The Future of Space 2060 and Implications for U.S. Strategy: Report on the Space Futures Workshop

Air Force Space Command

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Executive Summary

"Control of space means control of the world."

(Lyndon B Johnson, Vice President, Senate Armed Services Committee Hearing, January 1959)

This report provides a long-term perspective on possible space futures to inform strategic decision-making. Economic, political, technological, and military space trends indicate that we have passed the tipping point for space as a vastly increased domain of human endeavor and a key element of national power. Other countries recognize the advantages of U.S. space leadership, as well as the value space capabilities provide, and are moving aggressively to challenge the U.S. To ensure continued U.S. space leadership, a coordinated, short-, mid-, and long-term national strategy is required.

Air Force Space Command (AFSPC) hosted a Space Futures Workshop (SFW) to explore the role of space to the year 2060. Participants from the DoD, NASA, NATO, industry, and academia used an alternative futures analysis technique to develop a range of future scenarios and to explore how they relate to national power. Eight future space scenarios were developed and explored along civil, commercial, and military conditions by defining positive and negative bounds. These bounds were developed based upon an analysis of technical, value, and national interest trends and assumptions as to the overall economic, political, and military state of the world in 2060.

Key conclusions reached were:

- The U.S. must recognize that in 2060, space will be a major engine of national political, economic, and military power for whichever nations best organize and operate to exploit that potential.
- The U.S. faces growing competition from allies, rivals, and adversaries for leadership in the exploration and exploitation of space.
- China is executing a long-term civil, commercial, and military strategy to explore and economically develop the cislunar domain with the explicit aim of displacing the U.S. as the leading space power. Other nations are developing similar national strategies.
- A failure to remain a leading space power will place U.S. national power at risk. To avert this, the U.S. coalition must promote and optimize the combined civil, military, and commercial exploitation of space to best serves the nation's interests.
- The U.S. military must define and execute its role in promoting, exploiting, and defending the expanded military, civil, and commercial U.S. activities and human presence in space.

The workshop produced the following recommendations:

- The US must develop a long-term, national space strategy to ensure continued leadership. This strategy should be developed across government, industry, and academia to ensure synergy of efforts to optimize and promote overall U.S. national space power and grand strategy.

- AFSPC should commit the resources to complete the strategy as outlined in this report as a part of its organize, train, and equip mission. U.S. Space Command should similarly commit resources to this effort as part of their strategic and operational execution missions.

- The strategy must address how the national security establishment will defend the full range of expanded national interests in space *(i.e.*, civil and commercial space capabilities and citizens in space) - not just the services that directly support national security.

- Essential capabilities and technologies to enable positive future outcomes must be developed by the whole of government. An investment, policy, and regulatory strategy must be pursued to ensure those capabilities.

- The nation must commit to investment in science and technology to drive the rapidly changing global space environment as a key element of the strategy.

This report presents results from the first step in a three-step effort to support the development of this strategy. The three steps are:

1) Describe a range of possible future scenarios and explore the characteristics of those scenarios across civil, economic, and military realms and their implications for national power.

2) Determine a national strategy vision across these futures that promote those most advantageous to the U.S., and avoid those most disadvantageous, particularly with respect to national defense.

3) Determine the minimum essential capabilities and actions required to implement that strategy, with emphasis on the military role.

Next steps in this process will develop additional recommendations required to promote space futures advantageous to the U.S. Additionally, a minimum set of actions required by the U.S. space community to affect national strategy will be determined, with emphasis on the military role in that strategy. Subsequent follow-on work will include specific recommendations on science and technology focus areas and investments to ensure the U.S. is well placed to deter threats and maintain space leadership.

1. Introduction

"We don't know exactly when the human sphere of influence will expand to the Moon and Mars, but we do know it will happen."

(Major General Shaw, Vice Commander, AFSPC)

An examination of the convergence of economic, political, technological, and military space trends indicates we have passed the tipping point to futures with space as a vastly increased domain of human endeavor and a key element of national power. There is clear evidence of this emerging, new era for space:

- National leadership's acknowledgement that space is a warfighting domain and the consequent stand-up of the United States Space Command as a new geographic combatant command.
- The Vice President's tasking to NASA for a crewed mission to the Moon by 2024.
- China's development and implementation of a national strategy for space dominance.
- The continuing growth in the number of space faring nations and in their space capabilities.
- The rapid growth in "New Space" leading to expanding commercial endeavors to develop innovative space capabilities.
- The global explosion of space system and launch innovations driving the proliferation of lower-cost systems, and the beginning of space tourism.

For the last half century, the United States has been the dominant space power across the military, intelligence, science, exploration, and commercial domains. Other countries recognize the advantages of U.S. space leadership, as well as the value space capabilities provide, and are moving aggressively to challenge the U.S. To ensure continued U.S. space leadership, a coordinated, short-, mid-, and long-term national strategy is required. This strategy must be driven by a clear understanding of potential long-term space futures both favorable and unfavorable to the U.S., and of the drivers for those futures.
This report presents results from the first step in a three-step effort to support the development of this strategy. The three steps are:

1. Describe a range of possible future scenarios and explore the characteristics of those scenarios across civil, economic, and military realms and their implications for national power.
2. Determine a national strategic vision across these futures that promote those most advantageous to the U.S., and avoid those most disadvantageous, particularly with respect to national defense.
3. Determine the minimum essential capabilities and actions required to implement that strategy, with emphasis on the military role.

To address the first step, the Air Force Space Command (AFPSC) hosted a Space Futures Workshop (SFW) to explore space futures. In attendance were subject matter experts across the DoD, as well as from NASA, NATO, industry, and academia (see Annex G). This report documents the workshop's processes, results, conclusions, and recommendations.

An alternative futures analysis technique developed by Shell Oil Company was used. This technique develops and explores a range of scenarios which, while not explicitly predictive, illuminates the spectrum of possible futures, and how they relate to national power. Such scenario-based thinking is a powerful means to consider and clarify multiple perspectives on the future and to identify potential inflection points and drivers for the future. [1-3] The methodology is described in detail in Annex D.

This inaugural workshop focused on the challenges from peer rival China. Though focused on a single rival, these alternate futures align with those developed in the Air Force Strategic Environmental Assessment (AFSEA) 2016-2046. [4] From this scenario-based process, the workshop developed and examined eight future scenarios across the following axes:

- **Human Presence:** *How broadly and in what numbers do humans live and work in space?*
- **Commercial Potential:** *What is the economic level of new, persistent revenue from space activities?*
- **Leadership:** *To what degree do the U.S. coalition lead in the creation of the civil, commercial, and military space capabilities and in establishing the norms, standards, and international regulations in space? (e.g., based on free world concepts of a liberal international order?)*

The civil, commercial, and military characteristics of each future scenario was then explored (see Chapter 2). Based upon examination of those futures scenarios, we drew initial conclusions and recommendations (See Chapters 3 and 4).

2. Boundary Conditions and Future Scenarios

"Prediction is very difficult; especially about the future."

(Neils Bohr, Nobel Prize winner in Physics)

Eight scenarios, or alternative futures to 2060, were derived by defining realistic bounds as to the minimum and maximum developments along three axes of space power: human presence in space, economic importance of space, and U.S. coalition leadership in space. For this analysis we assumed that the states along each axis are independent of those along the other axes.

The upper and lower bounds of each axis are summarized below. The bounds are derived from the SFW brainstorming activities informed by the assumptions as to the global state and the extrapolation of current space trends to 2060. Annex A and B contain detailed information of these trends and assumptions, especially relating to China's space program. The methodology used to determine future scenarios is presented in Annex D.

Human Presence: *How broadly and in what numbers do humans live and work in space?*

Lower 2060 Bound

- Has advanced marginally beyond the level achieved with the space station
- Is driven by research, exploration, and a low level of tourism for the elite
- Space functions are controlled remotely or robotically using autonomous and artificial intelligence systems
- Humans have returned to the Moon and landed on Mars, but there is no permanent presence at either

Upper 2060 Bound

- Thousands of individuals from many nations live and work from Low Earth Orbit (LEO), across the cislunar, Moon, Mars
- Increased human presence supports civil, commercial, and military needs and interests
- There are one or more crewed bases on the Moon supporting science or economy
- There are crewed habitats across cislunar space supporting the overall logistics for space manufacturing, tourism, and resource extraction
- Habitats in space, the Moon, and Mars are progressively constructed and maintained using extraterrestrial resources

Commercial Potential: *What is the economic level of new, persistent revenue from space activities?*

Lower 2060 Bound

- The space economy advances marginally beyond short-term projections of the current state
- The economic value of the space economy is some small trillions of dollars and represents at most 1-2% of the global economy
- The space economy is confined primarily to LEO/Geosynchronous Earth Orbit (GEO) and principally supports terrestrial needs for communications; position, navigation, and timing (PNT) capabilities; information gathering; and a low level of tourism

Upper 2060 Bound

- Overall, the space economy is expanding rapidly, contributing at least 10% of global gross domestic product (GDP) with wide, diverse participation from nations
- The economy includes power, planetary communications, global information services, manufacturing, resource extraction, and tourism
- Major industrial capacity for power, resource extraction, and manufacturing has developed, driven primarily by terrestrial demand, but increasingly to support the space economy
- Space tourism is a major industry available to a wide cross-section of the public

Leadership: *To what degree does the U.S. coalition lead in the creation of the civil, commercial, and military space capabilities and in establishing the norms, standards, and international regulations in space? (e.g., based on free world concepts of a liberal international order?)*

Lower 2060 Bound

- Many national, international, and transnational commercial interests operate in space
- Leadership in space is not based on an extension of the fundamental terrestrial tenants of a liberal international order
- The U.S. coalition is not the space leader in that they are at a serious disadvantage in protecting their interests and capabilities in the civil, commercial, and military realms

Upper 2060 Bound

- The U.S. alone or with its allies holds the lead power position in aggregate across the civil, economic, and military realms
- Space is protected as a free domain under a rules-based, international order with established norms of behavior that promote the philosophy of open trade and space as a commons for all of humanity

For this analysis we assumed that the states along each axis are independent of those along the other axes. These combinations of bounds produced eight future scenarios, shown graphically in *Figure 1*. Maximized values of the axis bounds are show in dark gray symbols. Minimized values are shown in open symbols. Scenario titles are derived from the predominant characteristics of the scenario. Green icons are those generally favorable to the U.S., while orange and red represent those generally unfavorable to the U.S.

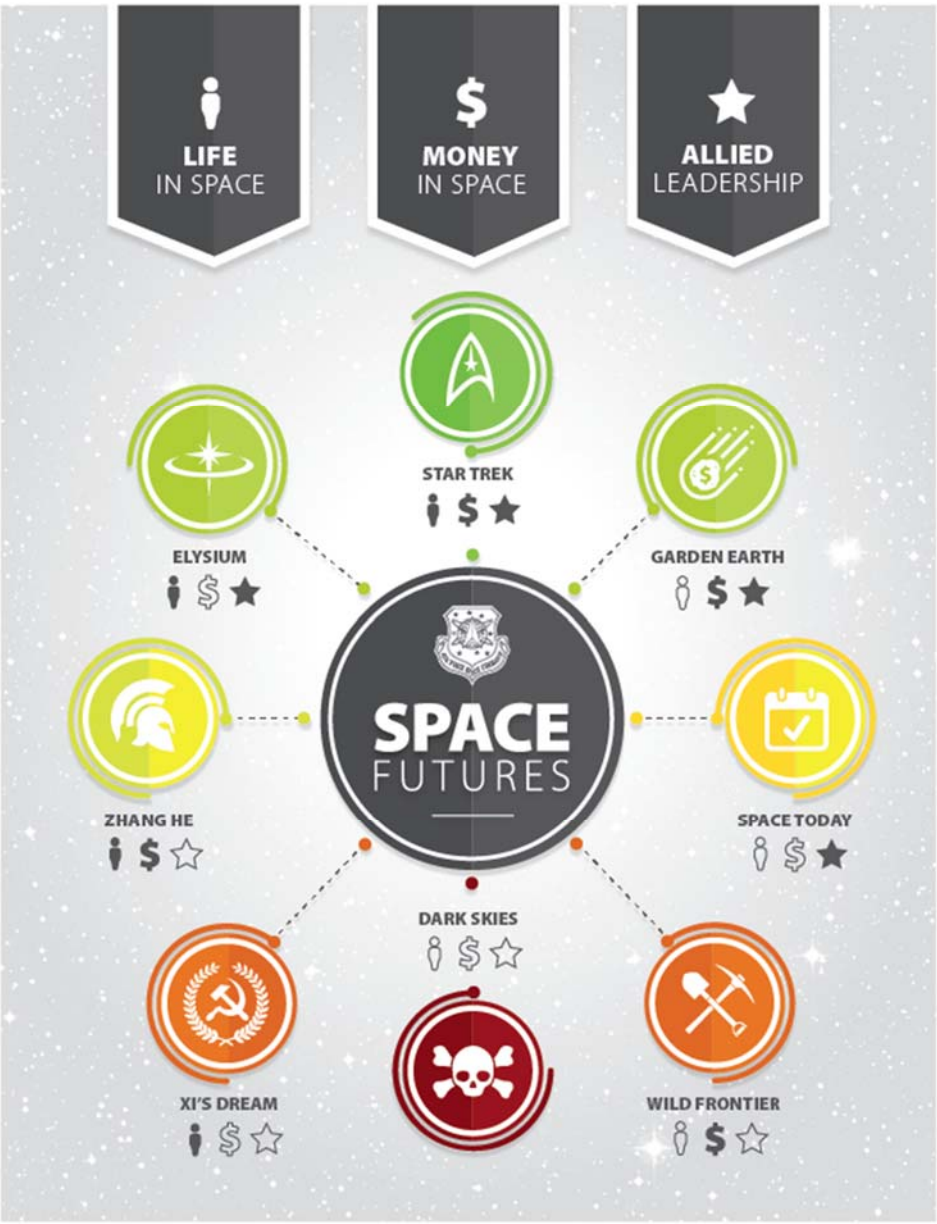

Figure 1. Eight space future scenarios.

A. Positive Futures: Star Trek, Elysium, and Garden Earth

These three scenarios assume a major increase in the importance of space globally, with the U.S. coalition retaining space leadership across the civil, commercial, and military realms. Further, they broadly share similar characteristics in the civil, commercial, and military realms. Brief descriptions of these scenarios, as well as key resulting characteristics, are provided below.

Star Trek: *Most optimistic and expansive*
The U.S. coalition retains leadership over the space domain and has introduced free-world laws and processes that have led to significant global civil, commercial, and military expansion in space and resulted in large revenue streams. Thousands of humans live or work in space at a variety of habitats across cislunar space, the Moon, and Mars.

Garden Earth: *Optimistic and expansive*
The U.S. coalition retains leadership over the space domain and has introduced free-world laws and processes that have led to significant global civil, commercial, and military expansion in space and resulted in large revenue streams. However, human presence is limited and most processes are controlled remotely or robotically.

Elysium: *Optimistic and expansive*
The U.S. coalition retains leadership over the space domain and has introduced free-world laws and processes that have led to significant global civil, commercial, and military expansion in space. Thousands of humans live or work in space at a variety of habitats across cislunar space, the Moon, and Mars. However, large revenue streams have yet to materialize. Commercial activity is focused in LEO to GEO terrestrial communications, information, PNT, and to provide key parts of the civil and commercial infrastructure required for the continued expansion of human presence in space.

Key Resulting Military, Civil, and Commercial Characteristics

Military

- The U.S coalition is the lead military space power. Other space faring nations continuously challenge that lead through expansion of their own capabilities or through alliances with other space faring nations. The U.S coalition has the range of military capabilities necessary to:
    - Protect the critical elements of their extensive civil, commercial, and human presence across cislunar space from conventional and cyber threats.
    - Protect the combined commercial, civil, and military command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) infrastructure to monitor and control space operations and provide information services in, through, and from the cislunar environment during peace and conflict.
    - Project military power throughout the cislunar environment to exercise selected space superiority in time and place as needed for conflicts within space and as part of larger, cross-domain conflicts.
    - Preempt any other nations monopolizing key logistics points (lunar poles, Lagrangian points, *etc*.) or key assets (asteroids, lunar water, *etc.*) for military uses.
- Space military power is widely distributed across space faring nations with the preponderance not controlled by the US coalition. The US coalition's technological and operational lead is continually challenges by shifting alliances and increased capabilities of potential adversaries.

Civil

- The U.S coalition successfully leads to establish civil norms of behavior, rules, and laws for space that support their beliefs and interests (free and open markets, open access and transit, *etc.*).
- The U.S coalition promotes and leads in multinational development of critical infrastructure (communication, situational awareness, collision avoidance, *etc.*) while developing independent infrastructure required to ensure national interests during peace and conflict.
- There is limited ability to accomplish civil goals unilaterally. Power is distributed among many space faring nations and entities with a wide range of space capabilities and interests. Competitors and

adversaries pursue alternate civil strategies to limit the U.S coalition. There is an expanded set of first-tier commercial space powers: China, India, the U.S., the European Union, Russia, Japan, and Brazil.

- Competitors and adversaries pursue alternate civil strategies to limit the US coalition's influence.
- The US coalition leads in space explorations with international outposts and colonies on the moon, an outpost on Mars, and asteroid exploration. Other major space faring nations and alliances have competing, commensurate, civil-focused, exploration programs.

Commercial

- The size of the space economy has increased greatly, more so in "Star Trek" and "Garden Earth" but still substantial in "Elysium."
- Commercial space capabilities provide the preponderance of raw materials and manufactured products to further expand space capabilities.
- The U.S coalition is the lead commercial space power and attracts a disproportionate fraction of global space investment, but the preponderance of commercial capability is distributed across many nations and entities, with China, India, US, the EU, Russia, Japan, and Brazil as first-tier commercial space powers.
- US coalition's leadership is continuously challenged by other first-tier, commercial players and by the continued proliferation of space commerce across nations and multinational companies.
- Multiple nations have moon bases or colonies competing with the U.S. coalition in providing key infrastructure for commercial exploitation of the moon and continued development of manufacturing and facilities across cislunar space.

B. Negative Futures: Zhang He, Wild Frontier, and Xi's Dream

These three future scenarios posit a major growth in the importance of space and share the characteristic of an alternate to a U.S. coalition as the leader across the civil, commercial, and military elements of space power. They further posit a significant power advantage of this lead space power over the U.S. and its allies. While who might develop to be this leading space power is uncertain, we have chosen names with a Chinese reference since China is presently the most likely candidate. In these futures, the alternate lead space power views the U.S. coalition as a rival at best and a potential adversary at worst.

Zhang He: *Expansive but most pessimistic*
An alternate nation exercises leadership over the space domain and has introduced laws and processes that promote their interests or limit the actions of rivals. Leveraging their growing technological edge and by using non-competitive practices, they attract a growing, disproportionate share of global space revenue streams. Thousands of humans live in space to maintain lunar and Mars bases to promote national prestige, further patterns of dependency, and support the technology and infrastructure for commercial and military space leadership.

Wild Frontier: *Expansive but pessimistic*
No clear space power exercises leadership over the space domain. However, the growth in space capabilities of national and private entities has resulted in global civil, commercial, and military expansion in space and led to large revenue streams. However, human presence is limited, driven primarily by national prestige, exploration, and tourism.

Xi's Dream: *Expansive but pessimistic*
An alternate nation is the lead space power, though the importance of space is driven by the increased human presence in space for exploration, tourism, and to support and maintain commercial space capabilities. Large revenue streams have yet to materialize. Commercial activity is focused in LEO to GEO terrestrial communications, information, PNT, and to provide key parts of the civil and commercial infrastructure required for the continued expansion of human presence in space.

Key Resulting Military, Civil, and Commercial Characteristics

Military

- The alternate chief space nation and its allies lead in military space power and has the range of military capabilities necessary to:
    - Defend the critical elements of their civil, commercial, military, and human space assets, as well as a C4ISR to monitor and control space operations and provide information services in, through, and from the cislunar environment during peace and conflict.
    - Project power to achieve space superiority across the cislunar domain and across the full range of conflicts in space or that extend to space.
    - Leverage their commercial and civil leadership to maintain and further their lead in military space power. They use their commercial lead to exclude other space faring nations from critical locations and resources in space. They use their cost advantage from their space commercial infrastructure to out produce other nations' space military capabilities.
    - Further their civil and commercial leadership by exerting pressure or by threats of force.
    - Restrict their unilateral military actions to avoid the development of alliances amongst the nations holding the preponderance of military space power. The US coalition works to create such military alliances.
- U.S and other space faring nations are forced to create independent infrastructure to ensure national interests during peace and conflict.
- Alternatively, the dominant player(s) do not hold the preponderance of military space power. This restricts their ability to act unilaterally in space. The U.S and its allies work to create alliances to counter their lead.

Civil

- The alternate, chief space power promotes norms of behavior, rules, and laws for space that serve their self-interests. Where not possible, they exploit the diversity of interests of space faring nations/entities to limit the establishment of space norms, rules, and laws that impact their lead position or limit their range of actions.
- They lead in developing multinational space, civil infrastructure to promote alliances, to exert infrastructure control to their benefit in peace and conflict and to establish patterns of dependency for other terrestrial and space powers/entities.
- The preponderance of civil space power is distributed among a large and various group of space faring nations/entities, limiting the ability of the alternate, chief space power to act exclusively in its self-interest.
- The US coalition forms alliances to oppose the lead powers actions and have built alternative, civil space infrastructure to support their nation interests.
- Multiple nations have established bases/colonies on the Moon and Mars and pursued asteroid exploration but the alternate, chief space power leads in civil exploration to promote national prestige,

further patterns of dependency, and support the technology and infrastructure for commercial and military space leadership.

Commercial

- While the preponderance of commercial power is distributed across a number of nations with the US coalition having a significant space commercial presence, the alternate, chief space power has a large and growing technological and market-share advantage over all other space-faring nations that attracts a disproportionate share of global commercial space investments.
    - They have a significant advantage in scale and pricing for space structures (satellites, habitats, *etc.*), power, and low-cost and flexible launch.
    - They lead in space resource extraction to meet critical space and terrestrial needs for raw materials providing them commercial and political leverage.
    - They have de facto control over key locations in space (Lagrangian points, *etc.*) and on the Moon (polar region, space elevator lunar point, key mineral deposits, *etc.*).
    - They have a commercial space enterprise increasingly independent of systems and elements produced on Earth.
- They use non-competitive practices to maintain and extend their lead position with limited capability by the US coalition or other nations to counter these practices. They limit these actions as required to avoid encouraging alliances to oppose them.
- The US subsidizes US space industries supporting critical national needs where supply by the lead space power or its allies pose unacceptable risks.

C. Military Dominance Futures: Space Today and Dark Skies

These futures take the lower bound for human presence and the space economy. In these futures, human presence is primarily limited to government-supported space exploration and commercially to information services, communication, and PNT between LEO and GEO, and some tourism. The dominant value of space in these futures is in supporting global military information dominance and in disrupting or denying it to adversaries. These futures are polar cases where either the U.S. and its allies or the alternate leading space power and its allies maintain or achieve a significant lead in space information dominance and the ability to exercise space superiority.

Space Today (Space as a Warfighting Domain): *Positive*
The U.S. coalition is the leading military space power, though space is a highly contested warfighting domain and an essential element in integrated, cross-domain warfare. Commercial and civil space activities are limited to LEO to GEO systems with minor levels of tourism. Military space systems are highly resilient, maneuverable, robotically refuelable, self-healing to attack, highly integrated, artificial intelligence driven, highly autonomous, and reconstitution ability is enhanced. The U.S coalition holds the advantage in using civil and commercial capabilities to support military capabilities.

Wild Frontier: *Negative*
Same as above except an alternate nation and its allies are the dominant space power.

Key Resulting Military, Civil, and Commercial Characteristics

Military

- The importance of space as a warfighting domain has grown, including support to cross domain conflicts.
- Importance has grown driven by the increased capabilities for space systems to support global military information dominance and superiority in C4 capabilities both in and through space.
- The nation with a superior space military capability to obtain and maintain space superiority as required in time and space during conflict has a significant advantage in cross-domain warfare.

Civil

- The leader in civil space has significant advantages in:
    - Influence on or control over the civil space infrastructure to its own benefit, particularly during times of conflict.
    - Establishing norms of behavior, rule and laws for space that advantage its military use of space.
    - Forcing the non-dominant power to produce its own civil space structure.
- The distribution of the preponderance of civil power among space faring nations poses for the lead space power challenges to shape the civil structure to their benefit.
- The non-lead power pursues alliances to counter the lead power's civil advantages.

Commercial

- There is a significant commercial space economy primarily focused on communication, PNT, and Earth observing, with some level of tourism.
- The lead commercial space power has a significant advantage in the size and strength of the industrial base to support military space systems, providing the lead nation with advantages in the cost of production and number of its military assets.
- Commercial dominance provides greater ability to exploit the commercial sector capabilities to support military operations.

3. Conclusions

Predicting the future with any fidelity is impossible. However, in this work, we have defined the broad characteristics of a range of futures and explored their critical elements in terms of U.S. national power. The eight scenarios that we developed based on the bounds of the human, economic, and leadership continua are a starting point for further analysis, thought, and strategy. Most importantly, through this first round of analysis, we have identified broad conditions that could have significant positive and negative outcomes for the U.S. in terms of overall national power.

Subsequent workshops will identify possible inflection points that could lead us toward each of those future scenarios. Hopefully, this process will illuminate critical decision points and actions that will positively influence those futures. These additional workshops will also take a deeper look at other peer and near-peer space rivals besides China. This overall work will provide recommendations for the U.S. and allied space strategies and clarify near-term actions, policies, and investments relevant to achieving the desired end-states by the year 2060. A significant benefit of these efforts will be an aid to determine a minimum set of essential capabilities in space required by the U.S. These minimum essential capabilities will in turn guide long-term science and technology roadmaps.

To summarize, one of the potential future scenarios explored here stems from positive answers to the three questions we posed about the future. In this scenario, space is a major contributor to the human economy, people live and work widely in space, and the U.S. coalition leads in civil, commercial, and military aspects of that future and have shaped the norms of behavior, rules, and laws that moderate space activities to reflect our concepts of a liberal international order (fairness, open commerce, freedom of movement, and international cooperation). This is the most positive future for the U.S. and it represents an aspirational goal for the nation. Our actions going forward should drive toward that future.

On the opposite end of the spectrum, the space contribution to the overall human economy and human presence in space is small such that space's most important function is military. In this future space has grown as a contested environment and as a key element of cross-domain warfare and another nation has displaced the U.S. coalition as the leading space power. As a nation we must identify the inflection points that might lead us to such a future and act to avoid this outcome.

From the SFW, six other potential futures were investigated between these two extremes in terms of their impact on U.S. interests and power. In order to move towards the positive space futures presented here, we draw preliminary conclusions from this exploration of these eight bounding scenarios.

- The U.S. should establish space settlement and human presence as a primary driver of the nation's civil space program to determine the path for large-scale human space settlement and ensure America is the foremost power in achieving that end. Accordingly, civil space programs must be assessed as to their utility to further space settlement goals.

- The Departments of Commerce, Energy, and Transportation, along with NASA, must execute a coordinated strategy to develop U.S space commerce and to incorporate space commodities and resources into the larger U.S and global economy. If entrepreneurs can achieve large returns from space commercial enterprises, the U.S. government must enact policies that ensure the U.S. captures the dominant position in that market.

- The U.S. must continue to lead in developing a rules-based, democratic international order for space. The U.S. must commit to having a military force structure that can defend this international space order and defend American space interests, to include American space settlements and commerce.

- The U.S. must establish a national approach to advance positive development along all three axes considered in this report. This strategy must emphasize unity-of-effort among the nation's civil and military space programs, as well as government departments such as Commerce, Energy, and Transportation, to deliver a space future that the American people desire and deserve. It must also maximize American and allied private sector involvement.

- The Department of Defense is a critical partner in such a whole-of-government approach to national space strategy and action. The DoD must embrace its role as an executing agent for this national strategy. It must commit to advancing American progress along all three space futures axes and its mission of defending U.S expanded military, civil, and commercial space interests. DoD programs must be assessed as to their military utility and strategic utility within the national space strategy.

- Examining long-term space futures along the axes of human presence, space economy, and space leadership is a powerful tool in developing a national strategy to achieve U.S. space interests. While the current work has defined reasonable upper and lower bounds for the state of space along these axes for 2060 and the futures they define, more work is needed to determine the key inflection and decision points that will determine the most probable end point along these axes for 2060 and the space futures they imply.

- The U.S. must recognize that in the world of 2060, space will be a significant engine of national political, economic, and military power for whichever nations or nation best recognize(s) the potential of space and organizes and operates to exploit and maximize that potential.

- The U.S. faces growing competition from allies, rivals, and adversaries to remaining the leading nation in the exploration and exploitation of space as an expanded domain for human endeavor.

- China is executing a long-term civil, commercial, and military strategy for exploration and economic development of the cislunar domain, to include the settlement of the Moon, with the explicit aim of displacing the U.S. as the leading space power. Other nations are developing similar national strategies.

- A failure to remain the leading space power will place U.S. national power at risk. The U.S. and its allies must promote and optimize the combined civil, military, and commercial exploitation of space that best serves the nation's interests.

- Maximizing the strength, range, and diversity of U.S. government and commercial space activities is essential to ensure the U.S. leads across a broad range of national capabilities. A commensurately strong space industrial base is essential.

- The U.S. military must define and execute its role in promoting, exploiting, and defending the expanded commercial, civil, and military activities and human presence in space driven by industry, NASA, and other nation-states.

4. Recommendations

This report documents the results of the first of a three-step process. It provides a longer-term perspective on possible space futures to inform current strategic space decision making. The next steps are to apply these scenarios across all of our competitors in space (not just China) and to determine the key inflection and decision points along the three axes of human presence, economic importance, and U.S. space leadership.

Initial recommendations are listed in *Table 1*. Future steps in this process will develop additional recommendations for the national strategy required to promote space futures advantageous to the U.S. Additionally, a minimum set of actions required by the U.S. space community to affect that strategy will be determined, with emphasis on the military role in that strategy. Subsequent follow-on work will

include specific recommendations on science and technology focus areas and investments to ensure the U.S. is well placed to deter threats and maintain space leadership.

Table 1. Workshop Recommendations

1. The US must develop a long-term, national space strategy to ensure continued leadership. This strategy should be developed across government, industry, and academia to ensure synergy of efforts to optimize and promote overall U.S. national space power and grand strategy.

2. AFSPC should commit the resources to complete the strategy as outlined in this report as a part of its organize, train, and equip mission. U.S. Space Command should similarly commit resources to this effort as part of their strategic and operational execution missions.

3. The strategy must address how the national security establishment will defend the full range of expanded national interests in space (i.e., civil and commercial space capabilities and citizens in space) - not just the services that directly support national security.

4. Essential capabilities and technologies to enable positive future outcomes must be developed by the whole of government. An investment, policy, and regulatory strategy must be pursued to ensure those capabilities.

5. The nation must commit to investment in science and technology to drive the rapidly changing global space environment as a key element of the strategy.

5. Annex

A. Trends

"Progress is not a straight line; the future is not a mere projection of trends in the present. Rather, it is revolutionary. It overturns the conventional wisdom of the present, which often conceals or ignores the clues to the future."

(Dr. An Wang, Founder of Wang Laboratories)

We identify three broad classes of trends driving the increased contributions of space to national power:

Technology
Advances in space science and technology enabling increased access and actions in space.

Value
Expansion in the range and value of commercial, civil, and military space capabilities.

National Interest
Increased understanding of the value of space capabilities to national defense and overall national power.

Technology Trends

Table 2 – Technology Trends

- Space launch innovation (e.g., driving down the cost of getting mass to space)
- Foreign competitors increasingly seek cyber capabilities to target space systems and infrastructure.
- Decreasing satellite bus and subsystem costs
- Increasing range of satellite bus sizes capable of complex functionality
- Decreases in payload size, power, and weight while increasing payload capability
- Distributed constellations of smaller satellites
- Robotics and on-orbit maneuvering providing revolutionary capabilities to construct, move, maintain, and replace complex structures in space
- Novel and deployable space power systems capable of supporting space infrastructure and potentially providing beamed power terrestrially
- New space-based commercial capabilities, including manufacturing, taking advantage of low/zero gravity effects, and access to vacuum
- National efforts (civil and commercial) creating technology to put humans into orbit and on the surface of the Moon and Mars as tourists, workers, and settlers
- Advances in methods for resource extraction and use on the Moon and from asteroids

Science and technology trends are transforming space as a domain for human endeavor. Broad advances in technology—especially in the commercial realm—are increasing access to space and opening up new applications and markets in space. This technology also has the potential to create new threats and will have unanticipated consequences in space. Any look at the future must include a careful examination of the benefits and potential hazards of new technology.

Today, the field of space launch is experiencing the greatest burst of technological creativity driving change in more than 40 years. Innovations in reusability are dramatically driving down the cost of launch for moderate to heavy lift. Coupled with the proliferation of small launch capability, this provides unprecedented flexibility in tailored access for smaller satellite systems. Advances in this area are pushing the cost of space access towards the limit of fuel cost and launch system maintenance—similar to today's commercial aircraft operations. On-orbit propulsion, refueling, and maintenance advances also promise to vastly increase space systems maneuverability and flexibility.

Electronic and mechanical miniaturization is quickly driving platforms away from the large-satellite-fits-all model. Advances in sensors, communication systems, and computation are increasing the capabilities of satellite payloads while radically reducing their size, weight, and power. Advances in satellite subsystem technology is enabling more capable satellites from cubesats to 10,000-pound systems. Assembly line production of modular satellites and standardized subsystems is radically driving down the cost of satellites. Advances in autonomy and artificial intelligence allows for the distribution of capabilities across proliferated mega-constellations of small satellites. Advances in robotics are advancing capabilities for on-orbit assembly, repair, and repurposing.

These current technology trends are driving potential new applications in space for the future, including in-space manufacturing of products for terrestrial use, biomedical advancements such as the growth of human tissue in space, large scale space power beamed to Earth, space habitats for workers and tourists and *in situ* resource extraction from the Moon and asteroids. These new activities will allow viable and growing commercial and industrial activity in space, and will advance civil and military space capabilities.

Value Trends

Table 3 – Value Trends

- Information gathering
- Precision pointing, navigation, and timing
- Global communication
- Emplacement and protection of critical space-based assets
- Expanding human presence in space, on the Moon, Mars, and beyond
- Creating markets for space tourism, manufacturing, biomedicine, space power, and resource extraction

This trend is an expansion in the range and value of civil, military, and commercial space-based capabilities. In the short- and mid-term, space capabilities have growing value in an increasingly global and interconnected world – particularly in the areas of information gathering; position, navigation, and timing (PNT); and communication.

- Space-based capabilities to globally observe and gather information with ever-increasing cadence, resolution, and sensitivity have become critical to political, military, commercial, and civil information dominance.
- National and world infrastructure is increasingly reliant on PNT for military operations, travel, communications, banking, and point-of-sale transactions. An expanding list of nations are building national or regional PNT systems.
- Space-based communication systems provide truly global coverage and minimize ground infrastructure and interferences by rivals and adversaries. In addition, space communication systems could achieve lower latency than ground-based fiber systems, and equivalent bandwidth with laser cross-, up-, and down-links.

In the mid- to long-term, the growth in value will derive from systems deployed widely in the cislunar space beyond GEO. Commercially, this value will derive from space manufacturing, resource extractions, human habitats, tourism, and power generation to provide products back to Earth and to further expand space infrastructure and capabilities.

Militarily, the mid- to long-term value of space will derive from an expansion of the space operational regime. Expansion of the space operational regime increases the adversaries' difficulty in locating and negating key space elements required for information dominance during conflict in space and cross-domain. This expansion also provides increased flexibility in positioning and maneuvering assets to project power throughout cislunar space to achieve space superiority where and when required both for conflicts in space and as part of cross-domain conflicts.

National Interest Trends

Table 4 – National Interest Trends

- Development and control of civil space infrastructure and space norms, rules, and laws
- Increased commercial space presence across a wide range of services and capabilities, a larger number of space entities, and an increasing number of space faring nations
- Growth in importance of space in extending military reach and providing global information dominance to support ensuring national objectives in conflict, to include preserving friendly essential secrecy
- Space as a key element of global infrastructure with DoD having an expanded role in protecting U.S. and ally civil and commercial space-based interests

The trend is for space to continue to grow in its contribution to national power across the civil, commercial, and military realms. New applications will unquestionably emerge, further elevating the importance of space to the nation and to humanity.

The current civil space trend is increased use of space for exploration and scientific research, Earth and space monitoring, global PNT, and the development of the infrastructure needed to support the expanded use and importance of space, such as space traffic management, orbital debris mitigation, and deep space communications. Along with this development, the civil norms, rules, and laws to govern interactions between nations will evolve as space expands as a domain for human activity.

The commercial trend is for space to increase in size and importance as part of the global economy and, as such, as a greater contributor to national power. Commercial space will continue to increase across a wide range of services and capabilities, a larger number of commercial space entities, and an increasing number of space faring nations in Earth orbit and across the cislunar domain.

The military trend is to extend the reach of military operations within the cislunar environment and to refine and expand space's role in ensuring global information dominance to support national objectives in conflict. The spatial domain of operation for space systems will expand beyond GEO to potentially encompass the entire cislunar domain with increased capability for and speed of maneuver across that domain. In addition, military actions will extend to the protection of military, civil, commercial, and human space assets. The trend is for space to become a more critical domain of potential conflict and an increasingly integral part of cross-domain conflict.

Indications of Trends

These trends directly shape the future of space as a domain of human activity. These must be considered in developing the U.S. national space strategy along with the nine key trends described in the U.S. Air Force Strategic Environment Assessment 2016-2046 (AFSEA). [4] The AFSEA more broadly covers geopolitical, warfare, and human trends affecting all warfighting domains. This report and the AFSEA broadly set out the trends shaping the future. Recent events illustrating these space trends are:

- China's space program is expanding, evidenced by the 2019 landing of the Chinese lunar rover Yutu-2 in the Von Kármán Crater to perform the first in-depth scientific investigation of the far side of the Moon from the lunar surface. The Chang'e 4 Mission is the latest step in China's long-term plan to put humans on the Moon by the year 2036. This goal is an element of China's "grand strategy" to secure global technological dominance by 2040 and is integrated with the "Belt and Road Initiative" to secure world-wide economic dominance.

- NASA is pursuing a return of humans to the Moon via its Gateway in lunar orbit and is moving forward to land humans on Mars. Vice President Pence and the National Space Council have set a goal for NASA to land American astronauts on the Moon by 2024. NASA is collaborating with commercial and international partners to achieve these goals.

- Commercial space investments are at an all-time high, led by inspired industrialists such as Elon Musk, Jeff Bezos, Richard Branson, the late Paul Allen, and an increasing number of venture capitalists looking to harvest new space revenue streams. At least one company, SpaceX, is developing a large lift and spacecraft system to explore and colonize Mars, with a goal of the first launch in the mid-2020s. Another company, Blue Origin, is focused on establishing space tourism, moving heavy industry off planet, and developing the Moon.

- President Trump published his National Space Strategy (March 2018) and has signed four Space Policy Directives providing direction in areas ranging from expanding the human sphere of influence across the solar system to recommending the standup of a Space Force within the DoD.

B. Assumptions

In addition to considering specific trends affecting space, defining space futures requires assumption as to the larger global state of the world in 2060. We make the following assumptions as to overall global economic, political, and national defense to the year 2060.

Economic Assumptions

- A tripling to quadrupling of global gross domestic product (GDP) with an annual average growth rate of 3%-4% over the period to 2060.
- U.S. economy doubling with an annual average growth rate of 2% over the period to 2060.
- U.S. portion of global GDP decreases from current 22% to between 10% and 15%.
- Large, developed economies experience similar or lower growth rates relative to the U.S.
- Chinese and Indian economies significantly exceed U.S in size but lag in per capita GDP.
- World population increases 30% to near 10 billion, primarily in developing nations.
- Top economies are China, India, United States, Indonesia, Brazil, Russia, Mexico, Japan, Germany, and the United Kingdom.
- Global economy is more integrated and driven by automation, artificial intelligence, robotics, and additive manufacturing.
- The growing economy increases demand and competition for natural resources.

Political Assumptions

- Global political power is distributed across a wide range of nations driven by increases in overall global wealth and a more evenly distributed technical base and world economy.
- U.S. remains a first-tier power, but with its political power diminished relative to other first-tier nations.
- Tiering of nations by level of power continues with narrowed differences between and within tiers.
- Europe and North America continue to control a disproportionate percentage of global power relative to their populations.
- U.S. is not the preeminent world power by multiple measures.
- Wider distribution of power increases potential for competition and conflict.
- Premium on flexible partnerships and alliances to support shifting national needs and priorities and changing geopolitical balance.

National Defense Assumptions

- The continuation of great power competition.
- A highly multi-polar world with a significant number of nations and alliances having equivalent economic power and technical infrastructure but diverse and divergent interests.
- Conflicts increasingly integrated across the air, land, sea, cyber, and space domains and extending globally and across cislunar space.
- The cyber domain is critical to space operations. Foreign competitors increasingly seek cyber capabilities to target space systems and infrastructure.
- Conflicts occur at greater speeds and range across an ever increasingly diverse set of integrated and flexible platforms and systems.
- Technical advantages between major powers has narrowed or disappeared.
- Success is driven more by resources, logistics, and successful alliances rather than by technological advantage.
- Wide range of conflicts involving a wider set of countries with significant military power.
- Increased global competition leads to an increased number of conflicts.

C. Industry Perspective

Members of the aerospace industry were invited to provide their perspectives during two workshops hosted by the Rocky Mountain National Defense Industry Association that preceded and followed the government based SFW. The first workshop solicited industry perspectives on the technical, economic, and political needs and gaps, investment opportunities (commercial and government), strategic importance, and the DoD and whole of government role for the following topics:

- Exploitation of novel orbits and Lagrangian points
- Domain sustainment
- Lunar and asteroid resources and logistics
- Space logistics and infrastructure
- New and enhanced markets and services from space

These perspectives were used as background information in the SFW workshop. The eight potential space futures developed during the SFW were discussed at the second workshop. Participants were then divided into three groups, each focusing on one set of possible futures: positive, negative, or military dominance. Three questions were posed to start the discussion:

1. What is industry's perspective on their role in each scenario?
2. What might be the inflection points that would drive us to each scenario?
3. What would be the industry approach to pushing us toward the positive scenarios and avoiding the negative ones?

Results were compiled to identify both unique and shared perspectives between industry professionals. The outcome to the industry role revealed common points of emphasis:

- The ultimate strategic objective of industry is to maximize profit. National pride and prestige are important, but the aerospace sector is becoming more international.
- In scenarios where the U.S. is not the dominant power in space, industry will turn to providing goods and services to alternate nations to continue maximizing profit.
- Industry's role always involves petitioning the government(s) for policy changes that make commerce more accessible. Governance changes are deemed to be required for markets expanding beyond GEO.
- Industry is interested in investing for and expanding to new viable markets.

Inflection points varied by the "goodness" of the scenarios considered and are listed below:

<u>Positive Futures Inflection Points</u>

- A significant increase in U.S. government investing and incentives in the space industry
- Updated International Traffic in Arms Regulations (ITAR) to encourage U.S. industry
- A revitalized curriculum of STEM education and workforce development
- Technology developed that allows the following:
    - Broadly affordable access to orbit
    - Identification of locations of valuable resources
    - Viable human tourism in space

<u>Negative/Military Dominant Futures</u>

- Lack of U.S. government investment and incentives in the space industry

- The U.S. fails to develop and adhere to a long-term strategic plan for space
- A country other than the U.S. surpasses the U.S. in launches and mass delivered per year
- A country other than the U.S. achieves any of the following milestones:
    - A definitive "first" event comparable in scale to the moon landing
    - Control of cislunar space via a space station or other means
    - Discovery of a revolutionary new technology providing them a competitive edge

These inflection points drove industry answers to the third question. The path they suggested is multi-pronged and includes:

- U.S. government establish a regulatory and economic framework that enables space commerce, including, but not limited to, amended ITAR, treaties, tax incentives, liability, definition of applicable laws, *etc.*
- U.S. government increasing financial incentives for science and technology innovation through both prizes and government contracts
- U.S. government and industry increasing technical investments
- U.S. government and industry investing in the future American workforce via STEM education and other programs.

D. Methodology

The objective of the Air Force Space Command (AFSPC) Space Futures Workshop (SFW) was to scope the alternative space futures to the year 2060, and identify turning points, potential long-term drivers, and challenges impacting the role of space in the long-term. Specific focus was applied to U.S. and allied power and interests in the political, economic, and technological realms. China was the primary space rival considered during this first workshop.

The SFW was conducted at the U.S. Air Force Academy over three days, with 52 senior scientists, decision makers, leaders, and professors participating. Participants were from the Air Force Air University, the Air Force Space Command, the Air Force Research Laboratory, the Defense Innovation Unit, the National Aeronautics and Space Administration, industry, federally funded research and development corporations, and academia. The list of participants is provided in Annex G.
To provide a common foundation of background information the participants were briefed on the following topics:

- Role of space in the multi-domain environment and U.S. government posture
- Long term science and technology challenges
- NASA's long-term mission strategy [5]
- North Atlantic Treaty Organization's (NATO) 2017 strategic foresight analysis and key trends [6]
- Pax Astra, or the "lifting up" the concept of Pax Americana through dominance of the space domain (*i.e.* "peace in the stars") [7]
- Chinese long-term space goals (strategic infrastructure and power projection) [8]
- Chinese national grand strategy to 2049
- Importance of peace time initiatives [9]
- Strategic importance of cislunar space [10]
- Visions of future space missions and prospects on a timeline for human expansion
- Space power theory and primacy of space power [11]
- Foresight techniques for deep futures [12]
- Fourth Offset Strategy (2040) and key offset technologies for 2060 [13]
- Exponential drive decomposition and long-term waves [14]
- Global economic order in 2050 [15]
- Combined NATO alternative analysis and futures analysis technique [16]
- Established futures think facilitating techniques from the futures studies field

Workshop participants were divided based on preference and experience among three groups focusing on the realms of politics, technology, and economics. Each group proceeded to accomplish the NDPP futures analysis steps through a facilitated process, completing the following steps:

1. **Building Each Realms' Taxonomy**
   Identify "Which areas are deemed relevant enough with regards to the role of space in U.S. and allied national power?" Answers were clustered to define 10-12 categories as a basis for taxonomy in their realm area.
2. **Structured Brainstorming** [17]
   Groups identified as many ideas as possible to fill out the categories of their taxonomy. Ideas were unconstrained by judgement as to quality, feasibility, practicality, or originality. Similar ideas were aggregated. The most relevant content was determined by a vote.
3. **Inverse Futures Wheel** [18]

Top scoring content interrelationships were graphically visualized (futures wheel) with the chosen content as the core concept. This provided a structured way to brainstorm the direct and indirect consequences of the core and nodes, including the effects of drivers and resistors.

4. **Starbursting a Blue-Winning Perspective**
   Two to four central topics from the futures wheel were investigated further using a starburst exercise. This technique focused on generating questions to ask about a topic rather than producing solutions to it. This first starburst was completed from the perspective of a positive U.S. (blue) viewpoint.
5. **Brainstorming Mitigations to Critical Incidents**
   Using the results of the blue-win starburst, two to four critical incident scenarios with a distinct red (adversary) perspective were examined. The group brainstormed ideas to mitigate the incident with respect to the original taxonomy.
6. **Starbursting a Blue-Losing Perspective**
   The starbursting exercise was repeated from a perspective of a negative U.S. (blue) viewpoint.

After these exercises were completed, the facilitators and senior advisors synthesized the results to define scenarios. On the final day of the workshop the facilitators organized the plausible futures along three axes in a three-dimensional alternative futures analysis. To do this, an alternative futures analysis technique developed by Shell Oil Company was used. This technique develops and explores a range of scenarios which, while not explicitly predictive, illuminates the spectrum of possible futures, and how they relate to national power. Such scenario-based thinking is a powerful means to consider and clarify multiple perspectives on the future and to identify potential inflection points and drivers for the future. [19] This analysis consists of three key steps, outlined below.

Step 1: Determine the key trends, identifiable today, which will most influence space futures. From the workshop these were determined to be:

Technology

Advances in space science and technology enabling increased access and actions in space.

Value

Expansion in the range and value of commercial, civil, and military space capabilities.

National Interest

Increased understanding of the value of space capabilities to national defense and overall national power.

These were examined in the context of the nine key trends described in the U.S. Air Force Strategic Environment Assessment 2016-2046. [4] The AFSEA more broadly covers geopolitical, warfare, and human trends affecting all warfighting domains. The details of these trends are included in Annex A.

Step 2: Establish assumptions as to the general state of the world in 2060 that will affect space futures. These were determined to be:

Economic

The size of the global economy, the distribution of wealth, the degree of economic integration and the size and distribution of population.

Political

The distribution of power amongst nations, alliances and other entities.

National Defense

The nature and extent of potential conflicts and the distribution of military power across domains and nations.

The details of these assumptions are captured in Annex B.

Step 3: Define axes for space futures, define the maximum and minimum expected states along these axes in the context of the trends and assumptions, create a bounded set of space futures and scenarios, and determine the civil, commercial, and military characteristics of those futures. The three axes established for the future space scenarios were:

Human

How broadly and in what numbers do humans live and work in space?

Commercial Potential

What is the economic level of new wealth and persistent revenue streams from space activities?

Leadership

To what degree do the U.S. and allied nations lead in the creation of the civil, commercial and military space capabilities and in establishing the norms, standards, and international regulations in space? (e.g., based on free world concepts of a liberal international order?)

The three axes defined by this three-dimensional alternative futures analysis are:

- **Human Presence.** This axis defines the degree of human presence in space. End points extend from no significant human presence, to continuous human presence in large numbers and over a spatial domain from near Earth to the Moon, beyond to Mars, asteroids, and the other planets. Critical questions to address to define the scenarios along the human axis are:
    - For sustained human presence at large scale – is life possible in space for a broader audience, not just limited to professional astronauts and governmental entities?
    - Is it possible for self-sustaining communities to exist?
    - Is there an underlying economic rationale for continued human presence in space?
    - Is it possible for large-scale, closed-cycle life support to enable human settlement (families and new births)?
    - Is the technology possible, and have we achieved an ability to enable permanent settlement of meaningfully sized communities?
    - Are we limited at the ability of the International Space Station to support very few government employees for short periods of time, at great expense, externally supplied, and unable to reproduce in space?

- **Space Economy:** This axis defines the degree of economic activity in space. End points extend from limited niche applications in communications; position, navigation, and timing (PNT); and information gathering to a complex economic ecosystem extending from Low Earth Orbit (LEO) to the Moon and beyond, with viable and growing capabilities extending to tourism, space-based power, resource extraction, space manufacturing, *etc*. Critical questions to address to define scenarios along this axis are:
    - In what economic areas is space activity profitable?
    - What is the return on investment for these areas?
    - Are there significant new industries that can be self-sustaining in space that generate significant revenue? Examples include: space-based internet, in-space transportation, in-

space propellant manufacture, lunar and asteroid mining, space-based solar power-beaming, orbital and lunar tourism.
    - Will space be a minor part of the global economy limited to current markets of satellite communication, PNT, and Earth observation?

- **U.S. and Allied Leadership in Space.** This axis defines the degree of economic, political, and military leadership in space that the U.S. and its allies retain. The end points extend from the U.S. and its allies ceding its present dominant position across any of these areas, to the U.S. and its allies retaining a dominant position in all three of these areas. Critical questions to define scenarios along this axis are:
    - How interdependent are economic, political, and military space leadership?
    - Do economic and political leadership require military leadership?
    - To what degree is leadership in all three areas required to establish standards and norms for space that are advantageous to the U.S. and its allies?
    - In a flatter world economically, politically, and militarily, what is the degree of space dominance possible or required to secure national interests?

As a starting point and to constrain the analysis, two limiting states were defined along each axis representing minimum and maximum realistic contractions and expansions. It was assumed that the states along each axis are independent of the states along the other axes. These three axes produced eight different named scenarios.

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F. Acronym List

AFSEA	Air Force Strategic Environmental Assessment
AFSPC	Air Force Space Command
AI	Artificial Intelligence
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance
DoD	Department of Defense
GDP	Gross Domestic Product
GEO	Geosynchronous Earth Orbit
LEO	Low Earth Orbit
MEC	Minimum Essential Capabilities
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NDPP	NATO Defense Planning Process
PNT	Pointing, Navigation, and Timing
SFW	Space Futures Workshop
U.S.	United States of America

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