctness and how it plays into group think
• Autocratic elected leaders
• Lack of maintaining national infrastructures, e.g., power grids
• Politicians funded by and beholden to billionaires

Table 20. Virtual NASA Internal Roundtable Trends and Disruptors (6 of 7)

THREAT
Trends
• *Chicxulub asteroid*
• *Climate Change tipping point*
• *Tsunamis + earthquakes*
• *Ecosystem collapse*
• *"Limited" nuclear war*
• *Amazon buying up launches for next 3 years*
• *Unsustainable Federal Budgets (large cuts to science and tech in the future)*
• *Cyber security*
• *Science + technology illiterate public*
• *Catastrophic orbital debris event makes region of near-Earth space unusable*
• *Decrease in funding for government agencies and funded science*
• *Extreme weather*
• *Domestic terrorism*
• *Food insecurity*
• *Satellite constellations in LEO and the Kessler effect*
• *Anti-science sentiment*
• *Removal of tenure*
• *Gene drive: genetic modification designed to spread faster than typical inheritance*
• *Nuclear war*
• *Water wars*
• *Targeting of satellites*
• *Dumbing down of primary school education*
• *Economic warfare*
• *Political dictators*
• *Brain drain loss of technical and science expertise*
• *Climate crisis*
• *Deterioration of IDEA initiatives leading to loss of expertise in the workforce*
• *Reduced reproductive health options*
• *Long term threat if there is sentient alien life: Sending Earth's location out to reach aliens is a controversial idea space*
• *Exodus of medical practitioners from the field*
• *Cyberwars*
• *Fear of nuclear weapons impacting how nations protect vulnerable nations*
• *Ukraine budget impacting Congressional spending*
• *Social media bots*
Disruptors
• *Cheap high- tech countermeasures to military action*
• *Creationism and flat earthers entering into government decision making roles*
• *Lack of redundancy of space technology (loss of GOES or national satellites)*
• *Freeze on supply chains for US Space and aviation due to cold war*
• *World War 3 with China, Russia, etc. on one side*
• *Failing electrical grid*
• *"Insider threat' - hacking of biotechnology (pacemakers, etc.)*
• *Russia using Ukraine war*
• *A couple of collisions in LEO*
• *Blight drastically reduces food staple crop (rice and corn)*
• *A >Carrington event*
• *Persistent low- level armed incursions*
• *China dominating space*
• *Gene-targeted viruses*
• *Climate change releases viruses from permafrost thaw that we are not prepared for and MRNA techniques unable to design to*
• *Mega constellations impacting comms/earth science*
• *Another pandemic*
• *Extraterrestrial object (high speed/no forewarning)*
• *Nationalism*
• *CubeSats mitigating satellite safety*

Table 21. Virtual NASA Internal Roundtable Trends and Disruptors (7 of 7)

SPACE
Trends • *Competition for control access and use of space environment* • *Some accomplishments of China in Space surpassing US* • *EMP attacks and war* ***Disruptors*** • *Terraforming* • *Breakthrough Starshot/Interstellar travel*

The roundtable participants were divided into three groups for the mash-up activity where each team identifies three signals and brainstorms the combine impact and implications of the signals. Three rounds of the mash-up activity were performed by each of the three teams. The summarized results noting the three signals used for each mash-up activity and the key takeaways for the nine mash-ups are shown in Table 22 and Table 23. The Miro boards from Team 1's three mash-up rounds are shown in Figure 42 through Figure 44. The Miro boards from Team 2's mash-up activities are shown in Figure 45 through Figure 47. Finally, the Miro boards from Team 3's mash-up activities are shown in Figure 48 through Figure 50.

Table 22. Virtual NASA Internal Roundtable - Mash-up Summary (1 of 2)

Mash-Up	**NASA Internal- Virtual**	
	Signals	**Takeaway**
Mash-Up #1	1. Geoengineering the atmosphere: NASA is not yet recommending geoengineering to bounce heat back into space but recommends an "emergency plan" be investigated 2. Increased High Risk Capital: The amount of capital that is available for high-risk endeavors has increased 3. Cooling Upper Atmosphere: Long- term data on the mesosphere, the layer 30 to 50 miles above the earth's surface, has revealed that it is cooling and contracting	Unintended consequences of potential meddling with Earth's climate/atmosphere; could NASA perfect geoengineering off-world and bring it back?
Mash-Up #2	1. 3D- printed lung-mimicking air sac brings functioning bioprinted organs a step closer 2. New Study Highlights the link between greater green space and reduced loneliness 3. Philanthropic funding of future science and technology	Ensuring NASA and other public entities remain relevant, as capabilities, funding, and infrastructure building shift to outside parties. Important to maintain public interest, don't let everything go to commercial, it's a balance.
Mash-Up #3	1. Extracting water from dry air: Researchers at MIT and elsewhere have significantly boosted the output from a system that can extract drinkable water directly from the air 2. Deep space imaging, combining 8 radio telescopes of the event horizon of a blackhole 3. Increase use of 3D printing houses, buildings & structures	One key capability/technology can change the art of what's possible (e.g., thriving in the desert, living off-world, or looking deeper into space than ever done before)

Mash-Up	NASA Internal- Virtual	
	Signals	**Takeaway**
Mash-Up #4	1. Federal debt continues to rise 2. SettleMint is exploring the use of blockchain technology to reduce corruption in the public procurement process 3. Russia, China to sign agreement on international lunar research station	Increasing US debt is putting NASA in a tough spot; NASA seen as a luxury not a necessity - not seen as needed to survive (cancer research, military) - loss of funding means less likely to make it to the moon - wouldn't be able to be at the forefront of norms of behavior in space; would need to rely on partners - Russia/China could drive diplomacy norms Our response won't be another Apollo like program - try to tap into entrepreneurial nature of US - driven by commerce; science done will be driven by what has a high ROI (not beneficial for NASA or commerce - lots of discoveries critical to commercial haven't been through commercialized efforts)
Mash-Up #5	1. A race may develop between major players toward artificial general intelligence (AGI) once it becomes clear that AGI's creation is possible with resources available at the time 2. Researchers Devise Card Game to Create a more Inclusive Experience for Awareness of Urban Planning Research for Kuwaitis 3. People are starting to come from more non-traditional educational backgrounds - e.g., Coursera to augment knowledge instead of going back to university setting	NASA collecting so much data - can't actually process in a meaningful way

Table 23. Virtual NASA Internal Roundtable - Mash-up Summary (2 of 2)

Mash-Up	NASA Internal- Virtual	
	Signals	**Takeaway**
Mash-Up #6	1. Ben Klein, Sandia's lead clinical psychologist, said he has seen "a rise hostile interactions and verbal conflicts between colleagues," which may be related to an increase in virtual work 2. Increase in hiring of IT support from North Korea with increase in virtual work opportunities 3. NASA, Intuitive Machines Announce Landing Site Location for Lunar Drill. Impact: Resource mining in space will raise new diplomatic concerns and lead to claim- staking in space	Cyber-physical investments may be a priority Need to find better ways to manage IT and cyber security risks
Mash-Up #7	1. Ben Klein, Sandia's lead clinical psychologist, said he has seen "a rise in hostile interactions and verbal conflicts between colleagues," which may be related to an increase in virtual work 2. Iceland Tried a Shortened Workweek And It Was An 'Overwhelming Success' 3. World's first living robots can now reproduce	Ethical issues with respect to reproducing robots
Mash-Up #8	1. 3D-printed lung-mimicking air sac brings functioning bioprinted organs a step closer 2. Neural net can detect leaky pipes 3. High Density, Ultra- low- energy digital computing	Potential to solve a problem of today that is hard to solve
Mash-Up #9	1. Iceland Tried a Shortened Workweek And It Was An 'Overwhelming Success' 2. Commercial suborbital flights allow for rapid travel 3. Ukrainian Refugees sent to "foster homes" not refugee camps - given some period of time in new country	Opportunity to learn and benefit global society

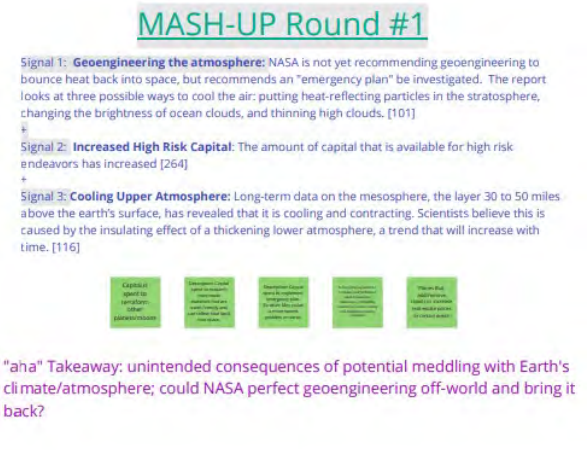


Figure 42. Virtual internal roundtable Team 1, Round 1 mash-up.

Figure 43. Virtual internal roundtable Team 1, Round 2 mash-up.

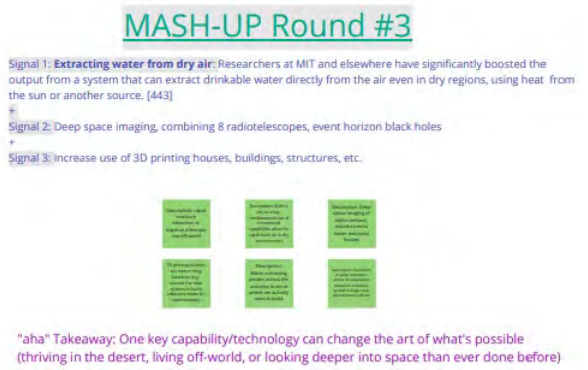


Figure 44. Virtual internal roundtable Team 1, Round 3 mash-up.

Figure 45. Virtual internal roundtable Team 2, Round 1 mash-up.

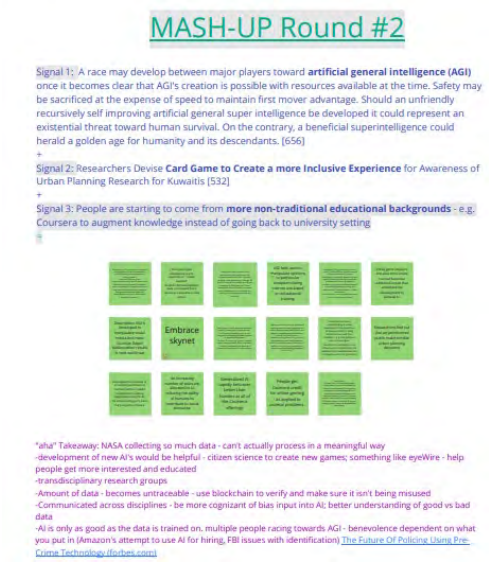


Figure 46. Virtual internal roundtable Team 2, Round 2 mash-up.

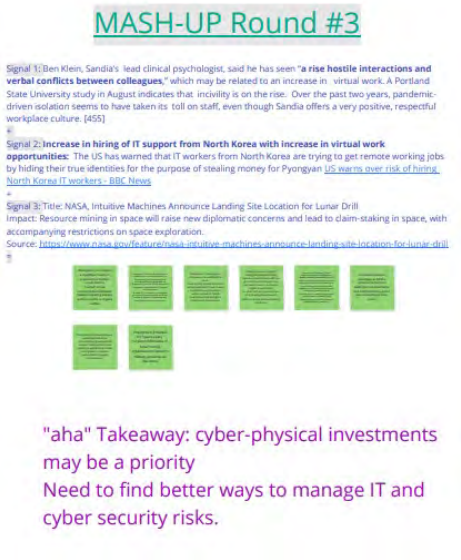


Figure 47. Virtual internal roundtable Team 2, Round 3 mash-up.

Figure 48. Virtual internal roundtable Team 3, Round 1 mash-up.

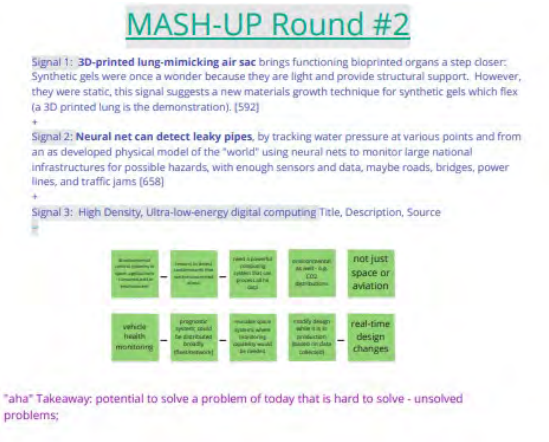


Figure 49. Virtual internal roundtable Team 3, Round 2 mash-up.

Figure 50. Virtual internal roundtable - Team 3, Round 3 mash-up.

Following the mash-up activity, the group was split into three breakout rooms for the futures web activity. Team 1 explored the near- and far-term possibilities associated with scaling inclusivity and equity in exploration, happening at scale as shown in Figure 51. Key takeaways for Team 1 included the value of a diversity, equity, and inclusion (DEI) expert to assess the impact of this scenario; identified threats that stand in the way of achieving this future state; and identified opportunities that exist to seed better DEI results in business, STEM, and social media.

In the futures web activity, Team 2 explored the near- and far-term possibilities associated with the commercial enterprise overpowering the government as shown in Figure 52. Key takeaways for Team 2 included (1) many potential threats if commercial took over; (2) NASA would need to lock in utility in commercial market (some semblance of what we do now, development, de-risking, oversight); (3) look at semiconductors (commercial market) and develop new technology together with commercial because it's so expensive (could NASA replicate and be that center?); (4) environmental threats from unregulated commercial activity are enormous—would need regulation and impact science observations, emissions from launch, threat from debris and collision issues, and put ground-based astronomy out of business; and (5) need unique leadership so both NASA and commercial can do what they do best.

In the futures web activity, Team 3 explored the near- and far-term possibilities associated with a breakthrough in interstellar spaceflight as shown in Figure 53. Key takeaways for Team 3 included (1) 10 years is too short timeframe—need to think long term, (2) dramatic change to NASA's goals and outlooks, and (3) NASA not necessarily the driving player/leader—industry and other nations have big roles.

The last activity in the virtual internal roundtable was the "Imagine If" free write describing the participant's organization's best possible self in a future state with customers, core values, purpose, attributes, and inspirations as shown in Figure 54. The answers to the second part of the exercise described the participant's organization in different aspects, focusing on types of problems it is solving, uniqueness, core capabilities, innovation, and internal coordination with other organizations.

The roundtable participants documented their big takeaways from the event, shown in Figure 55, answering the question "What are some key differences between today's state and the future state that will require big change?".

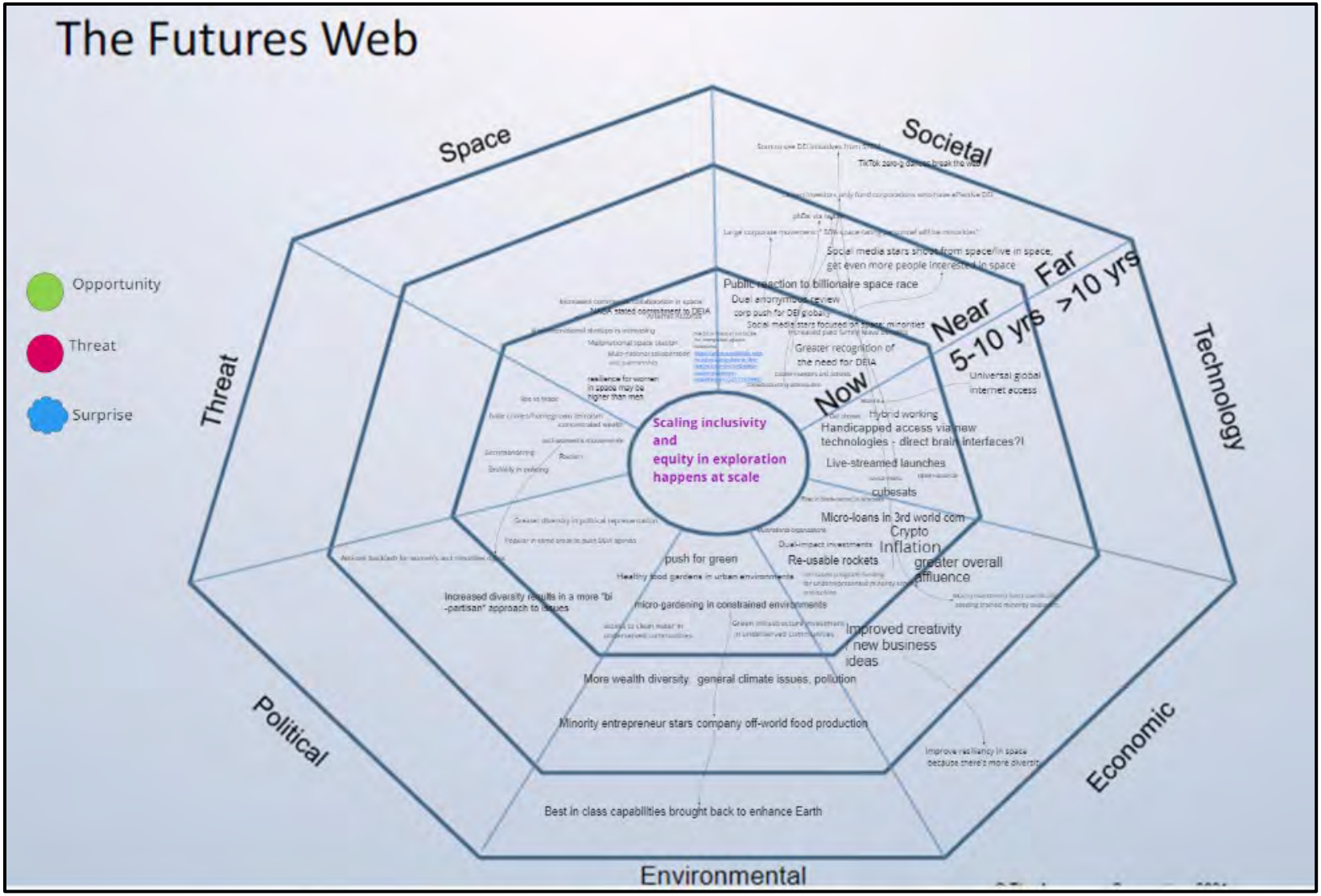


Figure 51. Virtual internal roundtable futures web - Team 1.

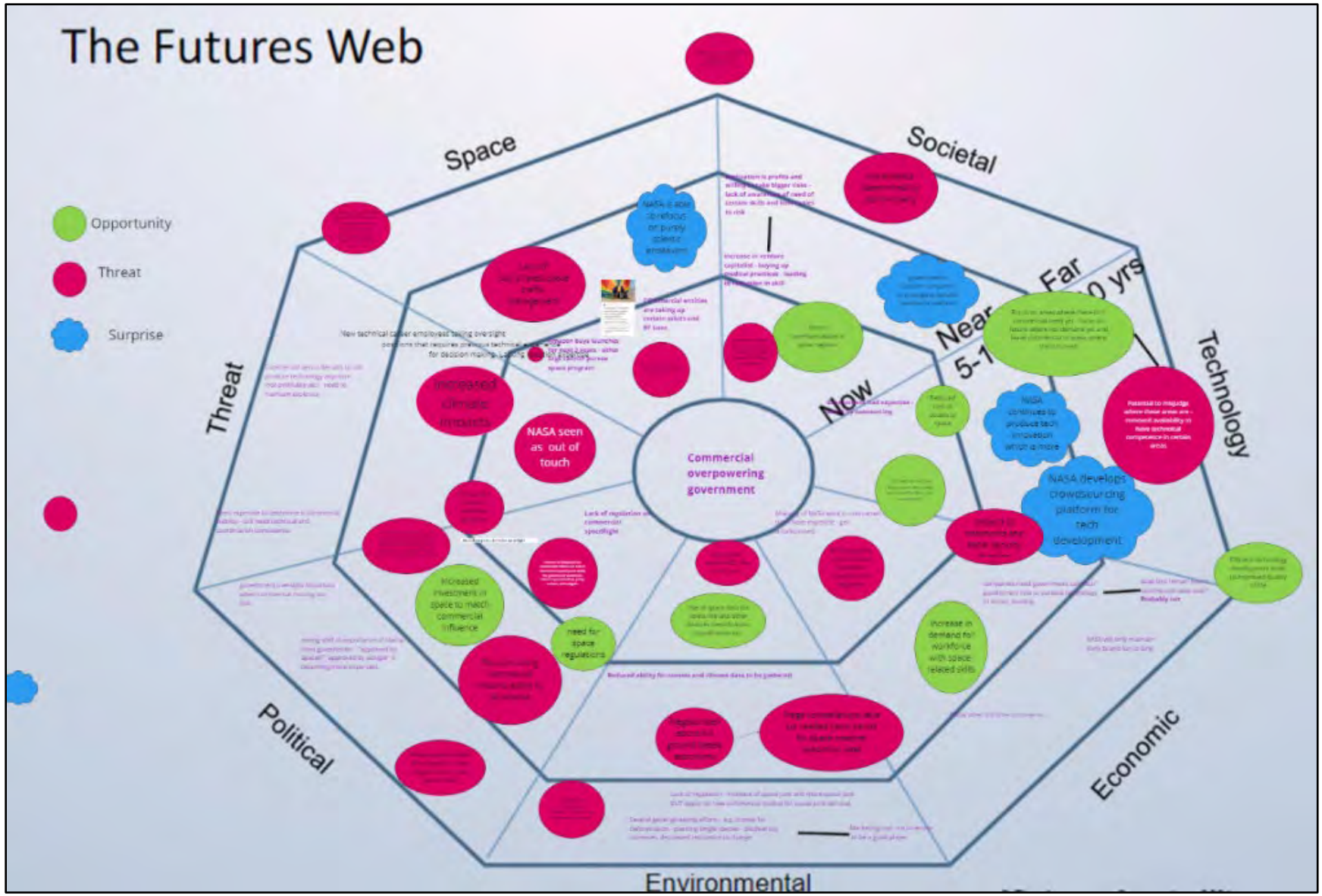


Figure 52. Virtual internal roundtable futures web - Team 2.

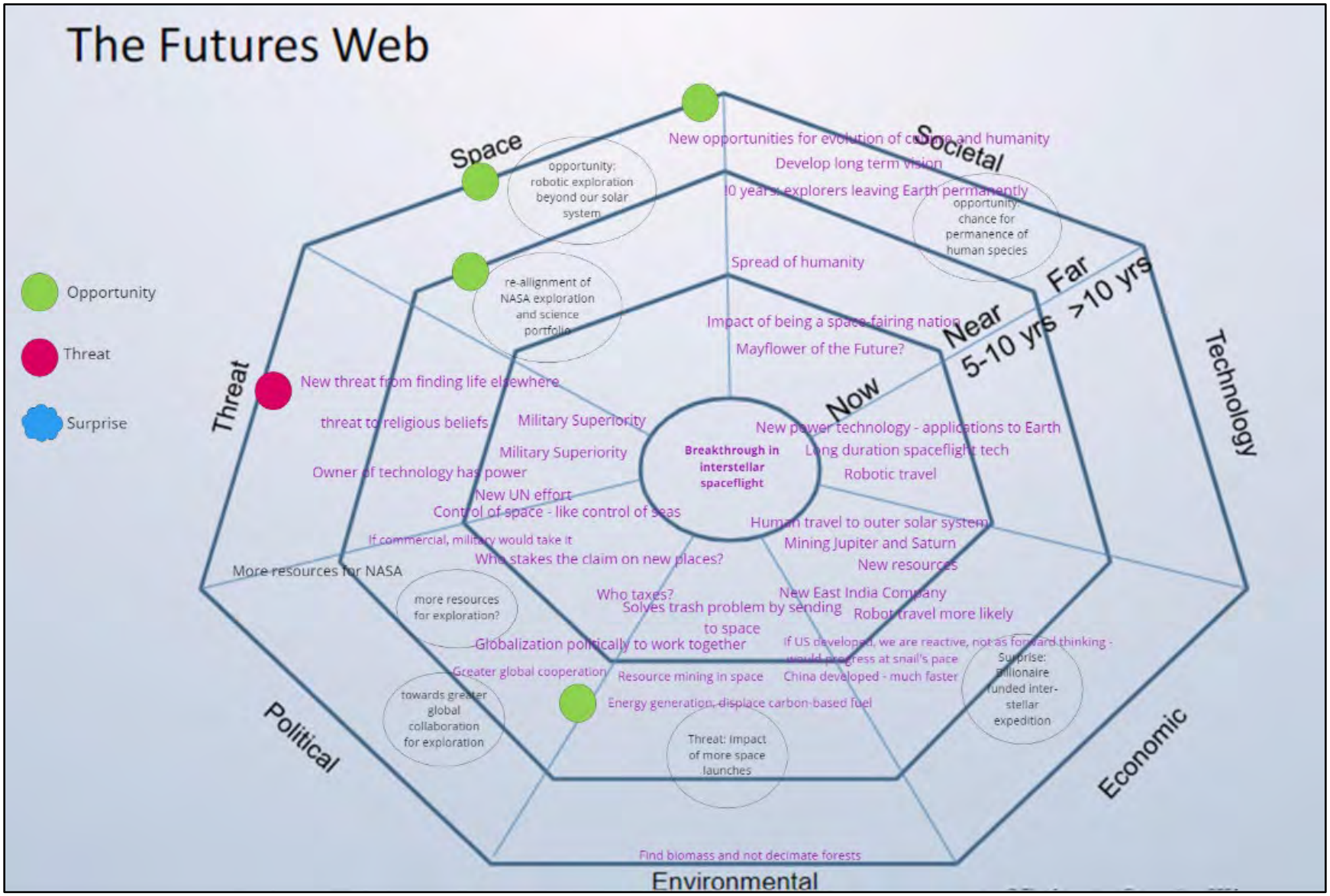
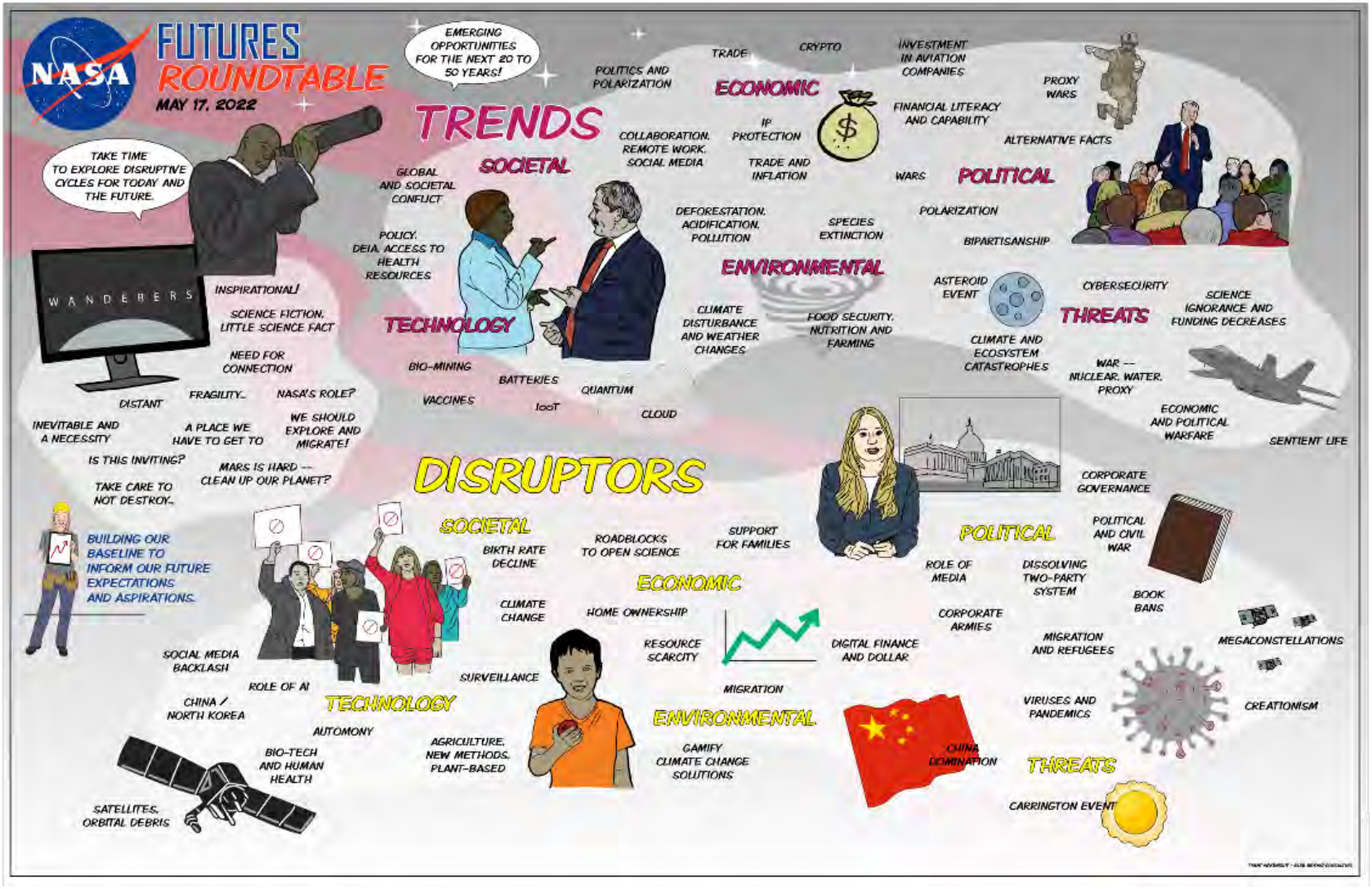


Figure 53. Virtual internal roundtable futures web - Team 3.

Figure 54. Virtual internal roundtable "Imagine If" free write.

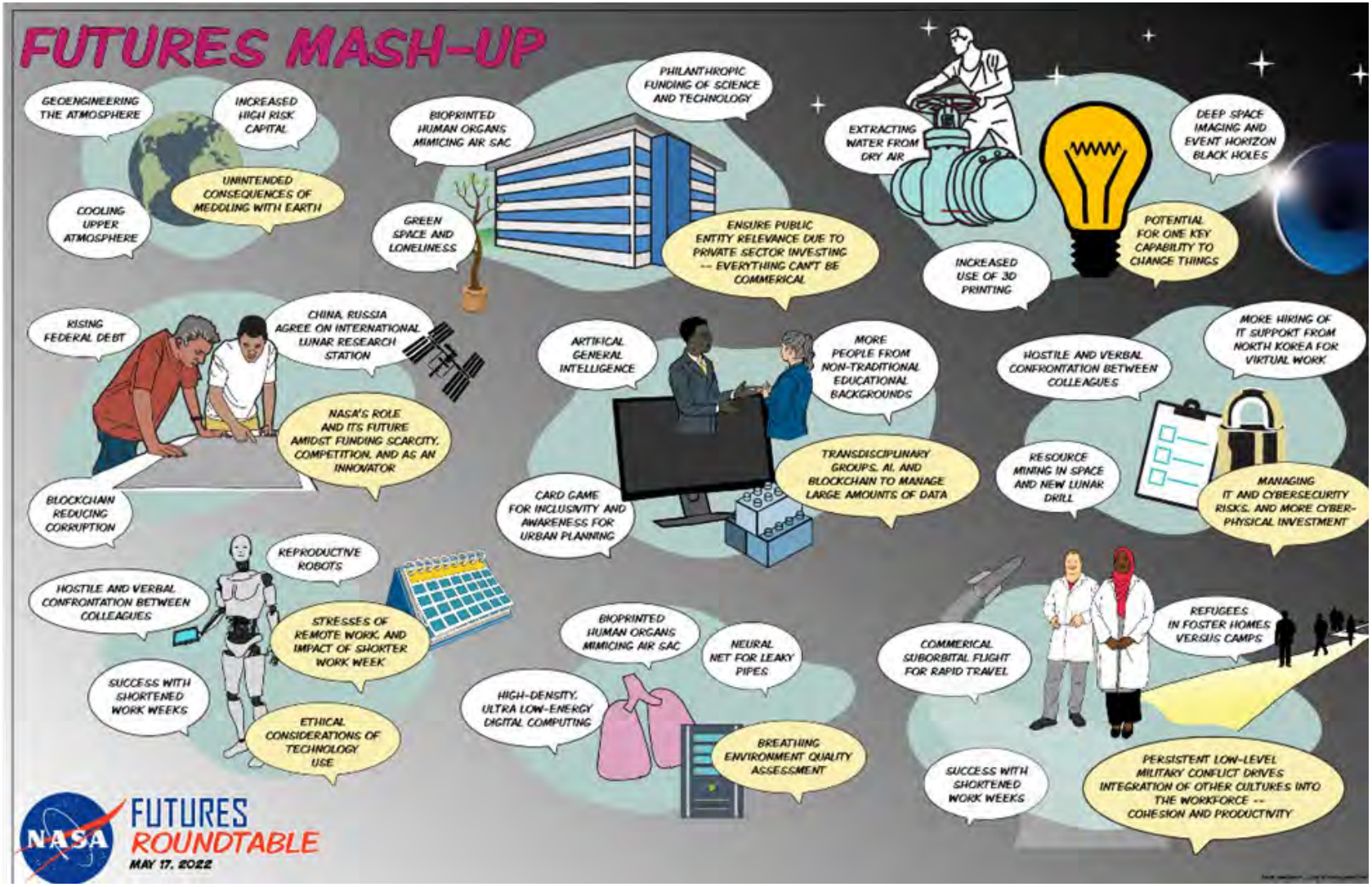
Figure 55. Virtual internal roundtable big takeaways.

The virtual internal roundtable session was graphically facilitated by Trent Wakenight of Blue Beyond Consulting, a visual communication consultant who supports complex technical projects with real-time illustrated story maps. The three graphic recordings are shown in Figure 56, Figure 57, and Figure 58.



Courtesy of NASA

Figure 56. Virtual internal roundtable graphic recording 1 of 3 (image created by Blue Beyond Consulting).



Courtesy of NASA

Figure 57. Virtual internal roundtable graphic recording 2 of 3 (image created by Blue Beyond Consulting).

Courtesy of NASA

Figure 58. Virtual internal roundtable graphic recording 3 of 3 (image created by Blue Beyond Consulting).

C.4 Virtual Early Career and Employee Resource Group (ERG) Roundtable

The Aerospace foresighting team hosted a virtual NASA early career and ERG roundtable with approximately 35 participants from across the agency in a 2-hour session. The roundtable focused on aspirational views for the future per the following agenda:

- Introductions
- Directed questions
- Trends and disruptors (STEEPTS)
- Mash-ups
- Key takeaways for NASA

The roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in this section. The first activity asked the participants to answer, "What is the most exciting thing happening in space in 2022 and in 2042+?" The responses are shown in Figure 59.

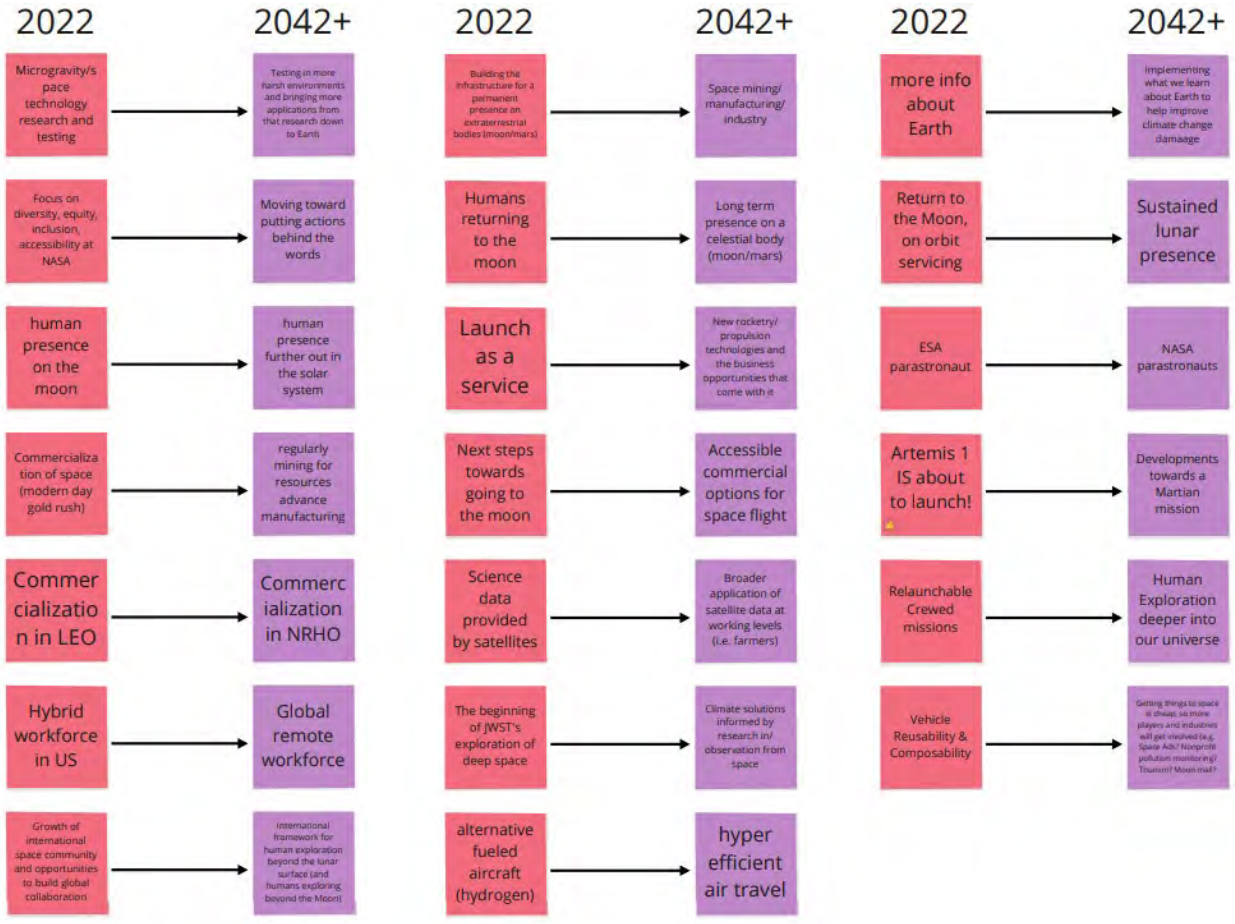


Figure 59. Virtual early career and ERGs roundtable directed questions.

Trends and disruptors were identified for societal, technological, economic, environmental, and political areas of impact as shown in Table 24 and Table 25.

Table 24. NASA Early Career and ERGs Virtual Roundtable Trends and Disruptors (1 of 2)

Societal	Technological	Economic
Trends • Belief that alternative solutions must be all- encompassing or perfect to be valid • Distrust in science/scientific community • Stigma around Mental health & Neurodiversity in workplace • Regular Use of AI • Us vs Them Mentality - lack of intercultural competency • Fear of change due to tech • NASA not encouraging geographically diverse applicants • Dearth of knowledge about variety of careers available at NASA • Ideological Polarization • Kids want to be TikTok influencers, not scientists • Generational miscommunication, driven by social media • Nomadic lifestyle (van life) • Normalization of overworking (long hours) and not taking vacations • Aligning career with orgs that share values • careers vs jobs (loyalty to companies) • Misinformation campaigns • Younger generation willingness to leave unsatisfactory jobs • People increasingly seeking morally aligned jobs • Waiting/deciding not to have kids • Cancel culture • reliance on technology • Diversifying representation	***Trends*** • high technology treated like seasonal fashion (buy iPhone 1200) • Cloud storage • Digital media replacing physical media • Self-driving vehicles • Smart homes/internet of things • Digital warfare • Data Sprawl • NST just announced quantum-resistant encryption • Regular use of AI • Autonomous vehicles • Devices that use natural language processing • Genetics (including editing) • Right to repair • Open science • Polarity between convenience and environmental impacts • Drones • Wearable technologies • Everything is a streaming service • Augmented reality • Electric Vehicles • Open-Source Coding • Importance of IT security • 3-D printed organs	***Trends*** • Toyota owns 50% solid state battery Patents (EVs) • Stagnant wages • Launch provider bubble • Shift to subscription model for all things • NFTs(and the death thereof?) • Not saving for retirement • retail stock investors coordinating stock sales • Job markets/lack of factory positions • What does virtual ownership mean/grant rights to? • Stolen intellectual properties • Renting vs Owning (struggle to buy houses, cars) • Universal paid parental leave • Universal basic income • College/university debt becoming untenable • Wage theft • Smaller satellites (micro, mini, nana size) • Gentrification of urban areas • Healthcare tech investment has quadrupled in 3 years (mostly direct-to-consumer) • Inflation • If possession in 9/10 of the law, what does "virtual possession" look like? • Discrepancies in funding resources between NASA centers - some projects can afford more tools than others • Increased access to space (decrease in cost per kg) • What does ownership mean for virtual things?
Disruptors • Improved access to healthcare via telehealth, but economic disparity in the technology needs it requires means the access isn't for everyone • Mass forced unemployment (automation) • The "Lying Flat" movement	***Disruptors*** • Free-to-use technology shifting to paid-majority disrupting government/education/institutions with little funding • "Laboratory on a chip" biomedical devices • Implants (cybernetic) • Gene editing is now in the human-trial startup space for moderate risk treatments (cholesterol) • Discontinuation of disruption of cloud services • Open-source software authors removing access to their code and breaking the internet (reddit users disrupted the stock market) • "Land" in the metaverse is being sold for absurd prices • Right to repair • Hacking of critical infrastructure • Modular Open Systems Approach (MOSA) for Space	***Disruptors*** • Housing Prices • Large companies buying all the homes to make them Airbnbs and other shady practices • Exponentially expensive world relative to stagnant government pay • Paying employees living wages • Startup companies going around laws and regulations • Gender equity at work, beyond and including pay

Table 25. NASA Early Career and ERGs Virtual Roundtable Trends and Disruptors (2 of 2)

Environmental	Political
Trends	***Trends***
• It's getting Hot in here (have you been to the South?) • City Planning to mitigate/adapt to climate change • Recycling capability not growing as fast as waste is produced • Negative attitude or apathy towards environmental issues both as individuals and corporations • More interest in public transportations (bullet trains) • Global warming impacting the food supply chain • In situ resource utilization in Space, "live off the land" • Carbon Capture tech • Indoor farming • Alternative fuels • space debris (tracking and mitigation) • Shifting recycling responsibility to consumers in place of increased scrutiny on industry • PFAS • Moon to Mars (tech that works for both environments) • Nuclear for space power and transportation • Light Pollution • Satellite constellations ruining astronomy • Greenwashing • Green energy - solar, wind	• Weakening of Chevron deference leading to decreasing gov't regulation • Deep fake interviews of politicians are now convincing • Expanding cooperation necessitating new legal frameworks • Decreasing trust in government • Claiming existing territories • Economic income inequality is now at 1900 levels • Erosion of right to privacy • mass migration to escape oppressive policies • Embracing both competition and collaboration • Independence in terms of space access (i.e., not relying on other countries) • We are less divided than media pretends we are • China • Russia • Worldwide trend towards nationalism • Budgets and advertised launch based on election terms • Corporate influence in DC / citizens united implications • Desire for overhaul of police/justice system • Changing administration affecting NASA vision • Term appointments Congress controls headcounts • LEO as a battleground • Ownership of Moon/Planetary territory • Artemis Accords • The future of Space Force and how it relates to NASA long term • Motivation to return to on-site work for political reasons • New and emerging space agencies
Disruptors	***Disruptors***
• Bacteria/fungus that can eat plastic • Will the next pandemic come from the thawing Antarctic? • Other countries could choose not to accept US trans • Space junk clean up • Will Methane increase exponentially and irreversibly due to the thawing permafrost • Dust Bowl 2.0 • Servicing / on-orbit spacecraft maintenance • Discovery of new species/organisms in space • Making climate change the #1 priority, especially in public policy • New recycle technology • Following Gen Z's example of a singular focus on the environment • Plant-based diets • Lab grown (plant-based) meat • Human habitation on another planets/moon • crypto mining	• Claiming a new territory (like on the moon) • EPA vs West Virginia • AI being used to filter out job candidates (ostensibly for cheating) • Dobbs vs Jackson Women's Health • capping terms of Supreme Court Justices • If we lose democracy will representatives from NASA states have the power to get us funding? • Competition with heavy lift launch vehicles • Can NASA maintain its bipartisan status esp. if we push the needle on social issues? • 10-year agency budget cycles • January 6, 2022

The group was divided into three breakout rooms for two mash-up rounds. The summary of the mash-up activity including signals used and key takeaways is shown in Table 26. In round 1, Team 1 used the following three signals: ownership of virtual items, four quantum-resistant cryptographic algorithms, and Google's AI system's developed feelings. The key takeaways were that NASA needs a plan on how to approach AI before this could happen, including reassessing what ownership means in this century. For round 2, Team 1 looked at the following three signals: decreasing ability of government to regulate, politics on Earth impacting partnerships in space, and space debris. The key takeaway was having NASA's own house in order impacts international relations.

In round 1, Team 2 looked at the following three signals: NHTSA regulations no longer require cars to have steering wheels or pedals, less than 7% of adults have good cardiometabolic health, and super worms that love eating Styrofoam. The key takeaway from Team 2, round 1 was that having autonomy

buys you more time, but it can be used for active pursuits like health and not just leisure. For the round 2 of the mash-ups, Team 2 looked at the following signals: Tesla absolving itself of liability/responsibility of its autonomous systems when you sign the terms of agreement, Ukraine war lays bare the fragility of the food supply chain in the developing world, and MIT tapping into million-year geothermal energy source. The key takeaway from this mash-up was as autonomy gets linked into more and more critical industries, the question of liability could have life-or-death consequences for both individuals and nation-states.

In round 1, Team 3 looked at the following three signals: the next dust bowl is on the way, implants to be used as an ID/wallet, and extinct parrots making a comeback in Brazil. The key takeaway from this mash-up were the need for more sustainable ways to source food and need for building off-world—could be opportunity to engage with citizen science and agriculture innovation. Also, how might NASA's futures ethics protocol evolve for enhancing biospheres for human sustainability? In round 2, Team 3 used the following signals: is "lying flat" China's next big import to the world, women in STEM need more than a law (only 29% of the STEM workforce is female), and new sources of raw materials will stabilize economies but destabilize geopolitics. The key takeaway from this round 2 mash-up for Team 3 was "who's controlling the resources will drive behavior on Earth and in space and it's important to understand your partners and competitors."

Table 26. NASA Internal Early Career and ERGs Roundtable Mash-Up Summary.

Mash-Up	NASA Internal Early Career and ERGs - Virtual	
	Signals	**Takeaway**
Mash-Up #1	1. Ownership of virtual items 2. Four Quantum-Resistant Cryptographic Algorithms 3. Google's AI Systems developed feelings	We need to have an idea of our approach to these technologies before they happen and not in reaction
Mash-Up #2	1. NHTSA regulations no longer require cars to have steering wheels or pedals 2. Less than 7% of adults have good cardiometabolic health 3. Super worms that love eating Styrofoam	Having autonomy buys you more time, but it can be used for active pursuits (like health) and not just leisure.
Mash-Up #3	1. The next dust bowl is on the way - society will need food, not engineers 2. Implants to be used as an ID/wallet 3. "Extinct" parrots making a comeback in Brazil	Need more sustainable way to source food, needed for building off-world; could be opportunity to engage with citizen science and agriculture innovation!
Mash-Up #4	1. Decreasing ability of government to regulate 2. Politics on earth impacting partnerships in space 3. Space Debris	Having our own house in order impacts international relations
Mash-Up #5	1. Tesla absolves itself of liability/responsibility of its autonomous systems when you sign the terms of agreement. 2. Ukraine War lays bare the fragility of the food supply chain in developing world. 3. MIT tapping into million-year geothermal energy source.	As autonomy gets linked into more and more critical industries, the question of liability could have life-or-death consequences for both individuals and nation
Mash-Up #6	1. Is "Lying Flat" China's next big import to the West? 2. "Women in STEM need more than a law" - while 50% of women are graduating from colleges, only approximately 29% of the STEM workforce is female 3. New sources of raw materials will stabilize economies, but destabilize geopolitics	As autonomy gets linked into more and more critical industries, the question of liability could have life-or-death consequences for both individuals and nation

The event concluded with the participants summarizing their biggest takeaway from the roundtable event, as shown in Figure 60.

Figure 60. Virtual early career and ERG roundtable takeaways.

C.5 Virtual NASA Intern Roundtable (Led by NASA)

Following the format of the Aerospace-led roundtables, a NASA employee organized and led a 2-hour virtual roundtable with over 30 NASA interns in attendance and Aerospace representatives observing. The stated goal was to "advise NASA leadership on mission priorities and studies/strategy for NASA's future." The data collected during the intern roundtable and summarized in this section is provided courtesy of NASA and included in this report since it was used to inform the study results.

The roundtable workshop was kicked off with two polls asking, "What excites you about the future (40+ years)?" and "What scares you about the future (40+ years)?" with the results summarized in the word clouds shown Figure 61 and Figure 62.

Courtesy of NASA

Figure 61. Virtual NASA intern roundtable Word Cloud 1.

Courtesy of NASA

Figure 62. Virtual NASA intern roundtable Word Cloud 2.

Questions were asked, including "Why exploration excites you?" with responses of "thought of the unknown and "it's a beautiful thing." Fears were expressed about political instability and NASA's ability to execute all its plans in an environment of instability.

The futures web exercise was centered around the question "What do you think the future looks like?" The futures web is shown in Figure 63 and includes the following:

- “Aging workforce in STEM: for a group of people who work at NASA and who stayed in roles, there is no upward mobility for people in their 30s and younger with a difficult environment for knowledge transfer.”

- “Training, development, and onboarding: suggest hybrid onboarding. Maybe VR and AR can help in onboarding process. Other suggestions include holograms for virtual/hybrid meetings and meetings in 3-D worlds. The way we work and learn how to do work should be next future step in working world.”

- “Theoretical warp drive: technically it doesn’t violate relativity. Explore feasible warp drive technology.”

- “Economics: the pay is lower at NASA. How to keep people working at NASA and not leaving for commercial?”

- “Potential for us to move beyond scarcity economics: adjusting how we go about distribution of resources, move away from energy and food scarcity and strive for equity for all.”

- “Environmental: biopunk—like solar punk—looking at genetic modification with technologies that preserve the environment but makes it more habitable.”

- “Innovation is both good and bad: Focus on technological innovation for climate crisis, although we understand so little about ecosystems that we are likely to develop technologies that make it worse.”

- “Extraterrestrial versus Earth: as government supplies more money, there is a dilemma about fixing things back on Earth versus space exploration.”

- “Independent space colonies: theory that once these bases become self-sustaining, they need no foresight from people back on Earth. Would they distance themselves from cultural heritage? Colonies more hyper religious—current political forum—colonists would be more conforming to some political ideology and create it from scratch.”

- “Certain countries will be at the mercy of other countries who control space resources: space is high barrier to entry and some countries would not have same equities.”

- “Humans to Mars: on tentative tract to Mars, political climate can delay or derail us from getting to Mars, need checkpoints to get there.”

- “Political side is biggest area of risk to Mars; we have enough money.”

- “Learn about the ethics of putting weapons in orbit or on the moon. Possibility that weapons in space in next 5 to 10 years will militarize space.”

- “Treaties about weapons in space (old treaties). If political scenarios change, then need to make changes to treaty.”

- “NASA and government are behind in regulating and monitoring technology.”

- “Roundtable chat is pessimistic about future.”

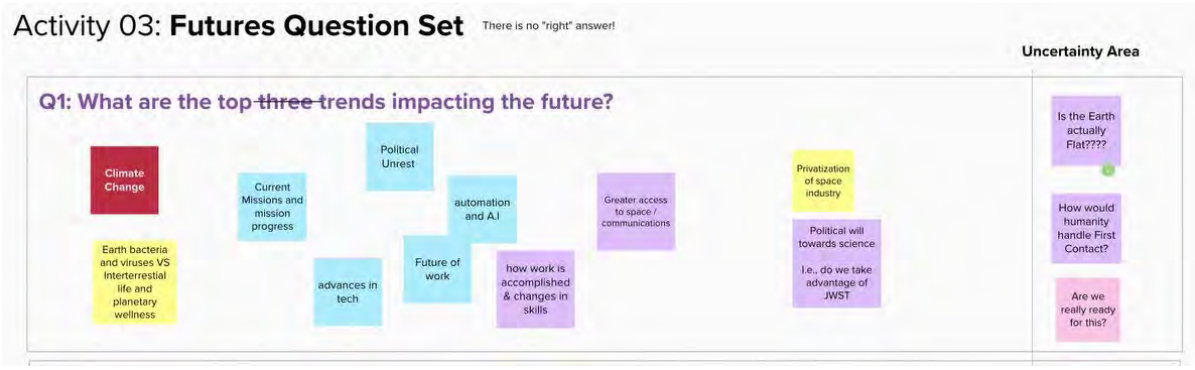
- “Post-it notes are more positive about the future.”
- “Send broad swath of society to space, not just billionaires.”
- “Technological innovation in space technology benefits society in other ways, but why focus on finding ‘accidental’ or roundabout solutions when we could be addressing actual problems directly.”

Courtesy of NASA

Figure 63. Virtual NASA intern roundtable futures web.

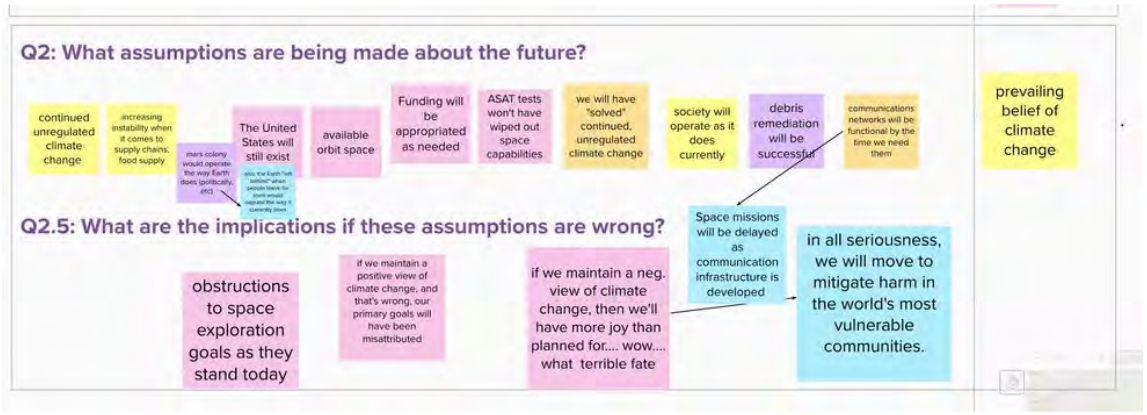
The group separated into three breakout rooms to answer one of the following questions:

- Group 1: What are the top three trends impacting the future? Response shown in Figure 64.
- Group 2: What assumptions are being made about the future and what are the implications if these assumptions are wrong? Responses shown in Figure 65.
- Group 3: What is the most important thing you recommend NASA act on in the near-term to best posture itself for a bright future? Responses shown in Figure 66.



Courtesy of NASA

Figure 64. Intern roundtable futures question 1.



Courtesy of NASA

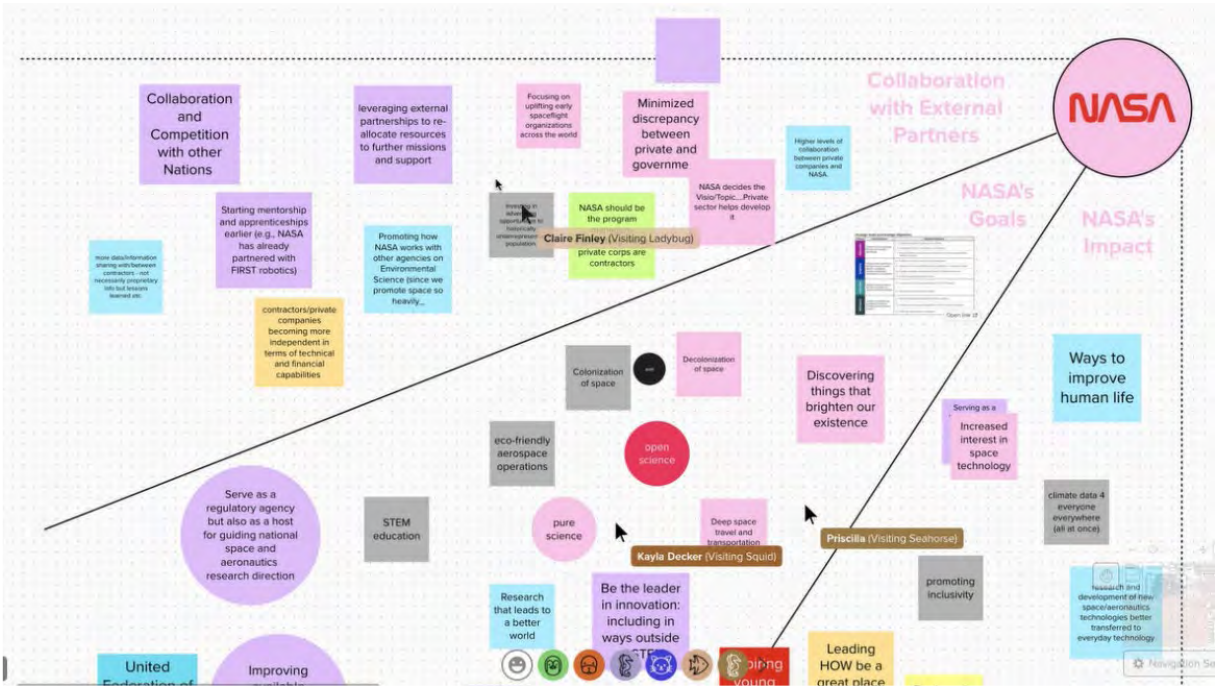
Figure 65. Intern roundtable futures question 2.

Courtesy of NASA

Figure 66. Intern roundtable futures question 3.

A futures web group activity regarding ideas for NASA's goals, impact, and collaboration with external partners was performed with an excerpt as shown in Figure 67. Comments included the following:

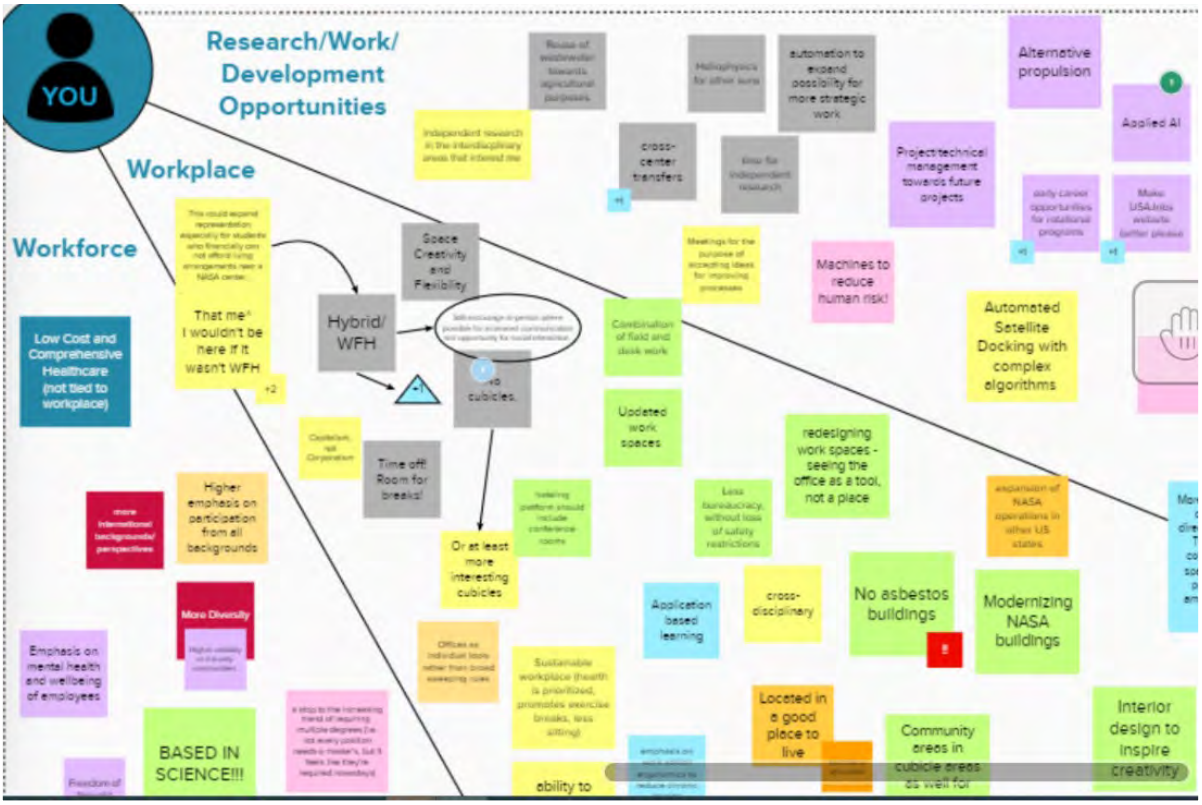
- "Lead on how to make NASA a great place to work—realistic working conditions in the space industry. Lot of non-government space agencies somewhat exploiting their workers and pushing them hard. Easy way for NASA to lead by example—get a lot done and not treat your people this way."
- "Push technology in areas where commercial isn't."
- "Do things that have value but not done by commercial."
- "Tie NASA to futuristic ideal identity, effect of TV and marketing."
- "Focus more on technical side of NASA."
- "Get young people to think about science—coolest logo and most positive government organization. Putting [a] man on moon is more important achievement over something like developing GPA."



Courtesy of NASA

Figure 67. Intern roundtable futures web.

The intern roundtable concluded with a futures web activity on "Your Ideal Future" as shown in Figure 68. Participants were rethinking the future office and future workspace characteristics. Some advocated for collaborative space like NASA Langley's redesign with more of a university feel. Several complained about asbestos and old facilities at Marshall Space Flight Center.



Courtesy of NASA

Figure 68. Intern roundtable "Your Ideal Future".

Appendix D. Detailed Observations from External Roundtables

Seven roundtable exercises were held to gather inputs. In this appendix, we detail the two external roundtables, providing data of any online Miro boards (virtual roundtable) or summarized notes (in-person roundtable) as well as graphic recordings. To have an open discussion, the roundtables were held per Chatham House Rule where no one is allowed to reveal or attribute comments to individuals. The data presented in this appendix is directly from participants and not the opinions/views of Aerospace.

D.1 Virtual External Roundtable

The virtual external roundtable hosted approximately 40 participants over the course of 4 hours, with a focus on aspirational views for the future per the following agenda:

- Trends and disruptors (see Table 27 through Table 33)
- Diving into exploration and discovery
- Mash-ups
- Futures web
- Reflections for NASA and closing remarks

The roundtable exercises, summarized notes, and any graphics, including the visual collaboration Miro boards, are included in this section. Additional details about each exercise can be found in the graphic recordings.

D.1.1 Key Trends and Disruptors

The trends and disruptors identified by participants across the STEEPTS are shown in Table 27 through Table 33. The “Threat” and “Space” categories were covered within the other categories and thus these categories were not focused on during the roundtable.

Table 27. Virtual External Roundtable Trends and Disruptors (1 of 7)

Societal
Trends
• The "Great Resignation"
• Broadening wealth gap
• Transfer of hard assets to digital
• Property rights no longer seen as inalienable - aka giga economy
• Reckonings with systemic inequities
• Aging populations
• Media Advertising/Presence Twitter/social media as news– citizen journalism
• Intentful inclusivity
• Expanding surveillance states
• Remote telework
• Space is the new battleground
• Broad availability of information
• Democracy as we knew it, is at risk "shifting family structures -fewer young people having children
• Urban/rural divide
• New frameworks for understanding gender identity
• Personal liberties vs common good (e.g., COVID vaccinations)
• Longer lifespans
• Misinformation
• Video for everything
• Breakdown of trust
• Agency vs apathy
• Rising feeling of being unsupported - can't count on help
• Increasing political divisions
• The "fake news" problem
• Communication desired from anywhere
• More brainstorming via Zoom
• Work from anywhere
• Constant presence – life shared via social media
• Global supply chains
• Indigenous futurisms/futurities are now a global aspect of thinking and creating
• Intergenerational and communal living arrangements
• Space as a feasible destination for non-astronauts
• Work from home
• What is truth?
• Finding new solutions to old problems, like water, clean energy, housing, vertical agriculture…
• Loss of critical thinking and questioning
• Challenges with verifying identity in the digital world
• Global cooperation in the face of global problems
• NASA as the most influential brand in the US Govt
• Distributed workforce
• Increasing power to the worker
• Profession with purpose
• Polarization around trust in science
• Felt uncertainty about the future
• "Empowering local communities to combat externalities
• Higher productivity
• Increasing automation, autonomy and changing labor markets
• Inflation
• Changing consumer preferences (Rise of Gen Z)
• Improved access to technologies, particularly mobile
• Desire for passion & meaning in work
• Bi-modal society impacts ability to get anything done!
• Surveillance
• Sustainability and renewable energy
• Generational gaps in values around everyday constructs (consumerism, health, etc.)
• Expectation of better health
• Tension around trust in companies
• Polarization of society in accepting and understanding science
• Broad scale denial of critical issues like climate change
• Equity and inclusion
• Gig work and/or/vs longer term roles
• Lack of privacy
• Lack of community
• Rise of activist corporations & leaders
• Truth is based on digital ecosystem
• Space science is great platform for improving science literacy

Societal

Trends continued

- Increasing interest in exploration and big questions
- What does it mean to society that habitable planets number in the billions in our galaxy?
- No plan B for planet Earth
- Space exploration could once again unite us
- Can we survive our technological adolescence?
- Land Back movements for tribal bands, including National Parks in the U.S. and Canada
- Trends continued
- Younger people wanting experiences more than owning things. Thinking of themselves as world citizens
- Addiction to sanctimony is revealed as a genuine drug high worse than heroin
- How can we get scientists and policy makers on the same page?
- Indigenous sciences globally becoming a strong component of all sciences globally
- Anxiety/mental health
- Social isolation
- Apollo and Hubble correlate with rise in religious non- belief
- Space as the new frontier
- Police violence George Floyd

Disruptors

- AI and machine learning
- Decline of tier 1 cities due to housing affordability
- Mass violence events
- Robotics everywhere commercial space travel
- Demand for "companion pets" up during pandemic
- Economic volatility
- War in Ukraine!!
- Climate change is the ultimate disruptor
- Looming infrastructure problems
- Age of Anxiety
- Increased reliance on AI, less reliance on "human intelligence"
- Pandemic memory and/or amnesia
- Distrust in science
- Political unrest
- NATO expansion
- Cyber-attacks by Russia on commercial space communications
- Energy prices and inflation
- Potential outcome of capitol riots inquiry
- VR-mediated addictions
- Biotech touching everyday life
- Gender-pay gap closed
- Fear of the future
- Mental health epidemic
- Elon Musk to buy Twitter
- The big lie!
- 5G (always connected)
- Restoration of the concept of ‘facts’
- Mental health decline
- Human rights violations
- The newest generation being raised with eyes open to the things listed above
- Fossil fuel process driving renewable energy
- Global connectivity
- Negative perception of the future
- Food insecurity from multiple sources
- Housing market bubble
- Zooming!!!!
- Half the eyes are open, but half are closed
- Is USA democracy ending?
- Inflation
- AI/ML can help with too much data
- Virtual interaction and engagement
- Rise of populism
- Orbital debris - huge problem!
- Too many big lies!
- Rising importance of metadata

Table 28. Virtual External Roundtable Trends and Disruptors (2 of 7)

Technological
Trends
• Cross-platform media
• Internet of things changing to internet of autonomy
• Increase in energy storage & distribution
• Reduction in launch costs
• Connectivity between devices
• mRNA
• Bitcoin
• Virtual reality
• Global ISPs from Space (LEO)
• Intelligent teaming of machines
• Global web access
• Exponential growth
• AI as a critical tool
• Ability to explore exoplanets
• Nuclear propulsion
• Cold fusion
• Racial and gender bias in AI
• Availability of space transportation as a service
• Understanding ethics in applied AI
• False AI scams
• Advances in quantum computing
• Renewable energy
• Synthetic biology
• Alpha Fold: machine learning for biology (protein structure from sequence)
• AI as new manager of failed interactions (e.g., airplane boarding)
• CRISPR based mods for (Real) affordable space
• Brain machine interfaces to enhance workflow
• China- led surveillance tech as new social paradigm (facial recognition, voice recognition, phone- tracking, DNA, etc.)
• Space Access
• AI/ML
• Crowd sourcing / funding
• Deep fake technology
• Robotics as anti-loneliness tool
• From global to fragmented Internet
• Decreased time- to- market for new technologies
• Increased crowding of LEO
• satellites"
• CRISPR
• Long distance learning ASYNCHRONOUS vs SYNCHRONOUS (tech to enable meetings/classes)
• Comms arrays block out the night sky
• CRISPR
• Deep fake technology and identity impersonation
• Easier access to software development with no- code, low- code tools
• Metaverse
• Persistent communication
• Smart Grids
• Neurostimulation to cure depression
• Digital personal assistants/friends
• Smart home technology
• NFTs
• Cloud computing
• Crypto
• Smaller sensors
• Augmented biology
• Computer coding decolonization!
• Too much data
• Real time custody tracking of most things on Earth’s surface
• Online learning
• Incompatible cloud solutions
• Integration of technology with biology
• Ability for constant surveillance (of anything)
• Jessica Hernandez's Fresh Bananas: Healing Indigenous Landscapes through Indigenous Science and many more
• 3D printing is making major changes in industry and design community
• Robotic Automation

Technological
Trends continued • Precision agriculture • Digital health assistants • Collaborative Digital Environments • Decentralized internet • Moving beyond technology • Decentralizing power generation • Not prepared for Carrington Event! • Sentient AI • Improved predictive modeling w/AI/ML tools • MS Teams • Vulnerability of technology • Technology has advanced much faster than humanity. Can humanity catch up? • Space as a platform for better understanding Earth • Exploration, not colonization ***Disruptors*** • Water crisis unresolved • Access to AI furthering • Economic disparity • Applications of cloud/ML/AI/GPU to deep technology • Automation of EVERYTHING • CRISPR based mods for space travel • 300x increase in sensitivity of quantum sensors • New forms of AI-inspired art • Weapon development • Rich kids excelling in sports thanks • to bio- hacking • Smaller, simpler tracking devices • AI (that takes jobs) • Machine learning • Decreased cost & access for biotechnology experimentation • Impact of recession on slowing of investment in technology • mRNA vaccine first in class • Weaponized privacy • Carbon sequestration event • Creating extensive orbital debris • Quantum computing • Decentralized internet • Metaverse • Solving human basic needs through technology • Wearable EEGs • Man- machine interfaces to augment remote medicine • Nuclear war • Designer babies • More private citizens having meaningful space experiences –this will significantly grow in 5 years • Major world power(s) disconnect from global Internet • Indigenizing sciences • Early Alzheimer's biomarkers • Synthetic biology-based computing and storage • Supply chain issues • Quantum encryption • Unleashing human time for non- work pursuits • Using cobots to unleash human time • Undersea fiber compromised // more resilient undersea fiber • Safe, effective human germline editing • Gold standard longevity biomarkers • Connected brains to create augmented intelligence • Potential for increased global community via communications networks • Rediscovering" traditional tech (agriculture techniques, wayfinding, fishery management, etc.) • Gaining control of human longevity • Cheaper compute! • RSA/encryption broken • Permanent presence on lunar surface • Transition to DNA-based computing • Successful agriculture on Mars • Vertical farming • EEG brain printing for encryption

Technological
Disruptors continued • The digital divide • Voice- assist to improve inclusion • CRISPR based mods for space travelers • DNA databases reflect global population • Synthetic biology bioweapon • Water security • Artificial wombs, decoupling fertility, age, productivity • More private citizens having meaningful space experiences – this will significantly grow in 5 years • The use of solar power in African nations • Desalination of water • Increased access to solar/renewables • Lack of unified space philosophy/narrative for the human species. Seems we are extending into space the very things that caused problems on earth: war, conquest, nationalism, exploitation of resources, and so on. • Integrated digital assistants • Digital divide closed • Artificial general intelligence demonstrates basic sentience

Table 29. Virtual External Roundtable Trends and Disruptors (3 of 7)

Economic
Trends
• Liquidity tightening
• Bell weather stocks decreasing (e.g., Elon dumping Tesla shares)
• SPACs trading <$2 = delisted
• Increasing global connectivity
• Companies making it out of valley of death
• Space architecture integrating commercial (buy before creating)
• Access to early-stage venture
• Hustle culture/ informal jobs
• Return to Oligarchy+ feudalism
• Company merges
• New 'ores' – asteroid + magma
• Private & commercial investment in Space (tourism, services, ISRU, etc.)
• Bitcoin
• Inflation
• Membership & subscription services
• Actual affordable space access
• Increased wealth and income disparity
• Lack of COVID vaccine in the third world
• Wall St Spends more$ on (predatory) AI than all academia
• Crypto crash
• Neomedieval city states
• Brands as markers of political identity
• Global Crypto Implications
• Is it possible for Public Teachers to make money $???
• Bimodal economic society
• Full spectrum of Equity Market funding opening up to space companies
• Ghettos and gated paradises
• Recession leading to short term thinking, less money for deep tech
• Collapse of taxation structures that support public infrastructure
• Rising interest rates
• Rich get richer
• Delay of retirement
• Crashing Stock Market!!
• Volatility of crypto currencies
• Disappearance of the middle class
• Widening gap between rich and poor
• Cryptocurrency
• Housing inventory remains low
• Transparency around climate change
• Uneven impact of climate change on low-income communities
• Stock Market not tied to most Americans' well- being
• US losing its stronghold globally
• Tens of billions will be invested in developing and operating the outer space yachting industry and community - NASA can help with advancing tech and we will need a Space Guard Service - like Coast Guard
• Response to globalization dependency
• Investment horizons lengthen
• User-centered digital markets generate revenue
• While many say space is integrated fully in the general economy, there is still a need to actual integrate with what makes a local economy actually succeed. My research of the case of Arizona is just one example that it’s not so black and white!"
• Maximizing stakeholder return instead of shareholder return
• Nation- states reorganizing economic alliances
• Rising cost of fuel
• Accelerating “fintech” experimentation cycles
• US dollar no longer the assumed global currency
• Wealth disparities >French Revolution
• Venture capital increase to women, POC, outside USA
• Pension funds misaligned to longevity
• Impact of inflation on R&D
• Impact of inflation on science
• Sustainability of business model vs. immediate return
• Growing interest in 4-day work week
• Increased federal spending on research is critically needed
• How does bankruptcy affect subsequent economic opportunities?
• Critical need for increased federal spending on basic research
• Create tourist “economy” for moon and Mars that is centered on environmental protection, a la the national parks and wilderness areas on Earth. The great national parks of the desert southwest in the USA are a perfect example. Treat the and Mars as objects of aesthetic/ecological/scientific appreciation, not lands to degrade

Economic
Trends continued Danger of knee- jerk reactions to economic volatility • Rise of Universal Basic Income • Expansion of access to stock markets • Sustainability from inception • Expansion, modification of definition of capitalism • What are religion's economic effects? • Economy as a political scare-tool • Rising cost of higher education • Growing student debt • Supply chain distributions continue • Rise of at cost generic pharmaceuticals • Insurance no policies longer / less available in high- risk areas • ***Disruptors*** • The 2022 Global Recession • Value of cryptocurrency dropped 10% over the last weekend • Near peer opponents controlling global economy (e.g., Russian oil critical to global economy) • 1 Gallon of gas costs more than a whole chicken at Costco • Overpowered shareholders • Gov (global) overregulation of just about everything • Gov (global) under regulation of what matters (like what is actual news, and true) • Pseudoscience, with loud voices and vast reach • Climate and environmental justices merging together • Nation- states are replaced by city- states, DAOs • NO lunar 'resources' other than a little ice • The thin line between what is commercial and personal • Reemergence of labor unions • Fear from the media • Stakeholders vs Shareholders • Terrorism enters the metaverse • Increasing privatization of space • Asteroidal ores crash metals markets • Risk for space activities can't be quantified --> inability to open up financial markets • More real estate is sold in Metaverse than in real world • New currency markets • Are oil execs making a mistake by maximizing profit (huge gas prices) and potentially driving people towards electric or do they see the writing on the wall and are trying to squeeze the last dimes out of their energy monopoly? • Competition for young thinkers in the global south • Economic warfare between "naturals" and "augmented" • Local sourcing • University degrees no longer valued • Hiring based on metaverse based interviewing, portfolios, CVs • Pushback against return to in- person • Median human lifespan to 120 years • Cognitively enhanced take over global markets • Cognitively enhanced take over virtual markets • USD replaced by digital currency as global currency • Model established to monetize stewardship of natural resources vs. consuming them • Marginalized start selling their stem cells, in addition to organs, for food • Artificial wombs decouple age, fertility, and earning potential • Rise of B- corps

Table 30. Virtual External Roundtable Trends and Disruptors (4 of 7)

Environmental
Trends
• Global Warming
• Ocean acidification
• Water shortages
• Changing climate
• Patterns
• Solid/plastic waste
• Ocean currents
• Forrest fires
• Loss of biodiversity
• Extreme weather events
• Reframing our understanding of "invasive species"
• Increasing space debris
• Return of a “real" solar maximum
• Wildfires
• out West
• Desalination
• Monsanto - GMOs, patent holdings, herbicides/pesticides
• The "Green Revolution"
• Impact on monoculture/factory farming
• Control/exploitation of public lands for private profit
• Our continued reliance of cement
• Shift of heavy industry to space
• The expansion of the Sahara Desert
• Controlling nature instead of working with it
• Glacial animal population decrease
• Bee population decrease
• Calling out Greenwashing
• Mining of rare-earth elements for technology (even Green Tech)
• Decoupling nature from food production
• Climate change refugees
• Effective batteries using common elements
• Reflexivity (bubbles in equity and RE markets)
• Electric vehicles
• Small nuclear reactors gain wide acceptance
• Melting polar icecap
• Genetic attention on heritage breeds
• Active intervention in coral decline
• Innovation in satellite monitoring of GHG emissions by private actors and NGOs using the narrative of “radical” transparency
• More frequent pandemics due to ecological disruptions
• Golden age of environmental RESTORATION
• Scaled desalinization efforts make water readily accessible to 75% of world's population
• Transformation of energy grids based on renewables
• Drought in the western United States
• Impact of animal protein consumption on environment
• Earth as a Biosphere/Spaceships as Biospheres
• Environmental justice being implemented Indigenous tribal bands
• The mastodon returns! See Steward Brand w/ Long Now
• Rise of YIMBY- ism (Yes in My Back Yard)
• Greater move to climate adaptation vs prevention of 2-3°C rise
• Transforming stewardship knowledge from indigenous communities, traditional jobs like small farming
• Understanding methane vs. CO2
• No point building habitats on Moon or Mars but for exploration
• Extreme weather events – fires and floods
• Mars is NOT plan B for Earth
• Arctic as major ocean trade route... leading to increased pollution
• Accelerated evolution due to climate change
• Fragility of wild/human interfaces
• Development of economic models for environmental protection
• Climate change may define humanity's L variable [Drake equation - ed.]
• Many people who visit Earth orbit have the Overview Effect & bond with the planet. Return to work to improve Earth environments
• Farming north of the Arctic circle
• The resources of Spaceship Earth are being depleted!
• Will lithium & other rare minerals mining for solar and other forms of "green energy" end up becoming the new uranium mines?
• Language around space being part of earth ecosystem or having intrinsic value
• Living things functioning as sensors
• Fire

Environmental
Trends continued • Legal case in US federal court that NEPA act (environmental impact assessment) should apply to satellites • Space monitoring for environment equates to seismic monitoring for nuclear nonproliferation • Youth focus on improving/saving the environment • Tar sand pollution • Mass extinctions ***Disruptors*** • High salt concentrations due to salt dumped from desalination • 'Verticulture' in urban and exurban areas • Tissue culture + veg Meat • Academia welcoming scholactivists embedded in climate/environmental justices that includes communities' alliances • New shipping routes based on melting polar ice • Large-scale environmental terrorism • A million people die in a single climate-related event • WW3 • Rewilding of strip malls • "Outside the seawall" • Farming north of the Arctic Circle • Seed banks stored on moon to preserve genetic diversity • Democrats control 3 branches of government • Republicans control 3 branches of government • Permaculture • Energy independence at the household level • Engineered microbes eating plastics • Mosquitoes eliminated • Climate mitigation • Rocket with nuclear payload blows up on launch • Space tourism increases the number of humans who see the Earth from Space and become guardians of the planet • Climate refugeeism • CRISPR and synthetic bio used to bring back many extinct organisms • Continued large- scale deforestation • Increasing reforestation • SEASONAL migration to avoid extreme heat • CRISPR based modifications for humans to tolerate A • Augmented organs to expel excessive heat • CRISPR and engineered plants that are more efficient at photosynthesis • Environmental education • Capturing water from rain and melt – regenerating water tables

Table 31. Virtual External Roundtable Trends and Disruptors (5 of 7)

Political
Trends
• Strategic competitor/peers declining
• Relationship of Russia versus the rest of the western world
• PRC continued pursuit of Taiwan
• Developing a coalition: China's Space Belt and Road Initiative
• US Ideological wars: abortion, gun control, immigration, vaccination, etc.
• Democracy without science literacy is unworkable
• How about a person you really want to vote for?
• Lack of personal property ownerships leads to eventual removal of borders
• How do we build an educated electorate?
• Polarization
• Continued reliance that societal problems need political solutions
• Hard to believe that in the 21st century we're still invading other countries
• Government led economy
• A sensible new political party
• Declining respect for US authority globally
• Ranked-choice voting
• Cultural bubbles
• Confluence of political identity and employment
• UK Brexit has been great for UK space agenda
• Basic insecurities give rise to more authoritarian govts
• Lobbying & inside influencers
• Politics controlled by financial interests not voters
• Return to 6000 years of feudalism
• Celestial wayfinding rather than the usual imperialist exploitation of the commercialization of space
• Everything is for sale
• Rise of DAOs (decentralized autonomous organization)
• Politically motivated "attacks" on technology companies
• Decrease in faith in US Gov
• Personal freedoms vs. societal needs and benefits
• Rising nationalism in many countries
• Ignorance of political candidates globally is frightening!
• Increased selfishness
• Tech billionaires fund new extremist politicians who will promote complete deregulation and the erosion of any corporate tax base
• Middle East states remake their image as they fund space ventures
• DAO = decentralized autonomous organization - these exist on the blockchain
• US moves to a popular vote
• Russia removes oil from economy – crippling Europe
• Greed as a critical political driver
• US increases oil production making Putin impotent
• Western hemisphere version of NATO
• Role of China in global politics
• 2- party system = no progress
• Larger executive control over policies = harder to long- term plan for government agencies when the president switches parties
• Politization of the CDC, OSHA, EPA, consumer protection, etc.
• The influence of religion
• African countries recognizing south, south cooperation may be better than listening to the narrative that the west will help them develop space capacity (instead of the current trend of working with Russia/China)
• Travelers as political prisoners
• Decline of US influence globally
Disruptors
• Russian invasion of Ukraine
• Restore 'fact' as a factor
• States secede from US
• State laws conflicting with federal laws
• "Bass Pro Shopville" as noncoastal city state based on employment + political affiliation
• Selfish individualism
• Excessive use of vetoes
• "Jan 6" riots and continued challenges to US democratic System
• WW3
• Less reliance on politicians to solve global challenges
• EU expansion
• Liberal democracies as innovation havens
• NATO Article 5 triggered
• Disruptors continued
• More civilian activism
• China takes over as global superpower
•

Political
Disruptors continued
• Social media groups of BIPOC communities moving forward with shifting our current political terrain towards activism that is welcomed globally
• DAOs develop their own constitutions, digital currency, and raise security teams to defend their virtual and real-world assets
• Decentralized democracies arise that cross nation-state borders
• Media- based disinformation
• Lack of neutral perspectives in the news
• Education as positive disruptor
• Challenge disinformation with wagers
• Significantly growing African youth interest in space is relevant as Africa will remain the most youthful region over the coming decades. This matters for the cure African Union space agency
• US Civil War v 2
• Puerto Rico & DC become US states
• Multiple new countries joining NATO
• More unified action in LATAM
• Synthetic/hybrid AGIs begin to run our government
• Algorithms used to solve critical problems in infrastructure, energy, education, food
• Thriving activism movements

Table 32. Virtual External Roundtable Trends and Disruptors (6 of 7)

Threat
Trends
• Increase in # of space capable nations and NGEs
• Russia dirties LEO to ruin it for US & Europe (ASAT)
• The West dissolves into internal strife
• Sabotage of the commons: LEO + GEO + shipping straits
• Imaging satellites dazzled to make inoperable
Disruptors
• Alien invasion and subsequent enslavement of humanity
• Deep fakes created by twinning humans whose biometric data has been stolen during interactions with the Metaverse

Table 33. Virtual External Roundtable Trends and Disruptors (7 of 7)

Space
Trends
• Space <> Sustainability
• Low-cost Earth return (down mass capabilities)
• Artemis Accords
• Middle East countries now funding space initiatives and research (UAE, Saudis)
Disruptors
• New startups in the space debris cleanup space
• Space-based sustainability spins off to Earth (recycling, water, farming/ag)
• Tourism = diving seas of Titan and Europa
• Nokia gets lunar 5G contract

D.1.2 Diving into Exploration and Discovery

The participants were shown a video showing graphics on potential future space exploration and asked to react. Below is a summary of their responses:

- “We’re a species of discoverers.”
- “I wasn't scared, but I got goosebumps and thought about all people in our species who are not explorers and just want to have [food to] eat and have babies and have a warm place to sleep; easy to take the feelings of our [space] community and map that erroneously onto everyone else.”
- “Exciting, but sadness; idea of leaving everything behind, thinking about connection, bringing things along made me feel better; exploring all these beautiful new places but leaving behind a beautiful place as well.”
- “Filled with promise, made me wonder about practicalities; what can we promise people alive today and what is the strangest wanders they can expect to do and what if the timeline goes out beyond a generation; will they want to participate?”
- “Mixed feelings; evokes exciting but also sadness and trepidation; do we want to go down this path and want to change our society?”
- “Balance between inspiration and sadness; curiosity to explore is wonderful, but we're never satisfied with what we have and what does that mean for society long term?”
- “Fundamental thing that makes us human is our curiosity; hope that we can do exploration without exploitation.”
- “All the problems of the world find their way to Hawaii, despite being thousands of miles away from populated continents. So, wouldn't they also find their way to space, to a space station, to a space colony on Mars?”
- “How will the artists of the future represent space and its vastness that integrates humans into it rather than alienates us from it?”
- “Lessen the focus on why it’s important to be human. Maybe our place in the system/universe is more important than the definition.”

D.1.3 Mash-Ups

The group broke into three breakouts, and each did two rounds of the mash-up activity where multiple emerging disruptors are combined to think through new possibilities. The mash-up summary, including signals used for each round and key takeaways are shown in Table 34. The mash-ups Miro boards from each team are shown in Figure 69 through Figure 74.

Table 34. Virtual External Roundtable Mash-up Summary

Mash-Up	External Roundtable - Virtual	
	Signals	**Takeaway**
Mash-Up #1	1. Sri Lankan shifts to 4-day workweek w/out pay cut, Fridays to grow crops in their own backyards 2. Corporate Executives encouraging their employees to take psychedelics to encourage creativity, team building, sense of purpose, mental health 3. Russia attacked commercial satellite (ViaSat), created space debris during Ukraine conflict	Human enhancement through psychedelics has been proven, should space-faring selection process be reconsidered and perhaps required?
Mash-Up #2	1. What if President set to put 100 people on moon by end of 2020s? 2. Nuclear push for green energy and space 3. Spanish regional airline ordered regional airships (blimps), doesn't involve passenger jet	In the face of ecological responsibility, is no-rocket, no pollution, slow airships/spaceships more socially acceptable?
Mash-Up #3	1. Development of Orbital Super Yacht community - space yachts that are owned by powerful families 2. College enrollment at undergrad level is down but at the graduate level is up 3. Increasing privatization of space - Space Act of 2015; give corporations right to mine moon and Mars for minerals for green tech	No key takeaway documented. Comments included “Rising inequality” and “Talent needed at graduate level” plus others
Mash-Up #4	1. Proliferation of global satellite networks - all humans would have access to knowledge and education 2. Rwanda spent $1B on OneWeb project; Rwanda filed for 300k satellite license from ITU 3. New study highlights the link between greater green space and reduced loneliness	No key takeaway documented. Comments included “access to connectivity is global in nature,” “education due to internet access is a great thing for women in particular,” and “green space and loneliness is Western-based point of view.”
Mash-Up #5	1. Robotic Process Automation - taking over human jobs 2. Saudi Space Agency funding neuroscience experiments on ISS 3. Cancer drug study with 100% becoming cancer free	Combination of robotics, AI, and pharmacology bringing new forms of development and shift in utilizing scarce resources to new resources in space
Mash-Up #6	1. In face of globalization, 2 decades of insurgent localism (combating colonization, protests of telescope on Mauna Kea) 2. Will JWST correlate with rise of religious non-belief in US and world as the Hubble Space Telescope did? 3. Elon Musk acquisition of Twitter and removing restrictions on voices	Social media polarizing with common voices - push back to maximizing diversity

Figure 69. Virtual external roundtable Team 1 mash-up Round 1.

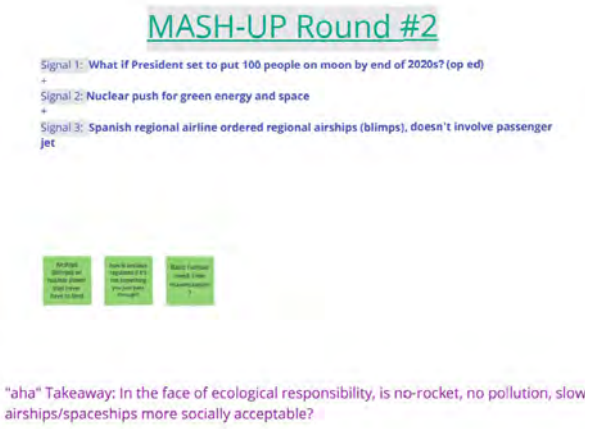


Figure 70. Virtual external roundtable Team 1 mash-up Round 2.

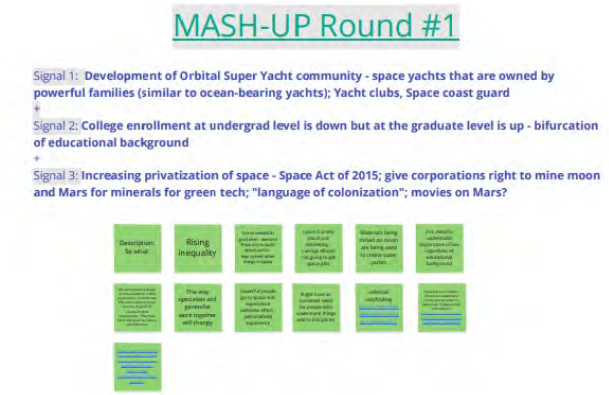


Figure 71. Virtual external roundtable Team 2 mash-up Round 1.

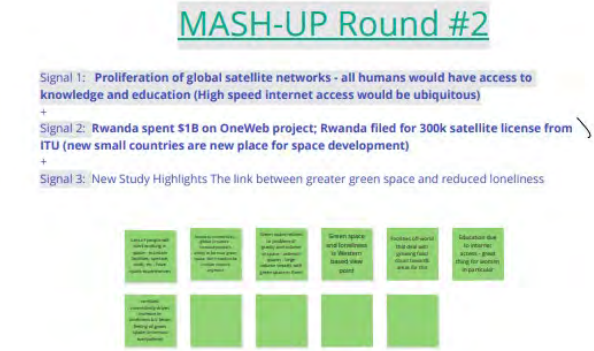


Figure 72. Virtual external roundtable Team 2 mash-up Round 2.

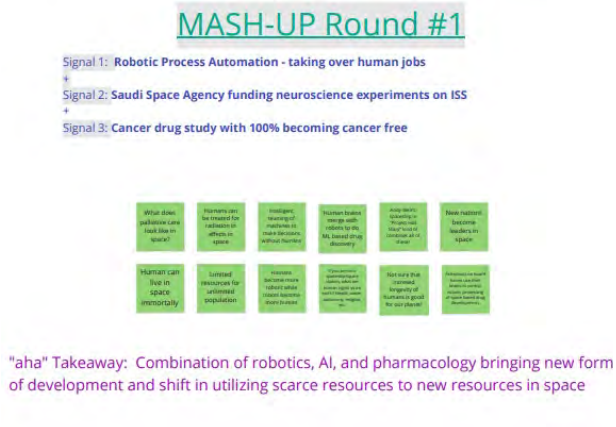


Figure 73. Virtual external roundtable Team 3 mash-up Round 1.

Figure 74. Virtual external roundtable Team 3 mash-up Round 2.

D.1.4 Futures Web

Three topics were explored in the futures web tool in breakout group: the future of research and development, the future of being human, and the utopian space settlements and off-world governance. The future of research and development web can be seen in Figure 75. The key takeaways from this group were: (1) whether we can create incentives for broader societal impact of research and development, (2) the ability of science to communicate its goals is key to advancing outcomes/endeavors, (3) budget cycles must help determine approach (USG, private sector, other nation-states, etc.), and (4) crowdsourcing/ leveraging more creativity will be key in the future.

The future of being human web can be seen in Figure 76. The key takeaways from this group were: (1) rapid advancement of technology and mankind's ability to understand and move forward with it will impact the definition of being human, (2) there will be an expansion of the definition of what it means to be human—beyond one word of human, (3) another definition of humanity is on the horizon—ETs, (4) a future that is human-directed evolution and breaks definition, (5) society needs to build in adaptability, and (6) adventure of space not human-centric but idea of creating a second biosphere off Earth—sending whole ecosystem into space, not just humans.

The utopian space settlements and governance web can be seen in Figure 77. The key takeaways from this group were: (1) what future value (currency and ideology) systems will determine everything, (2) there are two ways [space settlement] could happen: required because Earth is unfixable or utopian/aspirational, and (3) how do we move to exploration and wealth "for all" of humanity—this would mean moving from unhealthy competition to constructive collaboration.

D.1.5 Reflections for NASA

The takeaways from the virtual external participants are shown in Figure 78.

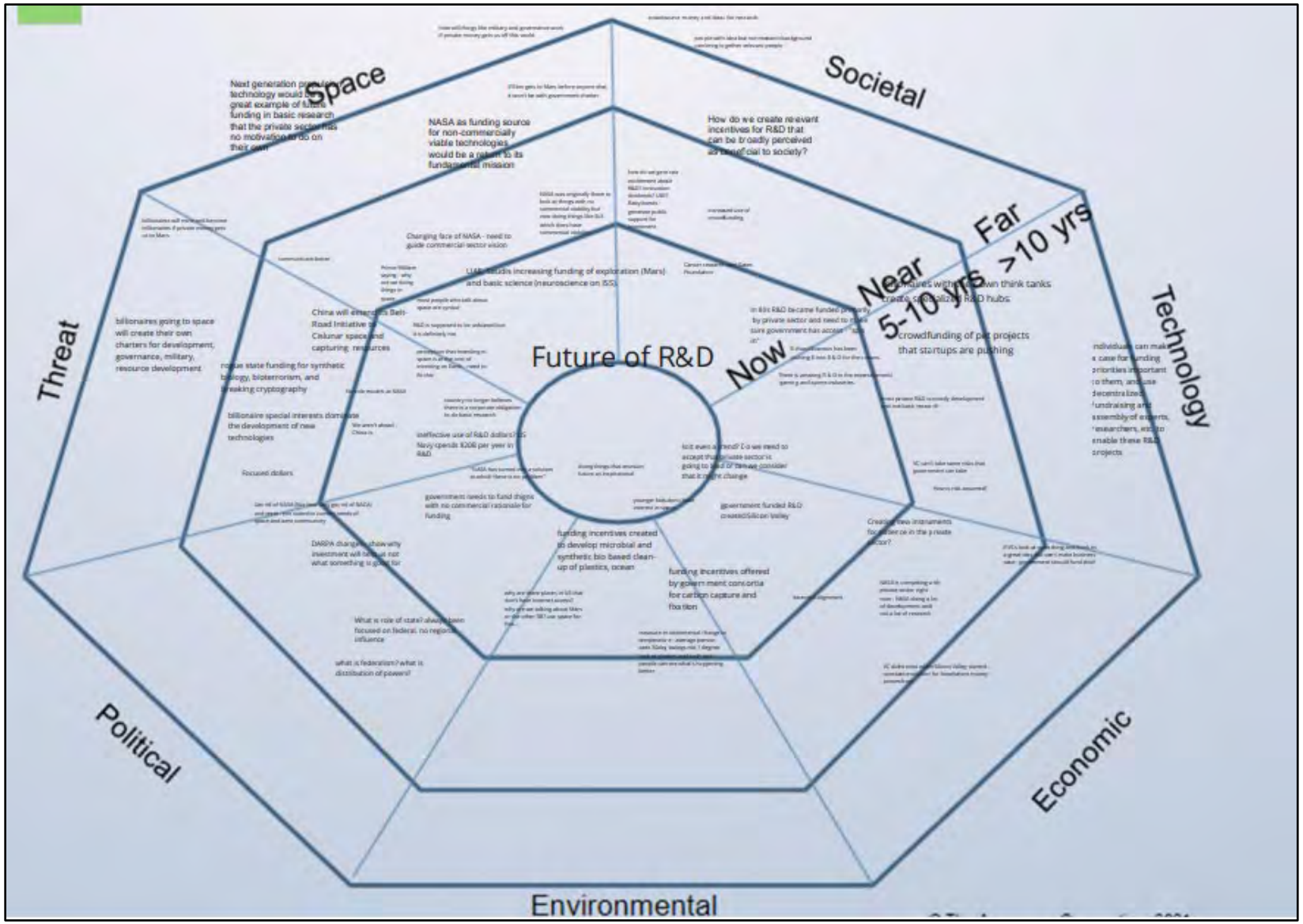


Figure 75. Virtual external roundtable futures web on the future of research and development.

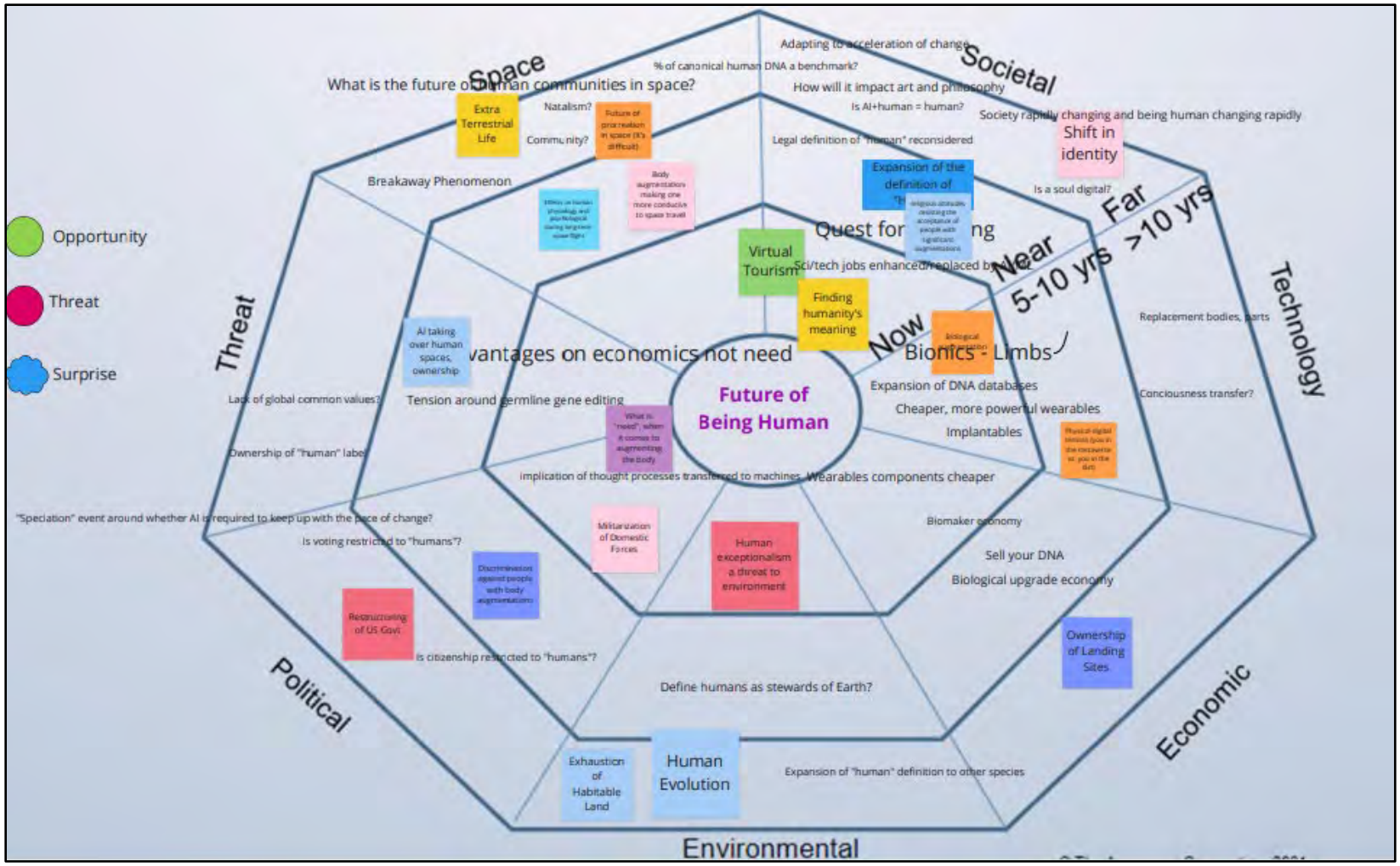


Figure 76. Virtual external roundtable futures web on the future of being human.

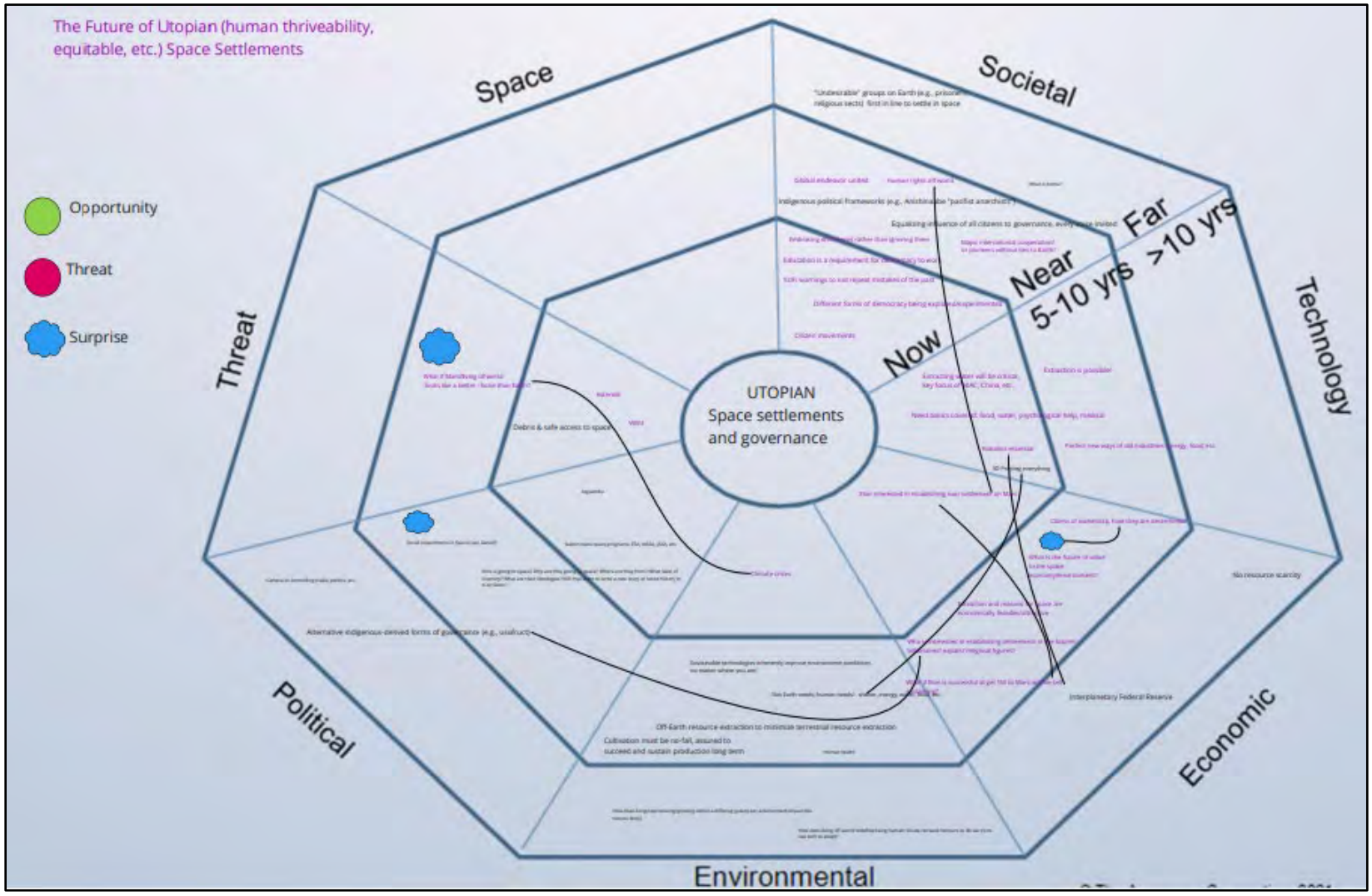
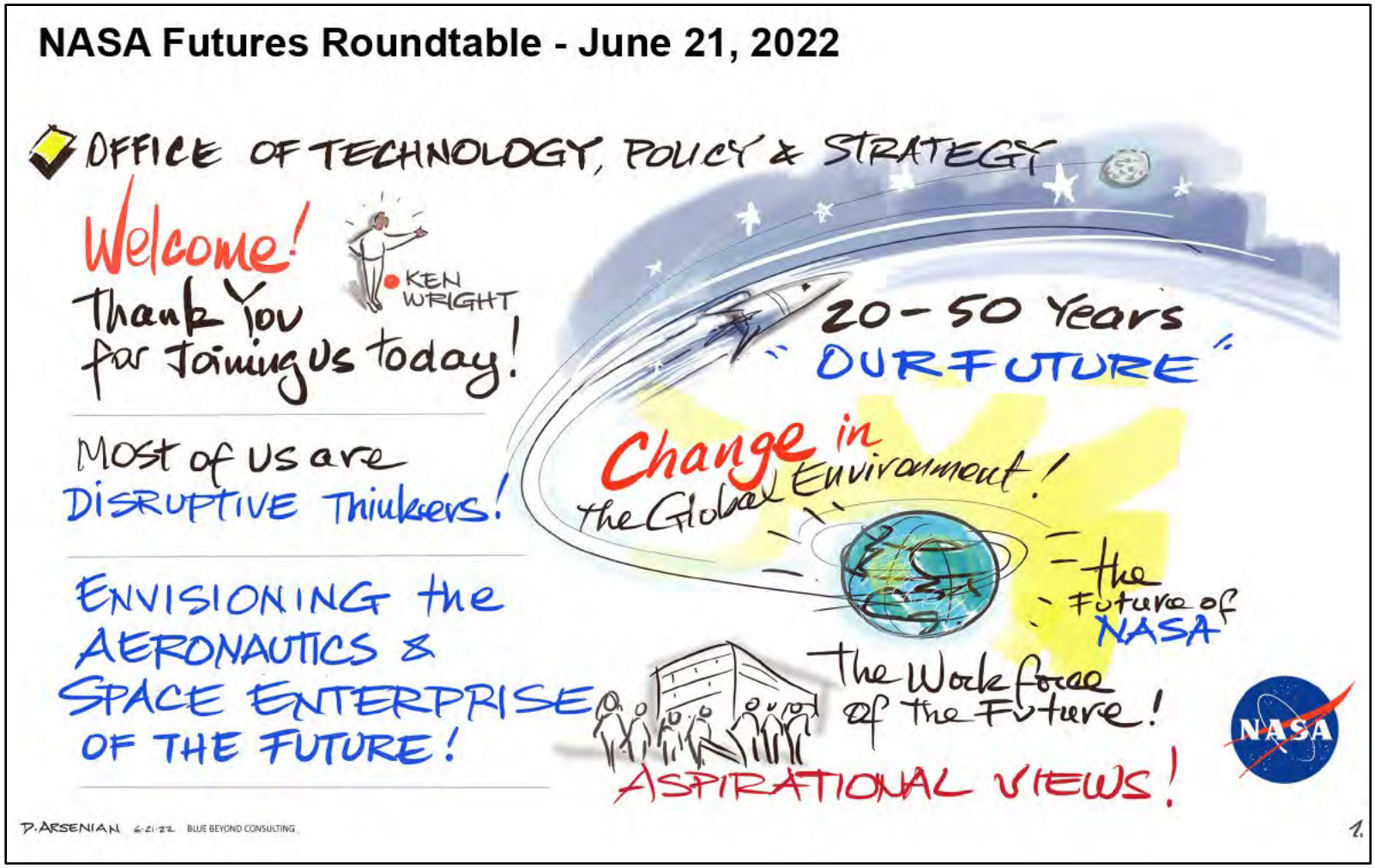


Figure 77. Virtual external roundtable futures web on utopian space settlements and governance.

Figure 78. Key takeaways from the virtual external roundtable participants.

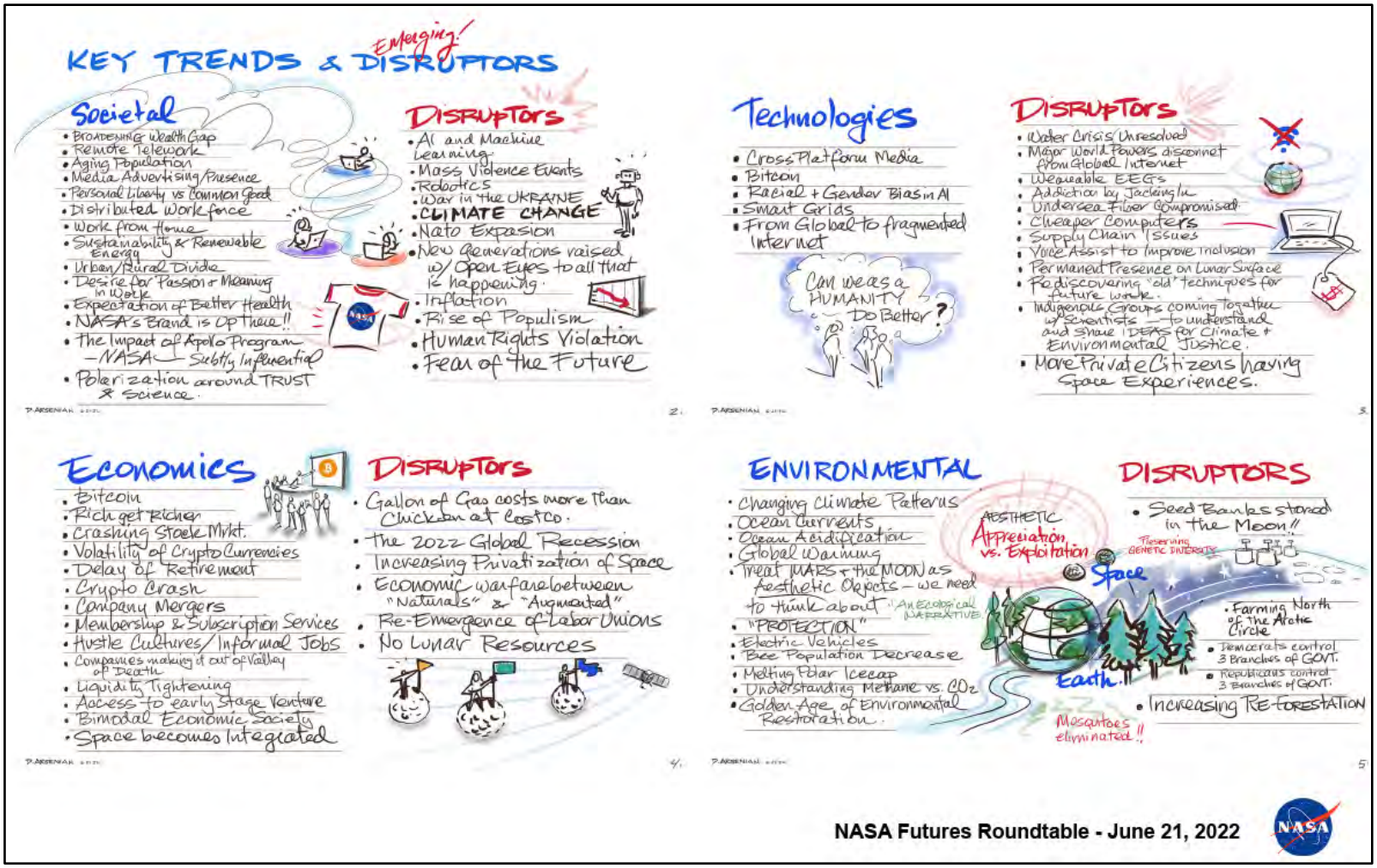
D.1.6 Graphic Recordings

The virtual external roundtable session was graphically facilitated by Blue Beyond Consulting, a visual communication consultant who supports complex technical projects with real-time illustrated story maps. The five graphic recordings are shown in Figure 79 through Figure 83.



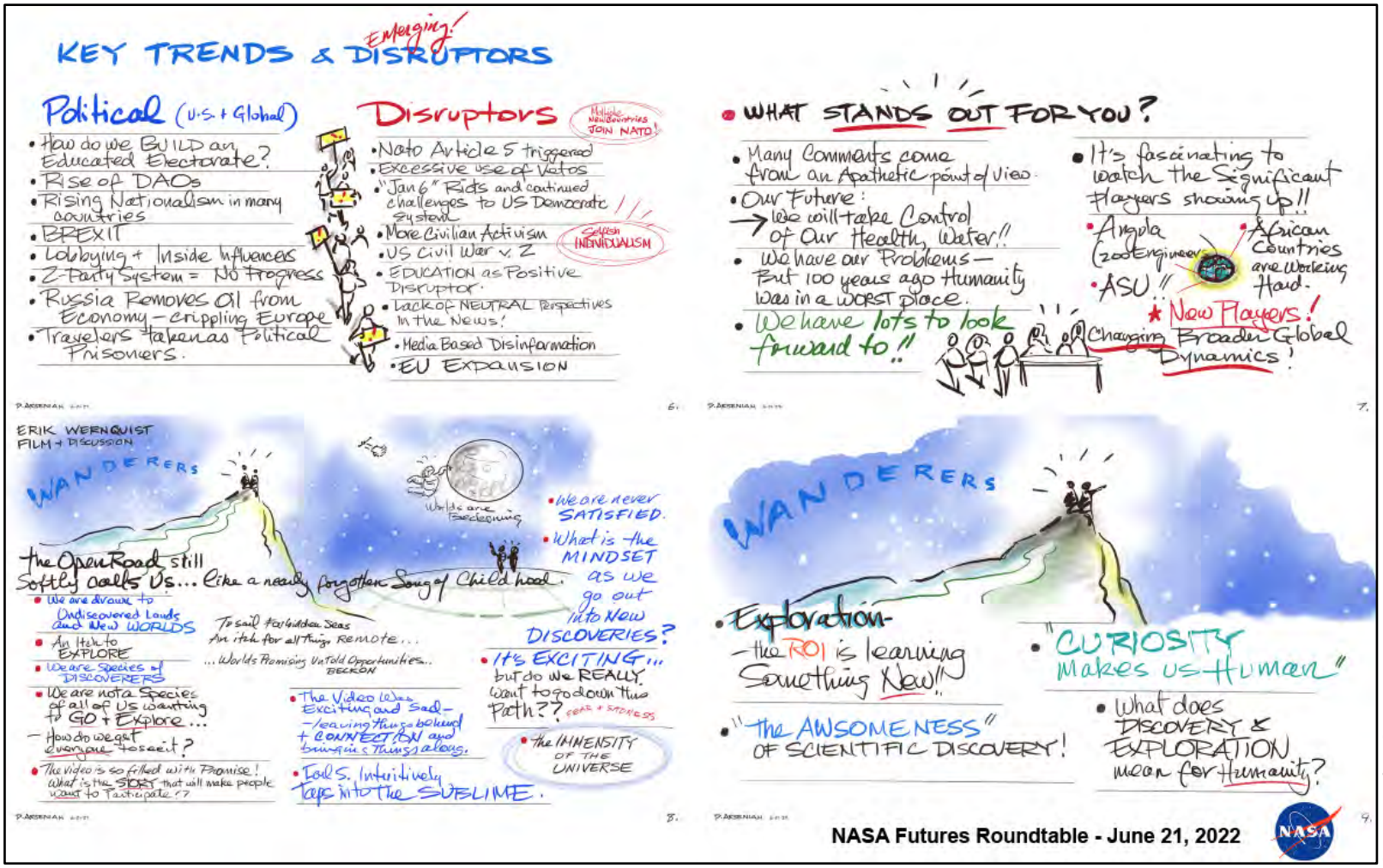
Courtesy of NASA

Figure 79. Virtual external roundtable graphic recording 1 of 5 (image created by Blue Beyond Consulting, courtesy of NASA).



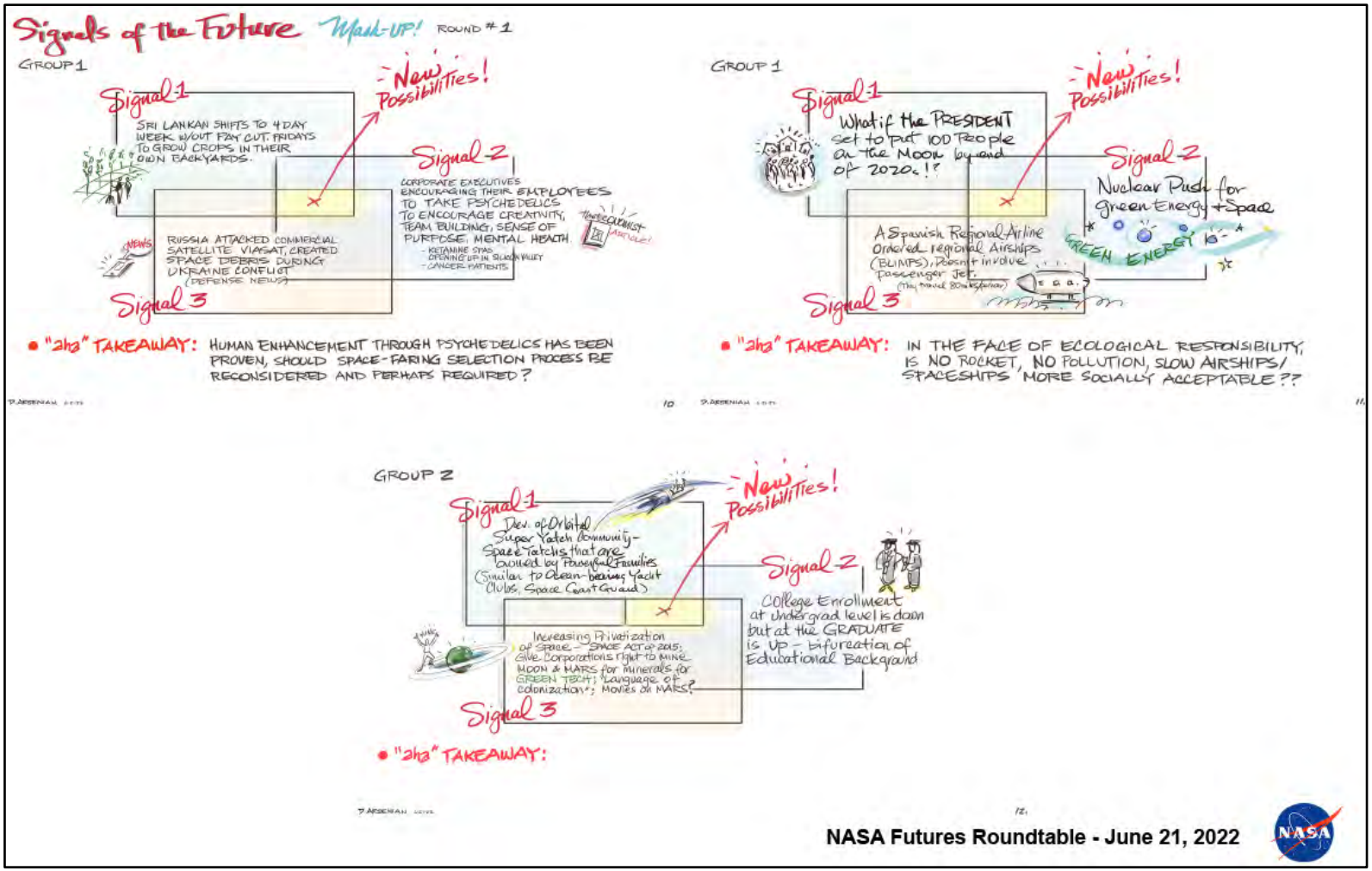
Courtesy of NASA

Figure 80. Virtual external roundtable graphic recording 2 of 5 (image created by Blue Beyond Consulting, courtesy of NASA).



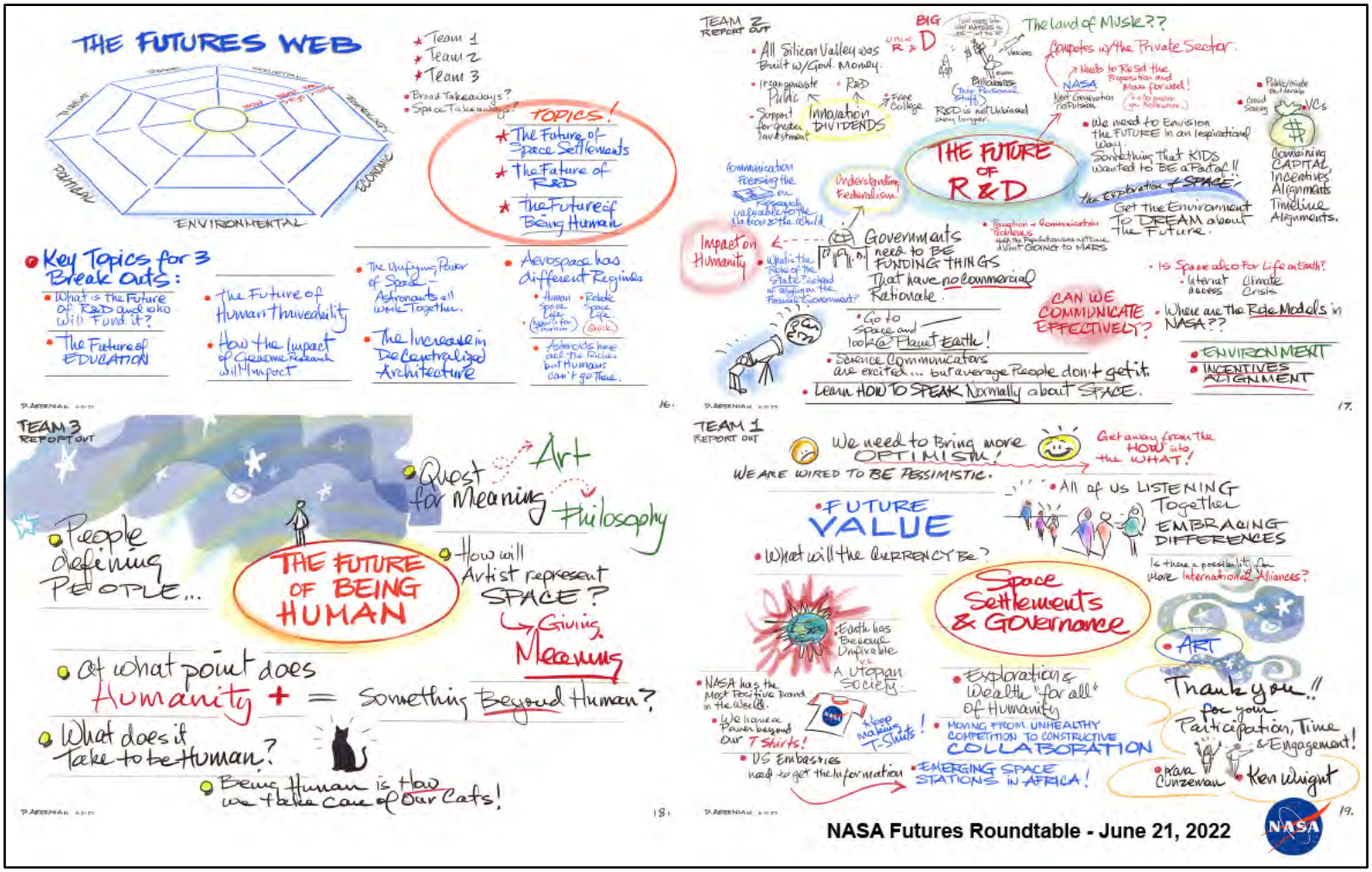
Courtesy of NASA

Figure 81. Virtual external roundtable graphic recording 3 of 5 (image created by Blue Beyond Consulting, courtesy of NASA).



Courtesy of NASA

Figure 82. Virtual external roundtable graphic recording 4 of 5 (image created by Blue Beyond Consulting, courtesy of NASA).



Courtesy of NASA

Figure 83. Virtual external roundtable graphic recording 5 of 5 (image created by Blue Beyond Consulting, courtesy of NASA).

D.2 In-Person External Roundtable

The in-person external roundtable hosted about 23 participants (2 were unable to attend due to travel issues) over the course of 8 hours. A detailed listed of attendees and their biographies is available in Table 40. The roundtable had the following high-level agenda:

- Exploring changing broader global environment (STEEPTS Section D.2.1)
- Signals mash-ups *(shown in graphic recordings)*
- Defining the possibilities of the future of discovery and exploration
- Defining the possibilities of the future of space discovery and exploration
- Sketch the future of discovery and exploration *(sketches not included here)*
- Insights and discussion

Following are summarized notes and any graphics for exercises not previously discussed.

D.2.1 Exploring Changing Broader Global Environment

The key trends and disruptors identified by participants across the STEEPTS are shown in Table 35 through Table 39.

Table 35. In-Person External Roundtable Key Trends and Disruptors (1 of 5)

SOCIETAL
Trends
• Inaccurate reporting/storytelling/lazy journalism
• Bias in searches and digital ecosystem
• "Bleeds it leads, Offends wins"
• Alternative realities, smart people believe this!
• Disembodied decision making (algorithms, don't represent broader society, subject to bias)
• Splinternet: geopolitical ties, institutionalized tech standards no access to alternatives, control =post-citizen
• Individual energy use on the rise
• General cultural homogenization across the globe (perhaps counter to the stovepipes). Subgroups now exist everywhere
• Disillusionment with higher education. 4-year colleges in the future?
• Great resignation, 110% drop of post-doc since 2018
• Different identities
• Labor unions (Amazon, Starbucks)
• Aging populations, lower birth rates
• Shortage in specialized careers
• Generational disconnect between what they want, cultural, work, etc.
• Disappearance of middle class
• Germany building coal fired, shutting down nuclear
• Geographic shift (in US specifically) due to COVID, Rent, Ecological factors
• Pandemic caused natural fascination shift, but also artificial. Need an app to make sourdough. Tension: inclusivity vs. isolation
• Rise of non-binary, change of family architype, gender dynamics, and its backlash, reverse on abortion decision (different globally, China very different for example)
• Absence of responsibility
• Leveling of expertise. Influencers have a weight.
• Hypocrisy is a lifestyle
• Narrowing in understanding in how things work outside of your experiences
• Risk and reward, examples: vaccines, overspecialization hurting societal confluence
• Alternative meat
• Rise of the rest (not US, not Europe, not China - desire for other systems or bring the rest in)
• GameStop run
• Collapse of supply chain
• Lack of basic skills
Disruptors
• Believable imagery, living in own cultural/artistic spaces that aren't necessarily "real"
• Future of identity verification, future of avatars security?
• Post-scarcity
• Post-covid as window to space
• Food system not sustainable, there will be a collapse = big link to space!
• The other 2 billion come online, what does that look like?
• Removeable of pieces of systems (as we shift into digital environment) = actor network theory)
• Potential for Global war (China invades Taiwan, ongoing Ukraine conflict…)
• Dynamics of trust, who do we trust, why do we trust?
• Next pandemic (migration of animals due to human impacts, bats)
• Democracy vs. fascism, vs. what's next? This is being taken advantage of.
• New generations totally different mindset, don't recognize boundaries, material goods, etc. How will this shape future behavior?
• Future of consumption, what's the future of capitalism?
• Future of power, social movements to drive financial impacts

Table 36. In-Person External Roundtable Key Trends and Disruptors (2 of 5)

TECHNOLOGICAL	
Trends • 3D printing (Food tech, plastics, etc.) • Primary persons (world of warcraft virus) vs. virtual lives • Synthetic biology • Vin locking, who owns stuff, Ukrainian tractors stollen and then bricked remotely by John Deere; you can't service things because you don't own them, different ownership structures • hacker culture to unbrick things • longevity research and view of aging as a disease • new nuclear (new fission systems) • continuous health monitoring in the home (non-invasive); telehealth • brain hacking • digital twins of everything and changing modes of transportation (eVOTL) • cyber security and one bad actor can freeze entire society; China concerned about how anti-fragile Starlink • global LEO comms • distributed infrastructure • cross-linking science and technology; citizen science • manufacturing in space, 4 major areas: DARPA award, ISS, DoD, NASA cislunar, funding indicates that this will be a disruptor • non-traditional education platforms like TikTok, YouTube, etc. ***Disruptors*** • nuclear, mobile nuclear project, fusion • rise in cyber-security threats EVERYWHERE • supply chain dependence on Chinese components or other single sources (how do you drive a more distributed supply chain?), same issue with rare earth elements • abandoning recycling • intersection of robotics and AI is real and happening now at a large scale • more personal robotics • alarm about microplastics and concerns over single-use plastics (microplastics found in fetal tissue, being consumed in surprisingly large amounts) • ways that technology is limited to reduce human concern not due to actual technical limitations (self-driving cars go slow through intersections) • expect first high-density fusion reactors very soon • integrated technology in our fabrics, etc. • 3D printed ear transplant • rise of NewSpace with different ethics, perspective, desire to reduce & reuse, could be a platform to model good behavior on earth	

Table 37. In-Person External Roundtable Key Trends and Disruptors (3 of 5)

ECONOMIC
Trends • Water (will become scarcer, create more problems) • Crypto currency • Crowdsourcing • Discover what the rest of the world works with everyday • Universal basic income/services, changing relationship to work and how our value is distributed • What does it mean to live beyond 100 and still have a viable social fabric? • Disappearance of cash and changing ways to pay • Governmental digital currencies • Social credit scores, social media as social credit, traditional credit scores • Social economic element in use of digital currency • Charging for public restrooms excludes homeless populations • Changing investment priorities • Digital currency vs. cash, cash is democratizing - anonymous, accessible to everyone / digital currencies are traceable, thus new social dynamics related to who gets to participate in each market • How to governments store reserve money? • Globalization of capital and markets - if you get a tiny penetration into large markets, you have larger market than entire US. Companies can be created quickly out of nothing, but need to have a track record of returns or executions (how are these new companies appearing out of nowhere?) • Decentralized digital assets—large projected market for things that individuals will make and sell that are non-material • Artificiality of our financial systems, easy to lose trust • Significant effort being put into nouveau capitalism, what's the next big picture framework for economies • Willingness of the consumer to be the product by selling our data - no mass movement to take back individual data ownership • What does money even mean in a realm where we can borrow massive amounts of money and always be in dept and be fine? • In the early 1900s was massive boom in innovation in every sector of society during and after WWs as opposed to right now innovation is mostly focused on communication • What are our most talented people working on? Apps vs. physical infrastructure? • United States isn't investing in human capital and workforce development to the extent of other countries or our past • Deep thought isn't supported as much now as past leading to distractions and many communication channels make it difficult to challenge large hard problems, what is efficiency? Reading lots of emails vs. spending time isolated focusing on a single problem • Deep thought and intellect—innovation is ideas having sex and you can't do that in a room alone • Lack of secular growth right now, our advancements in past have increased productivity of humans, recently growth will be about ***Disruptors*** • Anti-globalism • Workforce value • Currency shifts and use globally

Table 38. In-Person External Roundtable Key Trends and Disruptors (4 of 5)

ENVIRONMENTAL
Trends • As climate shifts populations will move, gain access to new areas and loose access to current areas • We will know a lot more about climate because of new sensing and data collection • Disconnect between environmental concerns and ability to do any physically big projects (there is no place to build another large space port), thus there is conflict between environmental needs and large infrastructure needs • Our ocean (used as refrigerator and toilet for years) and the lack of understanding of the importance of the ocean in our ecosystems • Since early humans we've been "takers" from the environment and need to make a transition to "care-takers" of our planet • Industry trends on the environment tend to be Western. Could look more into non-western philosophies like anti-land ownership vs. conquering and owning land? Reexamine the nature/culture divide • Personhood for nature (a river in New Zealand has been given personhood, there's been a push to do that for the moon) • Tragedy of the commons shows that areas that are non-owned are not maintained as well; counterpoint: could we use stewardship as a framework • Biomimicry, learning from the environment and nature to design smarter, better tech • New generation being disappointed that we haven't take care of the environment • Push-back against aviation, launch, fashion industries, etc. • Stewardship vs. ownership: ownership does not guarantee accountability, but future could see more accountability to enforce norms, etc. • Pendulum and interdependency, whether you can have ownership depends on scarcity - in a post-scarcity world shared-resources might be more feasible than if scarcity still exists • Eco-imperialist perspective: we can't go there because that would be evil colonization and might impact the ecosystem, but is that worse than taking resources out of Earth's environment? • Taking a stand against de-orbiting the ISS: individual can't litter but government can throw out entire space station ***Disruptors*** • Climate management, not nearly enough to oppose man-created climate change; we may want to prevent natural climate change if it impacts our way of life • Using natural alternatives to plastics (like mushrooms) • Kessler syndrome • Oil and gas industry is disrupting efforts to prevent/reverse climate change and climate issues • Societal greenwashing, black rock, "scrofrenia", we are not prepared to change our behaviors or give up our comforts to change climate problems • Should we pass off environmental decisions to algorithms and computers instead of humanity? • Sustainability as a concept

Table 39. In-Person External Roundtable Key Trends and Disruptors (5 of 5)

POLITICAL
Trends
• Rise of Africa (recognizing geographic advantages and pulling resources)
• Artemis vs. Russia/China - where is Africa, India going to break in space?
• Rise of authoritarianism (net GDP of authoritarian space is larger than free states)
• Rise of younger voices via social media, rise of female global leaders
• New governance models, digital communities, and societies
• Backlash against governments with guns
• United Nations Peaceful Use of Outer Space is now looking at space resource utilization - there are WAY MORE actors/voices now than when UN started this, will UN become completely obsolete with so many voices and requirement for consensus? Decision making could become impossible
• Paradigms of governance, transitioning to more block based, ability to make decisions for these block problems is revealing issues in current gov. structures
• Public-private partnerships are taking on different forms to solve big problems, how do we create interoperability between very different functioning orgs?
• Emergence of non-nation state organizations is being challenged by governments because they have guns and can push back
• ITAR is limiting international information sharing and collaboration
• All the ambiguities in space law, the American political way of handling space might not be best
• International law is traditionally made by sovereign nations, but the commercial industry can now make customary international law that nations will have to adopt/follow
• Lack of political will or apathy to vote - if people aren't supportive then we can't make real changes
• The way gender is being discussed and moving toward non-binary approach to gender, less black and white thinking and more understanding of nuances and spectrums, could result in a move away from fear-based politics
• Red vs. blue politics don't fit well with increasingly nuanced political identities
• If orgs like Anonymous use power for good that would be awesome, but they could also do bad things (traditional gov. vs. non-gov. actors)
• Some could say that UN makes rules in a universe that they don't own, move through a phase where we have a battle between corporate entity going into space and sovereign entities. At first, governments have the advantage because we'll still rely on Earth, but in the future space communities could be independent from Earth and Earth will have no control over them - we must come up with an ethos for space communities versus nation-state norms of claim to space
• Why do groups of people no longer want to be a part of nation-states?
• Race to the bottom in terms of licensing and regulations (US has lots of regulations, other countries may be able to offer less or no regulations to commercial space actors)
Disruptors
• Navigating where we are dropping astronauts/launching from, impact of space ports in impoverished nations (not bringing jobs to the host countries)
• Commercial sovereignties are starting to pop up and play a role
• Building nations without territories (in cyberspace, space, etc.)
• Virtual economies like Metaverse, Second Life - ways for people to make money beyond political borders, new religions, new economies, virtual sovereign nations,
• Rise in the discussion of equality in space, how do we ensure that non-space faring nations benefit equally from the use of space and the advancement of technology (focus on benefit for humanity vs. for our country/economy)
• Humans have also revolted against governments and virtual options reduce the cost to entry for revolting and creating your own country
• Virtual awards are becoming more integral to our daily lives and social spheres
• A Future where governments are decentralized and apply to people not geographic areas
• Capabilities that decentralized organizations can have, once you have the capabilities you can use them for any purpose (good or bad)

D.2.2 Defining the Possibilities of the Future of Discovery and Exploration

For this exercise, the participants were asked to find an article discussing a new way of discovery and exploration. Presented here is are inputs from the participants:

- "Off World Company—robots that can use AI to find veins for mining, reduces operational expenses, safer, less environmental impact, reducing power requirements, no humans involved"

- "In-space manufacturing is becoming more mainstream, Made in Space can make unique materials in space."

- "In the case of additive manufacturing, it was invented in 1983 and it takes a long time to see the full potential of that technology."

- "Dream chaser: as an investor the problem is that space for use on Earth has customers, but space for use in space doesn't have sufficient customers. So, in-space manufacturing of spacecraft isn't quite viable yet."

- "Treasure hunting company in the Bahamas has to give 25% to the government, but now the government is trying to define the treasure as a natural resource versus a cultural treasure."

- "Map making with Australian aboriginal people—thought that they were telling stories, but it was really verbal map making."

- "Maybe people with disabilities may be better suited to exploring space?"

- "If we bring in a bunch of new resources to Earth, we will increase the amount of those resources on Earth and devalue them—numbers might be tricky here to make a business case close."

    - "What materials are extremely common in asteroids and on the moon versus on Earth?"

    - "There may be no reason to send humans to mine off-world."

- "Augmented interspecies communication (FluentPet): discussion of whether pets can recognize the names of other animals, if they can use language techniques, changing the questions about how smart they are. Animals use buttons while no humans are in the room—it's a good model for how we have contact with other species."

    - "This analysis of the language of animals and even plants will change the way we interact with the environment. If we see it is as intelligent then we won't want to just interact with it in the same way."

D.2.3 Defining the Possibilities of the Future of Space Discovery and Exploration

For this exercise, we posed the following open-ended questions:

61. Define in 10 words or fewer what you believe space discovery and exploration means

    - "A long future for humanity"
    - "Responsibility to future generations"
    - "Why do humans deserve to continue and preserve our history?"
    - "We exist as a natural continuation of our biosphere's expansion."
    - "Opportunity to alter mindsets from one of scarcity to one of abundance"
    - "Exploration is hardwired into the human DNA. Up and out is our new West."
    - "Opportunity, danger, risk, reward, learning, fulfillment, failure, multigenerational"
    - "Disenfranchised people have an alternative exit—there is nowhere else to go on Earth"
    - "Our purpose is to explore and experience everything in the universe"
    - "Challenges our basic features and unites our species at a difficult time"
    - "Appreciating Earth and challenging us to live on it better"
    - "Five positives: hope, growth, prosperity, opportunity, and pathways. Negatives: restlessness, dissatisfaction, greed"

- "A quest for meaning. A quest to know ourselves by exploring the edge. Constantly redefining our own context."
- "Seeking the answers to some of the most important questions."
- "Most meaningful endeavor of our generation"
- *"Mission to Mars* by Michael Collins: we have a spiritual need for the new frontier"

62. What is the impact of discovery and exploration for humanity, U.S., individual?

- "For our generation versus future generations"
- "Possibility to create a more fair, equitable, and fulfilling life for all human beings. Humans tell stories of what ifs, pushing boundaries allows us to raise new questions and continue evolving"
- "For humanity, it's about survival, for the U.S."
- "We can't possibly imagine the value we'll gain through space exploration"
- "Impact on humanity is threatening…why are we doing this? Are we exploring to find an alternative to a dying Earth? Aspiration might not be a good thing."
- "Discovery and exploration are actions taken based on a purpose, and without a purpose we would not know how or why to explore. It's impossible to guess the impact without knowing the 'why.'"
- "As a biologist, it's essential for the survival and evolutions of the human species"
- "Carl Sagan believed that because we will have a deeper understanding of our place in the universe and truth, we can do good for the living things on the planet"

63. How do we make these ideas important to people that spend most of their time thinking about their own survival?

- "To keep it relevant to the masses, we need to think about the stories were telling and keep it inclusive and applicable to all"
- "How do we make sure we keep an inclusive pipeline to the exploration mindset?"
- "How do we communicate to the masses? Everyone is an underdog when we're in space."
- "The NFL doesn't feel like they need to make everyone think football is great. Not everyone will ever be a pioneer or a scientist. It's okay for NASA to do things that not everyone in the United States agrees with. NASA spends less money than a lot of much less well-known U.S. programs."
- "We all know that in a complex world, some countries are strong in niche industries and promote higher education but are never able to use that knowledge to become wealthy. In China, more young people might want to be space explorers versus in the United States where more kids want to be influencers"
- "We should still pay attention to dissent. Why are we taking a billion-dollar camping trip on the moon? Should we take the dissent more seriously as we see a rise in caretaker perspective from the next generation."
- "Democratizing access to space. This is cool but there's nothing for us to do to get to a future of space exploration. We're not going to make everyone happy—experiencing moon deniers and flat Earthers"
- "Not everyone has to buy in—teaching in design school, you'd be surprised by how much nontechnical people feel they fit into the bigger picture"
- "Why was it important for us to be ahead of the Russians in the space race—it was a rallying cry for people that weren't in the room making decisions on space programs."
- "When people ask an astronaut 'why go to space?' [they] would say 'why go to Yellowstone?' Just because you don't understand something doesn't mean it's not important."

- "Investing money into bringing communities in that haven't been represented in the past. When we had the inspiration for launch, we had similar protests. Put out a docuseries created by a black documentarian and made by HBCU students about what it's like to be a human in space."
- "It's hard to get people to buy into aspirational things and it's important to show people how much space impacts our day-to-day lives."
    - "A lot of these things are emotional. People LOVE space and have a relationship about space."
    - "Younger generations seem more combative and less interested in space"
    - "Maybe the way people approach science fiction might impact the way they think about space."
    - "Pool hall experience—a room full of people that work with their hands and think there's no place for them in the space industry"
    - "Not trying to convince everyone to want to go to space and the cultural experience that people are having [when they go to space] (people love sci-fi but aren't interested in actual space exploration)."
    - "People that are interested in science fiction view it as fantasy and not predictive of the future."
    - "'For All Man Kind' is impressive. Storytellers may be more impactful than NASA on people's interest in space."
    - "Sci-fi production is a cultural output that reflects anxieties about our times. What about our times produces dystopian sci-fi content?"

D.2.4 Attendees

Table 40. Biographies of All Attendees at the External In-Person NASA Roundtable

Name	Biography
Lee Anderson	Lee is a designer and strategist with a background in the fashion industry and a body of research exploring the intersection of space exploration and design through the lens of fashion. She is currently adjunct faculty at Parsons School of Design Strategies and a member of KPMG's Innovation Lab.
Greg Autry	Dr. Greg Autry is Clinical Professor of Space Leadership, Policy and Business at Arizona State University's Thunderbird School of Global Management and Visiting Professor in the Institute for Security Science and Technology at Imperial College London. He previously served on the NASA Agency Review Team (2016) and on the COMSTAC at FAA.
Shelli Brunswick	Shelli Brunswick, Space Foundation Chief Operating Officer, brings a broad perspective and deep vision of the global space ecosystem—from a distinguished career as a space acquisition and program management leader and congressional liaison for the U.S. Air Force to her current role overseeing Space Foundation's three primary divisions: Center for Innovation and Education, Symposium 365, and Global Alliance.
Kimberly Bryant	Kimberly Bryant is the founder of Black Girls CODE, a non-profit organization focused on diversifying the tech industry by introducing girls from underrepresented communities to technology. Her new company ASCEND Ventures Tech takes builds on her work in technology with innovative programs in Web3, sustainable entrepreneurship, and investment in overlooked founders.
Aaron Burnett	Aaron Burnett is the Founder and CEO of Spaced Ventures, the world's largest community of space investors. He is a relatively new entrant to the Space Industry, who brings more than a decade of marketing and community experience along with a proven track record of engaging digital audiences into the millions.

Name	Biography
Naia Butler-Craig *(could not attend due to travel issues)*	Naia Butler-Craig is an aerospace engineering Ph.D. student at Georgia Tech with a focus in electronic propulsion. She's funded through the NASA Space Technology Graduate Research Opportunity and is a NASA pathways intern.
David Colby Reed	I'm a designer, educator, and technology ethicist. Some of my past include designing public services for the City of New York, storytelling experiences for the Kigali Genocide Memorial, and financial instruments to advance economic security. I'm currently pursuing a Ph.D. at the MIT Media Lab, where I try to imagine desirable futures for equitable governance and space exploration.
Tom Cooke	Tom Cooke is the co-founder and CEO of Spacely, a digital marketplace connecting independent workers to the aerospace industry. Tom is a U.S. Air Force Academy graduate and spent 16 of his 24 years of service in space systems development and operations. After retiring from the Air Force in 2017 he began researching open talent marketplace utilization across industries and potential applications for the aerospace industry. This led to the formation of Spacely in January 2020. In June 2020, Spacely was selected to be part of a 5-year contract effort to bring forward aerospace-specific expertise to support NASA's Open Innovation efforts through an open talent marketplace model. Spacely's goals are to be a trusted network partner in providing access to fractional talent for the aerospace industry and to bring forward opportunities to those who want to contribute and take part in the growing space economy.
Dorit Donoviel	Dorit Donoviel, Ph.D. is the Executive Director of the NASA-funded Translational Research Institute for Space Health (TRISH), which relentlessly pursues and funds research to advance human health solutions for space exploration. Dr. Donoviel is an associate professor in Pharmacology and Chemical Biology and the Center for Space Medicine at Baylor College of Medicine.
Rob Gabbert	Rob Gabbert is an engineer and government affairs professional who has spent the last decade+ building ties to Congress and the Executive Branch. He has industry knowledge from helping companies working on OSAM, orbital logistics, and ISRU.
Michelle Hanlon	Michelle is Co-Director of the Air & Space Law Program at the University of Mississippi School of Law, Editor-in-Chief of the Journal of Space Law and the Journal of Drone Law and Policy. Michelle co-founded For All Moonkind, a nonprofit that is the only organization in the world focused on protecting human cultural heritage in outer space.
Peter Kleeman	Peter Kleeman is a historian and founder of the Space Age Museum project. He specializes in Space Age cultural history, particularly public engagement with space exploration and visions of the future.
Johnathan Knowles	An explorer, scientist, and technologist currently working in the space and ocean domains, Jonathan is focused on the dynamics of large-scale, long-term change with an emphasis on beyond the horizon science and technology. With 35 years in academia and in Silicon Valley leadership positions at Apple, Adobe, and Autodesk, Jonathan provides insight on the intersection of emerging technologies and closing the gap between the theory and practice of innovation in a world of rapidly accelerating technological capabilities at the Frontier Development Lab and Mission Blue.
Mary Robinette Kowal	Mary Robinette Kowal is the Hugo and Nebula award winning author of *The Glamourist Histories* series, *Ghost Talkers,* and the Lady Astronaut Universe, starting with *The Calculating Stars*. A professional puppeteer and audiobook narrator, she lives in Nashville with her husband Rob and over a dozen manual typewriters.
Graham Lau *(could not attend due to travel issues)*	Dr. Graham Lau is an astrobiologist and communicator of science. He serves as the Director of Communications and Marketing for Blue Marble Space, as the Director of Logistics for the University Rover Challenge, and as the Host of the NASA-funded show "Ask an Astrobiologist."
Savannah Mandel	Savannah Mandel is an outer space anthropologist and writer currently based out of Virginia Tech. She is earning her Ph.D. in Science and Technology Studies and is in the midst of completing a book that confronts imperialist space rhetoric and the socio-cultural outcomes of human space exploration.
Michael Mealling	Michael is a General Partner with Starbridge Venture Capital, a space-focused VC fund, where he invests in companies with real customers providing top decile returns to

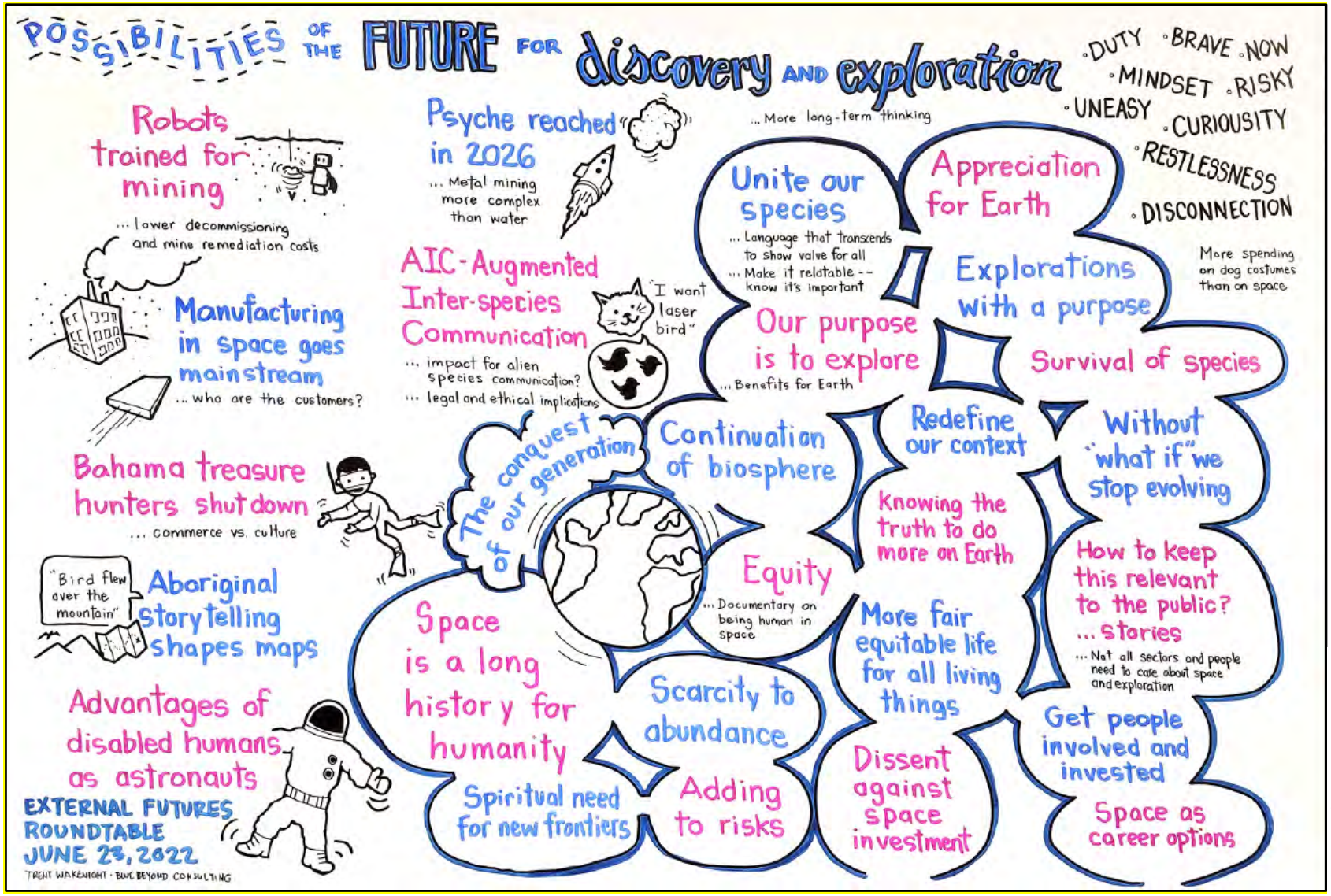
Name	Biography
	his limited partners. He is also an unabashed supporter of humanity moving into the solar systems and eventually the galaxy as fast as economically possible. The universe needs us.
Yvette Montero Salvitico	Holding a bachelor's degree in Finance and an MBA from the University of Florida, Yvette has over 15 years of corporate experience with large, multi-national firms such as Kimberly-Clark and The Walt Disney Company. Before co-founding The Futures School, she led the effort to establish the Future Workforce Insights division at the Walt Disney Company.
Frank Spencer	Frank Spencer is the Founding Principal and Creative Director at Kedge, a global foresight, innovation, and strategic design firm that empowers organizations to realize aspirational futures and transformational growth. He also co-founded The Futures School, a global foresight learning ecosystem that equips individuals and teams with a tangible mindset and framework to discover the future and create it today. He holds a Master of Arts in Strategic Foresight from Regent University.
Roger Spitz	Based in San Francisco, Roger Spitz is President of Techistential (Foresight Strategy) and Chairman of the Disruptive Futures Institute. Roger sits on several Advisory Boards of Companies, Climate Councils & Academic institutions worldwide; the VC funds he advises and invested in support the venture-backed ecosystem in Silicon Valley, across the U.S., Israel, U.K. & Europe.
Lee Steinke	Lee Steinke is the COO of Cislunar Industries, a licensed scientist, and a strategic advisor to the aerospace, defense, and energy industries. She has published a variety of technical papers and speaks to audiences across industries.
Scott Trowbridge	A Disney Imagineer since 2007, Scott Trowbridge is responsible for global concept development and integration of the Star Wars franchise across Walt Disney Parks and Resorts. Previously, Scott led Walt Disney Imagineering Research and Development and oversaw the organization's Blue Sky Design Studio, as well as development and oversight of new Guest experiences for The Disneyland Resort.
Rick Tumlinson	Considered one of the best speakers in the space field, Rick is listed as one of the top 100 influential people in the space field. He has been called one of the world's top space "Visionaries" and is credited with helping create the commercial space industry highlighted by Elon Musk and Jeff Bezos, often referred to as NewSpace. A leading writer, speaker, and six-time Congressional witness, he led the commercial takeover of the Russian Mir space station, signed the first private space traveler to fly to the space station, co-founded the Space Frontier Foundation, and was a founding board member of the X-Prize. As a result of his world-changing work, in 2015, he won the World Technology Award along with Craig Venter of the Human Genome project. He founded the SpaceFund venture capital company and his non-profit organization, the EarthLight Foundation, is creating an inclusive movement to use space to protect Earth and expand life into the cosmos.

D.2.5 Graphic Recordings

The virtual external roundtable session was graphically facilitated by Blue Beyond Consulting, a visual communication consultant who supports complex technical projects with real-time illustrated story maps. The four graphic recordings are shown in Figure 84 through Figure 87.

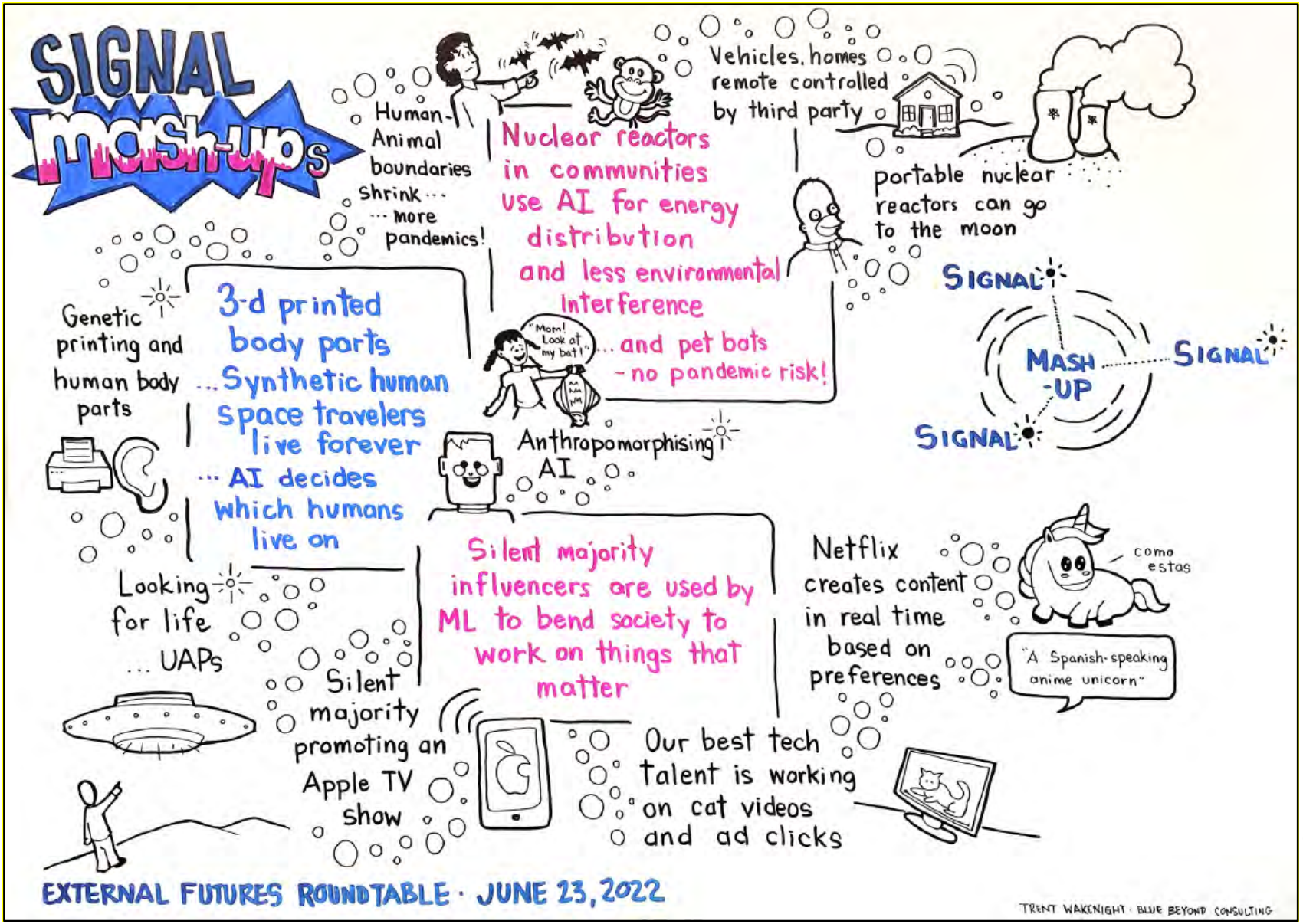
Courtesy of NASA

Figure 84. In-person external roundtable graphic recording 1 of 4 (image created by Blue Beyond Consulting).



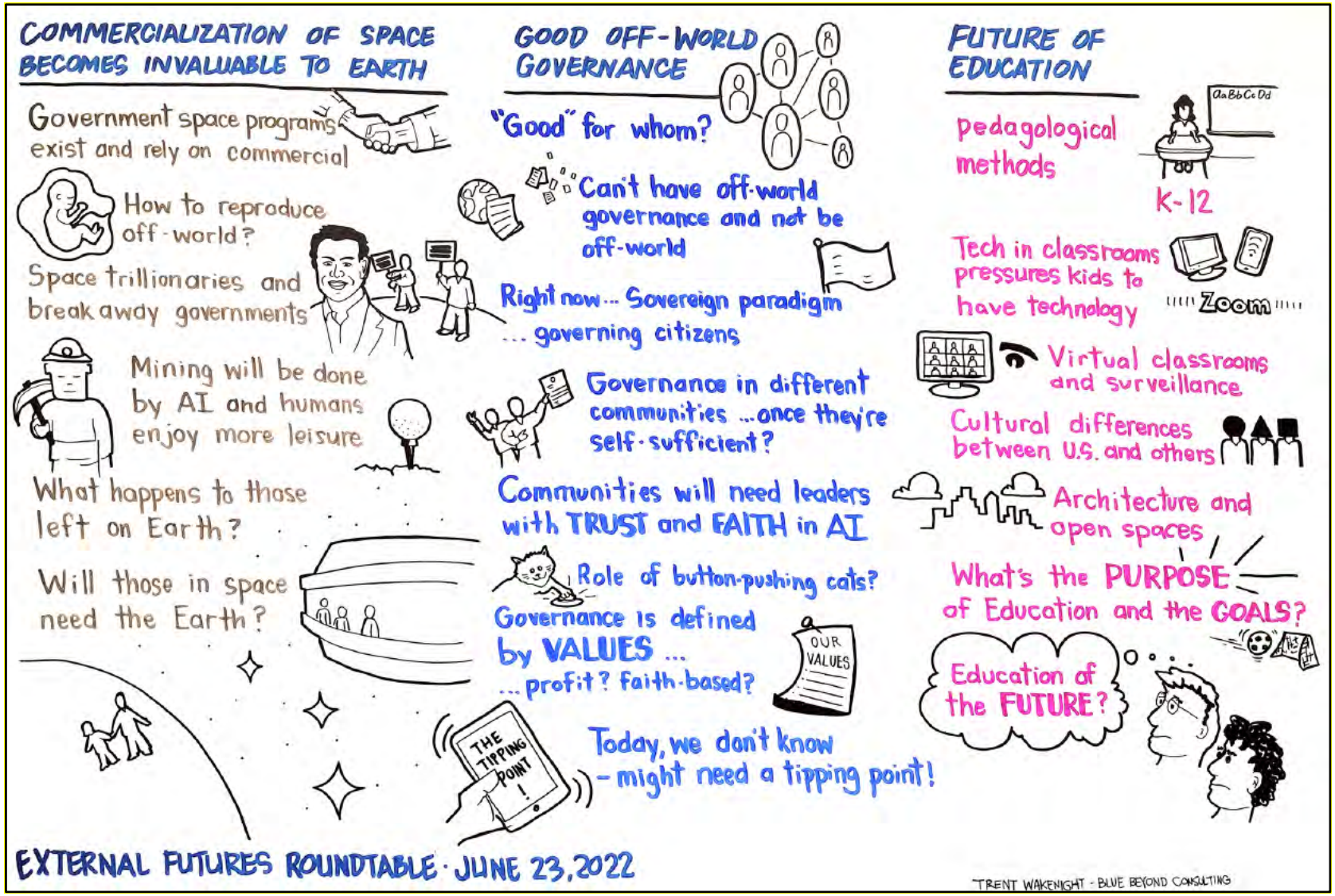
Courtesy of NASA

Figure 85. In-person external roundtable graphic recording 2 of 4 (image created by Blue Beyond Consulting).



Courtesy of NASA

Figure 86. In-person external roundtable graphic recording 3 of 4 (image created by Blue Beyond Consulting).



Courtesy of NASA

Figure 87. In-person external roundtable graphic recording 4 of 4 (image created by Blue Beyond Consulting

Appendix E. Summary of Commonalities/Contradictions across Input Sources

There were strongly consistent themes across the NASA-internal roundtables, NASA-external roundtables, and the NASA executive interviews. There were some inconsistencies across these groups indicating significant disconnects for NASA leadership to consider addressing as part of strategic planning. A summary of these high-level consistencies/contradictions is shown in Figure 88. The statements in this figure represent inputs we received that occurred in more than one group. We did not include any opinions/perspectives from participants if there was only a single instance.

Some participants from the NASA executive and NASA non-executive groups indicated that they were not aligned with the current NASA vision. These participants focused on the ethical considerations to humankind and Earth. They indicated that NASA could take a greater responsibility for these ethical considerations moving forward. There was a strong agreement that not enough was being done to create a diverse, equitable, and inclusive workforce and working environment. This was particularly noted in the executive roundtables.

However, some of the NASA-internal participants did not feel that radical change is necessary. This was in contrast with the feedback we received from the NASA early career staff and NASA-external groups who thought that there needed to be change. There was agreement that the trust of the public is critical to NASA's viability. They generally agreed that NASA should be a "storyteller" of space for the public.

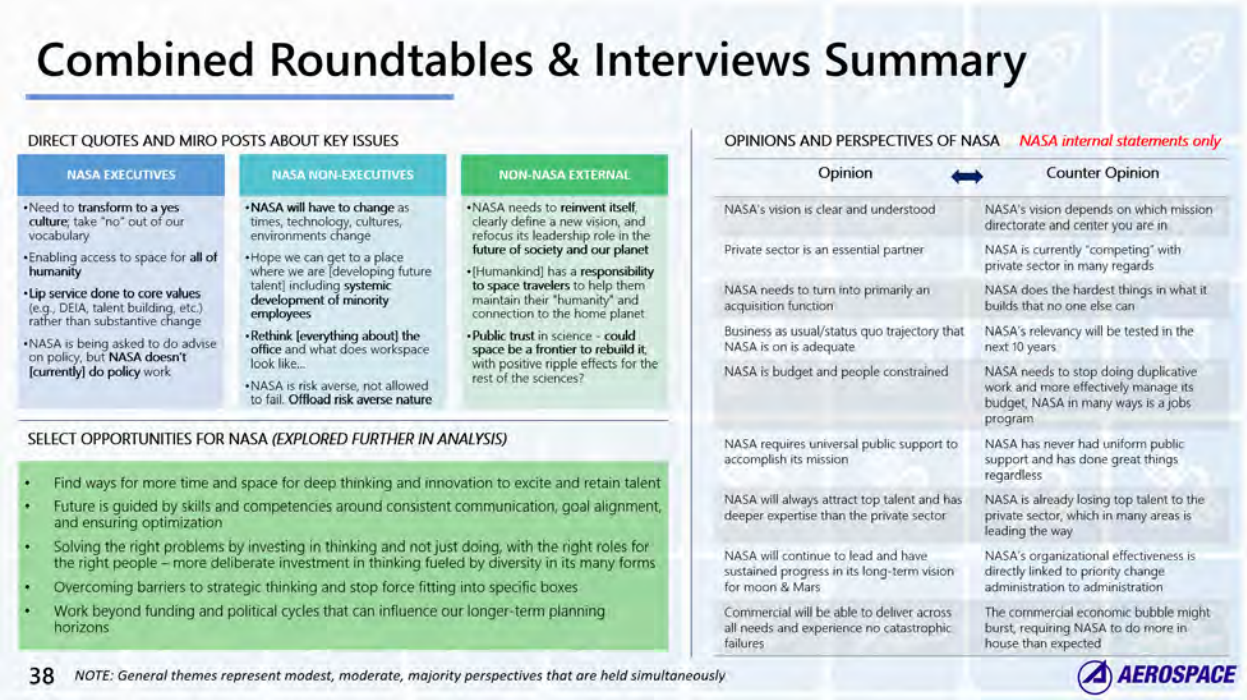


Figure 88. Summary of commonalities/contradictions across input sources.

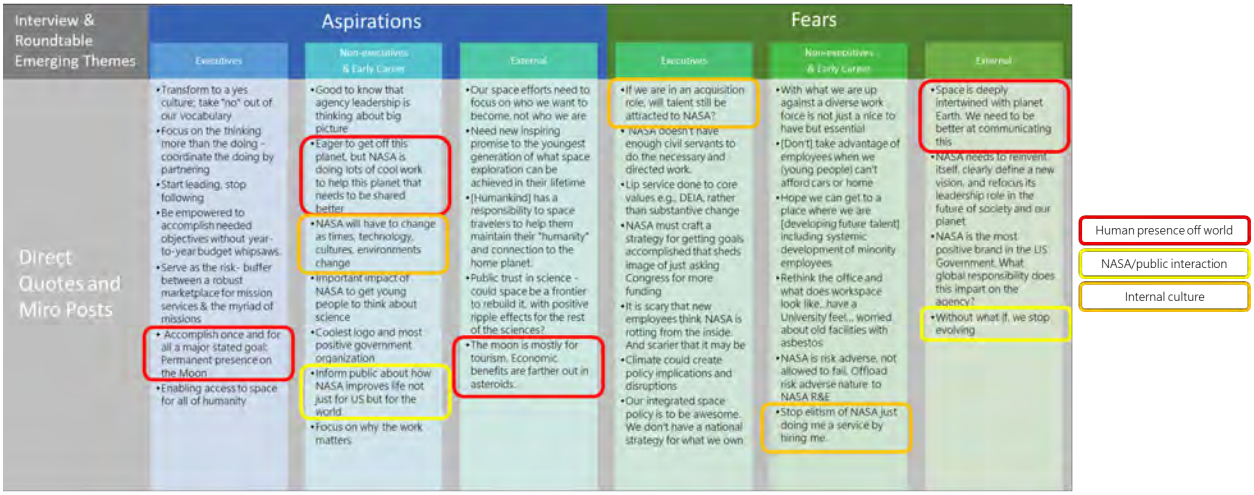


Figure 89. Themes and associated direct quotes/Miro posts across aspirations and fears for NASA.

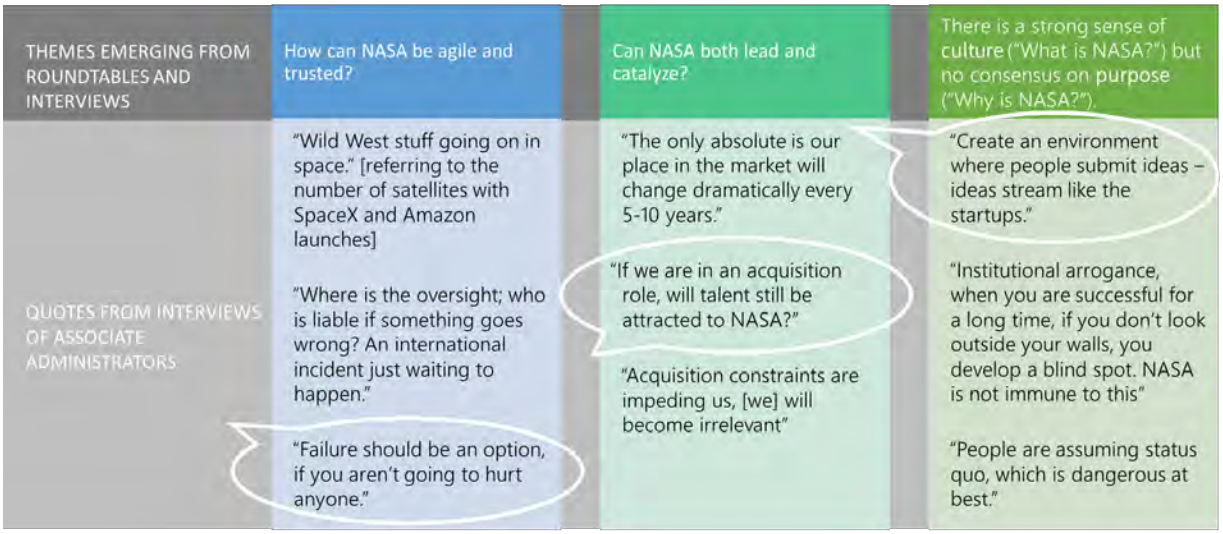


Figure 90. Quotes from executive interviews across a few key theme areas.

Appendix F. Lessons Learned

Diversifying the groups participating in the study was vital. Doing so illuminated blind spots, allowed us to see a bigger picture, and enabled us to collect the information necessary to deliver meaningful insights for the Agency. We also learned that continuing conversations and establishing routines for ongoing discussions about the future will help with organizational resiliency, communication, and planning. It is also essential to have the synthesizers of the data be objective for the design, facilitation, and analysis to avoid implicit institutional biases in the findings. Participants both internal and external were interested in seeing the results of the study and passing it along to their staff and peers. The early career staff were particularly enthusiastic to both participate and to see NASA leadership leaning forward on future thinking.

For strategic foresighting exercises to be helpful, there is a necessity to have stakeholders challenge current assumptions. Fruitful workshops are time intensive to plan. We feel that this pilot activity of roundtables was on an aggressive timeline and longer sessions would benefit participants. Additional roundtables would increase the diversity of thought feeding the process. Future planning of similar roundtable workshops should allow for more pre-planning to optimize participation, diversity, facilities, and methodology execution.

More work needs to be done to build the general population's understanding of strategic foresighting. As it is both a science and philosophical endeavor, understanding this process is required for the buy-in of participants and stakeholders.

Appendix G. Strategic Options and Supporting Roundtable Inputs

Table 41 details strategic options with a description and relevant supporting inputs from the executive interviews and roundtables.

Table 41. Strategic Options and Supporting Data

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
1. Maintain internal capabilities relevant to NASA's mission	Overlap exists between what NASA is doing and what commercial can do.	"The assumption that commercial will get everything done is a false assumption." "Infrastructure necessary to carry out the mission, most is over 80 years old, beyond end of life, is single biggest risk to mission." "No one launches without NASA, ability to support all demands is big, ... hard to maintain with declining budgets and support from Congress." "Commercial sector is a lot smarter than NASA isn't the case. There is the same diversity of talent." *NASA Internal Mash-Up #2 Takeaway*: "Ensuring NASA and other public entities remain relevant, as capabilities, funding, and infrastructure building shift to outside parties. Important to maintain public interest, don't let everything go to commercial, it's a balance."
2. NASA transitions to an acquisition-only agency	NASA employees are not actively building, integrating, or operating in house	"We are in an environment where people are breaking molds. Acquisition constraints are impeding us to becoming irrelevant." "Are we dependent upon outside actors? How much effort would need to go into shifting course if wrong?"

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
3. Skate to where commercial isn't	Fully transition commercial-viable capabilities out of NASA	"I think the things [NASA] can make repeatable and get for a service we should." "There is a vibrant aerospace industry, private investment, new entrants exist and continue to exist." "The way we work – not only internally but how partner and collaborate – collaborative environment (1/3 federal, 2/3 partnership); how we are going to work going forward." "Used to be governments had more control of technology due to having more money. Governments of the world today will have a smaller footprint." "Need to do contracting differently - ok for industry to make money." "Hard to do business with NASA since it's very scattered – need a single group that deals with outside world, so you don't need to guess from the outside." "NASA needs to take a look at their own footprint. Model for in-house work vs work that industry is already doing. Rethink NASA centers. Lots of assets that we have as NASA, country, and space community based on where they are – too expensive, industry can do it cheaper, etc." *NASA Internal Mash-Up #4 Takeaway*: "Increasing US debt is putting NASA in a tough spot; NASA seen as a luxury not a necessity - not seen as needed to survive (cancer research, military). Our response won't be another Apollo like program - try to tap into entrepreneurial nature of US - driven by commerce; science done will be driven by what has a high ROI."
4. Focus on basic research	Rebalance portfolio to be more research focused rather than mission-execution focused	"Do a lot of tech transfer" "Understand the world - climate, data, science" "How technology developed for space can be used on Earth" "Push early TRL work that others can't/won't do" "Facilities need to match the mission, look at own footprint, rethink centers, underinvesting in aging facilities Aging infrastructure - risk to mission, IT investment not moving at scale or speed, hard to maintain with declining budgets" Centers and Directorates resource constrained: "Centers lost control of what they had and lost flexibility ... no control over what they can fund like IR&D. ... The small centers are especially affected and hurting." "Not a set of money for all centers to do S&T development, so centers can get competitive with toxic relationships over fighting for resources."

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
5. Lead the frontier	Go as far and fast as possible, explore the unknown where no one else is	"Pursue things that are transformational in nature. It might be how we travel in space... manufacturing and assembling in space." "Hypersonics will be the dominant form of access to LEO," robotics in human exploration, "net zero emission by 2050 for aviation." "Pushing a new age of exploration across the board from small to large, science to technology." "Take things that have been dominant designs and break them because technologies can now break through these." "The area around transformational impact of technology – convergence/divergence cycle; at the borders between disciplines in technology, innovation is made possible at an accelerating rate." "Investment in technology is not up to par, not moving at scale or speed." “Failure should be an option if you aren't going to hurt anyone, perfect is enemy of good” "Why spend 8 billion a year on humans in space? Why go to space? No reason for humans to go into space if machines can do it. Only reason for humans in space is for human settlements. The reason for why we want to do that (human settlements) is if Earth gets destroyed." *NASA Internal Mash-Up #1 Takeaway:* "Unintended consequences of potential meddling with Earth's climate/atmosphere; could NASA perfect geoengineering off-world and bring it back?" *NASA Internal Mash-up #2 Takeaway:* "One key capability/technology can change the art of what's possible (e.g., thriving in the desert, living off- world, or looking deeper into space than ever done before)"

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
6. Catalyze access for all	Enable mechanisms for significant part of society to participate in exploration and science	"For the benefit of all...don't do work behind a closed door" "Improve lives of all Americans on a day-to-day basis" (coast-to-coast supersonic flights, etc.) "Making that dream to more affordable access to space environment a reality – one that reaches further down into humanity. Providing an opportunity to live/work [in space]." "If we are giving our data to people trying to disrupt, what does that mean for NASA?" "Do a lot of tech transfer" "Barriers to innovation, bureaucracy. If you've been successful at doing something, why try something else. Power of status quo is massive."`
7. Master in targeted areas, partner elsewhere	Self-sufficient in small subset of core competencies, partner elsewhere because you can't do it all	"Aerospace market, need to recognize that NASA plays a part in a global market that is ever expanding globally – have a structure that isn't overly inhibiting for partnerships, commercial and international." "Keeping development skills and knowledge - need partnerships" "Business core is rotten - need transformational activities and cross-enterprise sharing" *NASA Internal Mash-Up #2 Takeaway*: "Ensuring NASA and other public entities remain relevant, as capabilities, funding, and infrastructure building shift to outside parties. Important to maintain public interest, don't let everything go to commercial, it's a balance."

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
8. Maximize partnerships across all efforts	Value proposition as an integrator across interagency, international, etc., not necessarily an expert everywhere	Internationalization of space - other countries becoming players in space including tech development, not just U.S., also poses security and other challenges. "Globalization and continuing challenges around how to work across global lines effectively and security and challenges that come with globalization." "A NASA that is in a much more dynamic place from NASA of the past with achievements done in partnership with other nations and industry/commercial." "Re-energized 'can do' attitude with lots of partnerships" "Restrictions through ITAR - a place like NASA has a better chance at [international partnerships] than DOD, … NASA's mission should be more open to international partnerships." "Crowding weather - might have a consortium with nonprofit, profit, and government around climate. Why and how should the government get involved?" *NASA Early-Career Mash-Up #6 Takeaway*: "Who's controlling the resources will drive behavior...on Earth and in Space! It's important to understand your partners versus competitors"
9. DIY: don't partner	Complete vertical integration under NASA-funded efforts	"So many great things about culture, but it does enable some bad behavior like institutional arrogance. When you've been successful for so long, you don't look outside, believe only the right answer can come from within your wall." "Some things take a lot of patient capital, but more reliance on NASA to do more things, things will go slower because NASA will only get so many resources. If things slow down, ability to sustain political support also becomes challenging."
10. Be the best government option	Excel at providing the best work environment in the USG	"Demonstrate leadership and reward employees for progress toward change" "Train NASA people to be business-minded." "Talented people that care about this - think pipeline of people is phenomenal and each class is smarter than last." "Promote end state thinking and remind everyone how cool and important what we do is." "In lots of aerospace companies, talent want to do their best but become victims of their own success, competition of resources. Stakeholders operating under paradigm that you will get what you need to get done with whatever resources they give you."

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
11. Substantial effort to increase value proposition for attracting and sustaining talent	Push government swim lanes for talent acquisition	"One of the top administration priorities is the future of our workforce and our nation." "Differentiator is people - reinvesting in training and development." "Promote flexible, agile, quality of life at work and home." “Recognize experts to keep them from leaving, invest in training and development, quality of life, flexible and agile, and facilities that will attract people” "Infrastructure plus the people – if we can’t get access to people and they aren’t attracted because NASA isn’t awesome place to come – but people need to have a good place to come to." "Most leadership talent is homegrown; diversity of opinion is important." *NASA Executive Mash-Up #1 Takeaway*: "Human enhancement through psychedelics has been proven, should space-faring selection process be reconsidered and perhaps required?"
12. Compete with non-government for top talent	Break open new possibilities for getting talent	“Set up a national lab on the Moon” University of NASA, “turning some centers into world class facilities for academia and industry... some could turn into FFRDCs" "NASA's secret is their people." "Still getting 300 application per job at NASA, but framework doesn't allow to send people into private sector and then bring them back" *NASA Internal Mash-Up #3 Takeaway*: "Need more sustainable way to source food, needed for building off-world; could be opportunity to engage with citizen science and agriculture innovation!"

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
13. Arbiter of data not policy	NASA presents/provides data, but does not get involved in policy formulation or decisions	"As a scientist, view [NASA's] role as providing information and not shaping policy." "Geopolitics – party to party, admin to admin, have good ideas and need to stop the churn – work in a more apolitical/non-political environment." "Ability to use data - we have a ton of data inside NASA and we're just scratching the surface of way to unlock data to provide useful information of data in real time, whether climate, or other." "Get data in the hands of people who can actually use it." What data do you trust? "When to trust data?" *NASA Internal Mash-Up #5 Takeaway*: "NASA collecting so much data - can't actually process in a meaningful way"
14. Use NASA's voice to drive awareness for policy	NASA drives conversations on topics where it has expertise	"For NASA to be a true leader, need to lead to sustainable aerospace. NASA itself needs to find a way to a sustainable future and point way for whole of industry." "It [NASA] can guide what the whole world does in space with its vision and money." "What is our vison for the world? ...Economic is the key word in quote, bring the solar system into our economic realm....our economy [should] go up to the asteroid belt or Saturn by 2050." "Orbital debris is a concern...pollution in space is a real hazard. Wild West stuff going on... Where is the oversight? Who is liable if something goes wrong?" "Political pressure to deliver within 4-year political cycles when 6 years might be best answer." *NASA Early-Career Mash-Up #1 Takeaway*: "We need to have an idea of our approach to these technologies before they happen and not in reaction" *NASA Early-Career Mash-Up #5 Takeaway*: "As autonomy gets linked into more and more critical industries, the question of liability could have life-or-death consequences for both individuals and nation"

Strategic Options	Description	Supporting NASA Executive Comments and Roundtable Inputs
15. NASA as a direct influencer of policy	NASA as an explicit policy advocate through data-driven evidence	"Rushing into solar system without shared view of law and international agreements, precedents being set by industry, U.S. hands off but international more connected to industry." "The first one to do something sets the rules." Commercial vs government role, gov has an obligation to think about all citizens. "OIR thinks through [international partnerships] a lot and policy and potential changes to policy." *NASA Early-Career Mash-Up #4 Takeaway*: "Having our own house in order impacts international relations"

Appendix H. List of NLP Documents Scanned

Document name	Document Source
Trends Affecting Government and Society	GAO (Aerospace provided)
Global Trends 2040	NIC (Aerospace provided)
Future of the Connected World: Global Action and Recent Progress	WEC (Aerospace provided)
Technology Futures: Projecting the Possible, Navigating What's Next	WEC (Aerospace provided)
Work/Technology 2050	The Millennium Project (Aerospace provided)
Strategic Foresight for the Space Enterprise	Aerospace
The Future of Space 2060 and Implications for U.S. Strategy: Report on the Space Futures Workshop	Air Force Space Command (Aerospace provided)
Future Uses of Space Out to 2050	RAND Europe (Aerospace provided)
2005 NASA Executive Capability Roadmaps Report	NASA
2002 NASA Strategic Plan	NASA
2033 Mars Orbital Mission Concept	NASA
The Future of Space 2060 and Implications for U.S. Strategy: Report on the Space Futures Workshop	AAI (NASA provided)
Putative Deep Space Futures	AAI (NASA provided)
The Developing Econometrics Beyond COVID	AAI (NASA provided)
AFRC Innovation White Paper	NASA
AMES Innovation White Paper	NASA
ARMD Innovation White Paper	NASA
Embracing the fourth Industrial Revolution -Challenges, Opportunities and Path Forward for Propulsion	NASA
ASAP Recommendations	NASA
China Plan for National economic and Social Development	CSET (NASA provided)
Common Center and MD Themes	NASA
Cosmic Beachcombing V2 (Dennis Bushnell)	NASA
Future of Air Transportation (Dennis Bushnell)	NASA
Societal Issues (Dennis Bushnell)	NASA
Electric Aircraft V2 (Dennis Bushnell and Robert Moses)	NASA
Early Career Initiative Innovation White Paper	NASA
Analysis of NASA ARMD Megatrends, Findings, and Recommendations	NASA
Where is it all going? (Dennis Bushnell)	NASA
Financially Advantageous Approaches to Sustain the Ecosystem (Dennis Bushnell)	NASA
GRC Innovation White Paper	NASA
GRC ME Magazine	NASA

GSFC Innovation White Paper	NASA
HEOMD Innovation White Paper	NASA
Coordinating Innovative Technology Development at NASA	NASA
IFTF Vantage: A Partnership of Future-Ready Organizations	NASA
JPL Innovation White Paper	NASA
Massless Exploration –Humans as a Solar System Species	NASA
On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions	NASA
NASA Strategic Plan 2022	NASA
The 2013 Strategic Priority-Setting Process at NASA	NASA
NASA Strategic Roadmap Committees Final Roadmaps (May 22, 2005)	NASA
Commercial Space in The Age Of “NewSpace”, Reusable Rockets and The Ongoing Tech Revolutions	NASA
Prospectives in Deep Space Infrastructures, Development, and Colonization	NASA
Disruptive Technologies and Their Putative Impacts Upon Society and Aerospace- Entering the Virtual Age	NASA
Futures of Deep Space Exploration, Commercialization, and Colonization: The Frontiers of the Responsibly Imaginable	NASA
Continuous Improvement of NASA's Innovation Ecosystem: Proceedings of a Workshop (2019)	NASEM (NASA provided)
Observations & Recommendations of LaRC	NASA
Observations and Recommendations based on discussions with the Directors of National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC)	NASA
Astro 2020 Analysis	NASA
Application of Decision Analysis and Scenario Planning to Prioritization of NASA’s Strategic Mission Objectives	NASA
Concept for 2033 Crewed Mars Orbital Mission with Venus Flyby	NASA
SID Insights	NASA
SMD Innovation White Paper	NASA
STMD Innovation White Paper	NASA
Strategic NASA Roundtable Futures Topics	NASA
Team Antares Report	NASA
The Future of Space 2060	AFSC (NASA provided)

Appendix I. List of Acronyms

AI	Artificial Intelligence
AGI	Artificial General Intelligence
API	Application Programming Interface
AR	Augmented Reality
ARMD	Aeronautics Research Mission Directorate
ASAP	Aerospace Safety Advisory Panel
ASAT	Anti-Satellite
B-SURE	Biomanufacturing: Survival, Utility, and Reliability beyond Earth
BBC	British Broadcasting Company
BCI	Brain Computer Interface
CAB	Chargeable Atomic Battery
CDR	Carbone Dioxide Removal
CEO	Chief Executive Officer
CNSA	China National Space Administration
CO2	Carbon Dioxide
CONOPS	Concept of Operations
COO	Chief Operating Officer
COVID-19	Coronavirus Disease of 2019
CPU	Central Processing Unit
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
DARPA	Defense Advanced Research Projects Agency
DEI	Diversity, Equity, and Inclusion
DEIA	Diversity, Equity, Inclusion, and Accessibility
DHS	Department of Homeland Security

DIY	Do It Yourself
DNA	Deoxyribonucleic Acid
DOD	Department of Defense
DOE	Department of Energy
3D, 3-D	three-dimensional
EMP	Electromagnetic Pulse
EPA	Environmental Protection Agency
ERG	Employee Resource Group
ESG	Environmental, Science, and Governance
ETs	Extra-Terrestrials
ETF	Exchange Traded Fund
EV	Electric Vehicle
FFRDCs	Federally Funded Research and Development Centers
GEO	Geostationary Earth Orbit
GEOINT	Geospatial Intelligence
GDP	Gross Domestic Product
GMO	Genetically Modified Organism
GOES	Geostationary Operational Environmental Satellite
GPA	Grade Point Average
GPS	Global Positioning System
GPU	Graphics Processing Unit
HBCU	Historically Black Colleges and Universities
HTP	High-Test Peroxide
HQ	Headquarters
ID	Identification
IoT	Internet of Things

IP	Intellectual Property
IR&D	Independent Research and Development
ISAM	In-Space Assembly and Manufacturing
ISP	Internet Service Provider
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ITAR	International Traffic in Arms Regulations
JOBS	Job Opportunity and Basic Skills
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LEO	Low Earth Orbit
Li-ion	Lithium-Ion
MIT	Massachusetts Institute of Technology
ML	Machine Learning
MOSA	Modular Open Systems Approach
MSD	Mission Support Directorate
MSFC	Marshall Space Flight Center
NAS	National Academy of Sciences
NASA	National Aeronautics & Space Administration
NATO	North Atlantic Treaty Organization
NEP	Nuclear Electric Propulsion
NFL	National Football League
NFTs	Non-Fungible Tokens
NGOs	Non-Government Organizations

NHTSA	National Highway Traffic Safety Administration
NIAC	NASA Innovative Advanced Concepts
NLP	Natural Language Processing
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Cooperation and Development
OPM	Office of Personnel Management
OSAM	On-Orbit Servicing, Assembly, and Manufacturing
OST	Outer Space Treaty
OTPS	Office of Technology, Policy, and Strategy
PFAS	Polyfluoroalkyl Substances
PNT	Positioning, Navigation, and Timing
R&D	Research and Development
RNA	Ribonucleic Acid
ROI	Return on Investment
S&T	Science and Technology
SciFi	Science Fiction
SDG	Sustainable Development Goals
SFT	Strategic Foresighting Team
SME	Subject Matter Expert
SOMD	Space Operations Mission Directorate
SPACs	Special Purpose Acquisition Companies
STEEPTS	Societal, Technological, Economical, Environmental, Political, Threat, Space
STEM	Science, Technology, Engineering, and Mathematics
STMD	Space Technology Mission Directorate
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level

TSA	Transportation Security Administration
TV	Television
UAE	United Arab Emirates
UAVs	Unmanned Aerial Vehicles
UK, U.K.	United Kingdom
UN	United Nations
URL	Uniform Resource Locator
US, U.S.	United States
USA	United States of America
USG	United States Government
USSF	United States Space Force
VC	Venture Capital
VPN	Virtual Private Network
VR	Virtual Reality
VUCA	Volatile, Uncertain, Complex, and Ambiguous
WFP	World Food Programme
WWIII	World War III

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