#### AIR WAR COLLEGE

#### AIR UNIVERSITY

# CRITIQUE AND RECOMMENDATIONS FOR U.S. NATIONAL

## SPACE POLICY

by

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A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

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27 March 2020

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## **Biography**

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#### Abstract

Current National Space Policy does not adequately address the current era of Great Power Competition within the space warfighting domain. A National Defense Space Strategy is needed to ensure the U.S. retains its competitive advantage over all current and future adversaries in space. This strategy should prioritize the development of new space-based capabilities that extend beyond near-earth orbit into cislunar space in order capitalize on the resources and strategic advantage offered by this emerging space frontier.



#### Introduction

It has been 142 years since Commodore Robert W. Shufeldt argued in an impassioned letter to Congress, that the United States had fallen woefully behind in its investment in maritime capabilities and that the United States' future prosperity would depend on its ability to secure commerce and project power in the maritime domain.<sup>1</sup> While the response to Shufeldt's argument was by no means immediate, his voice in concert with others that came after him, all advocating for the prioritization of a robust maritime capability ultimately led to the United States developing and fielding the world's most powerful Navy. It was arguably the United States' commitment to and success in achieving dominance in the maritime domain which enabled it to achieve superpower status, the benefits of which it has enjoyed for the past 75 years. Now, almost a century and half later, the United States finds itself in a similar position within the space domain.

The importance of the space domain and our ability to field space-based assets and capabilities in the defense of our national security is self-evident. Our reliance on these capabilities will likely increase along with the ability of our potential adversaries and competitors to degrade those same capabilities. This vulnerability needs mitigation. Our current National Space Strategy and National Space Policy recognize the need to defend against threats and mitigate vulnerabilities, but they are characterized by an emphasis on preserving status-quo capabilities, specifically in the areas of Intelligence, Surveillance and Reconnaissance (ISR).<sup>2 3</sup> Furthermore, the U.S. space program is bifurcated between the pursuit of knowledge and scientific discovery, governed by NASA, and the preservation of our National Security interests in space governed by the Department of Defense. An examination of both current Defense and NASA related policies and strategies reveal little in the way of an integrated approach in pursuit

of a common objective. Instead, there only exists a delineation and division of responsibilities with regard to common use infrastructure or authority to develop and enforce regulations.<sup>4 5</sup> We are entering a period where our competitors, specifically China, are pursuing advances in space related technologies to explore new ways to project power in and through space beyond the simple interdiction or subversion of existing U.S. capabilities. What the U.S. needs is a new National Space Strategy that integrates our scientific and military programs with the goal of ensuring the U.S. and its allies retain leadership across all aspects of human space endeavors through the increased utilization and exploitation of space toward advancing our national interests and achieving our national objectives. While the Department of Defense should take a leadership role in pursuing military space capabilities, the size and scope of the domain along with the cost associated with space operations requires that the national space strategy direct the integration of resources across the whole of government to develop new military capabilities that move us beyond earth's orbit into cislunar space to ensure continued freedom of action in space. To illustrate how this strategy might be implemented, this paper will explorer an emergent spacebased capability of significant interest to both the United State and our nearest space-faring competitor, China; the expansion of space operations into cislunar space.

#### Thesis

What the U.S. needs is a new National Space Strategy that integrates our scientific and military programs with the goal of ensuring the U.S. and its allies retain leadership across all aspects of human space endeavors through the increased utilization and exploitation of space toward advancing our national interests and achieving our national objectives. While the Department of Defense should take a leadership role in pursuing military space capabilities, the size and scope of the domain along with the cost associated with space operations requires that the national space strategy direct the integration of resources across the whole of government to develop new military capabilities that move us beyond earth's orbit into cislunar space to ensure continued freedom of action in space.



## A Strategy for the Exploitation of Cislunar Space

## **Cislunar Space Defined**

The technical definition of cislunar space includes "...all space near and within the Moon's orbit, including low-Earth orbit, geosynchronous orbits, any lunar orbits, the lunar surface, and the five Earth-Moon Lagrange points."<sup>6</sup> For the purpose of this paper, discussion of cislunar space will focus on those areas outside of Earth's orbit. The lunar orbits and lunar surface are self-explanatory and the simple definition of the Earth-Moon LaGrange points are those points in space where the Earth's and Moon's gravitational forces cancel each other out. U.S. experience operating in cislunar space goes back to the Ranger and Apollo programs of the 1960's and 70's. However, while the Apollo program required an investment in resources at unsustainable levels by the United States., recent advances in technology and the discovery of vital resources on the Moon have made the prospects of a sustained cislunar presence feasible. Two of the most valuable resources that have a confirmed presence on the moon can provide sources of breathable air, water and fuel. The presence of oxygen in lunar regolith (soil) has been known for some time and the technology now exists to make the efficient extraction of oxygen from regolith in useful quantities feasible.<sup>7</sup> On the other hand, the more recent discovery of significant amounts water-ice and other volatile compounds in the lunar regolith at each of the Moon's poles has much greater implications for sustained operations in cislunar space due its potential for providing a virtually unlimited source of propellant outside of Earth's gravity well.<sup>8</sup>

## **Competition for Cislunar Presence**

To adequately implement a national space strategy that ensures the U.S. and its allies retain leadership across all aspects of human space endeavors, it is imperative for the U.S. to pursue an aggressive program that expands its space operations into cislunar space. The benefits of operating in cislunar space will be discussed later in this paper, however, the reality is that our principal space competitor, China, is on the path to achieving cislunar space capabilities ahead of the United States.

While there are arguably other lines of effort necessary to preserve the United States' preeminence in space, failure to lead in the exploration and exploitation of cislunar space will jeopardize the United States' position of leadership among spacefaring nations over the next several decades. In the past year, the Chinese have established a robotic presence on the far-side of the moon, demonstrating a capability to operate in an area of cislunar space where the U.S. has not.<sup>9</sup> Furthermore, published Chinese space strategy and plans indicate their intent to exploit the benefits of cislunar space.<sup>10</sup> What is clear is that the Chinese are aggressively pursuing the initial phases of what will ultimately result in the establishment of a permanent cislunar presence and a functional cislunar transportation and logistics network.

Some might argue that ceding leadership to the Chinese, or other emerging space powers, may seem like a benign, if not beneficial strategy for the United States. Why not let another nation expend resources developing the necessary technologies and procedures for operating in cislunar space? We could then apply their discoveries to establish our own cislunar presence and extract its benefits at a fraction of the cost. The fallacy in this perspective is twofold. First, the nation that leads in the exploitation of cislunar space will be able to monopolize the most advantageous resource locations and orbits. One of the misconceptions of space is that there is room enough for all to enjoy its benefits. While volume of cislunar space is vast, there are a finite number of locations within the domain, to include the lunar surface, from which a prospective operator can derive maximum benefit at minimum cost. Such locations include the Earth-Moon Lagrange points and the lunar poles. The significance of the Earth-Moon Lagrange

points is due to the balance in gravitational forces at those points which permit the placement of assets with the ability to maintain a stationary position (with reference to the earth and the moon) with little expenditure of propellent.<sup>11</sup> Similarly, the abundance of volatile compounds, most significantly water, at the lunar poles coupled with the near continuous solar radiation available on polar mountain peaks, provides the raw materials necessary to produce propellent and other materials necessary to expanding our presence in cislunar space in a manner that is not only economically viable, but ultimately highly profitable.<sup>12</sup> These are just two examples of finite locations within cislunar space that are critical for establishing a cislunar transportation and logistics system. While the Outer Space Treaty of 1968 forbids the claiming of space or the lunar surface by nations, there is little reason to believe that once access to Lagrange points and the lunar surface becomes routine, all nations will abide by the altruistic spirit of the treaty.<sup>13</sup> Reality will likely demonstrate that the first nation to establish a presence at either the Lagrange points or the lunar poles will not only have the benefit of selecting the most beneficial locations for their operations, but will also establish control or de facto ownership of those locations under the universal, unwritten dictum which states "possession is nine-tenths of the law". In order for the United States to assure its continued leadership in the development of space it must codify a National Space Policy which prioritizes the necessary objectives that will ensure it is the first to explore and exploit the benefits of cislunar space with the goal of establishing a stable and efficient cislunar transportation and logistics network.

The first nation to establish a presence in cislunar space will not only control the critical terrain but will also be in a position to control the development of the cislunar domain. To illustrate this point, one need only look at the development of near-earth space throughout the late 20<sup>th</sup> and early 21<sup>st</sup> century. The early years of human endeavors in near-earth space were

dominated by the cold-war competition between the United States and the Soviet Union. Following the success of the Apollo program and the later collapse of the Soviet Union, the United States emerged as the world's dominant space power. This dominance meant that other nations of the world looked to the United States for leadership in the development of near-earth space. Nations that did not possess the resources or expertise to exploit the benefits of near-earth space on their own partnered with the United States in order to gain access. Similarly, the development of private space ventures in near-earth space has almost exclusively involved corporations that are aligned with the United States and its allies. Leadership by the U.S. government in the development of near-earth space led to the development of a space industrial base within the United States that naturally branched into private enterprise once space operations developed to the point that they could be profitable. There is every reason to believe that the development of cislunar space will follow closely in the path of near-earth space. Ceding leadership to another nation would grant that nation the ability to establish the norms associated with operating in cislunar space and would result in all future cislunar development being centered on a nation other than the United States. The consequences of this potential future reality extend far beyond the loss of prestige. It would likely mean that the United States, along with the rest of the world, would be beholden to another nation for the privilege to access the benefits of cislunar space. If that nation were an authoritarian regime, such as China, one can easily conclude that the consequences of this scenario will not align with U.S. national interests and would be deemed wholly unacceptable to the American people.

#### **Benefits of Cislunar Space to National Security**

In addition to ensuring continued leadership in space, our national space strategy should also seek to develop new space-based capabilities that move us beyond earth's orbit to ensure continued freedom of action in space. Our ability to derive additional benefit from operating in near-earth space is quite clearly nearing a plateau. The development of a National Space Strategy that mandates an integrated, whole of government approach for the exploration and exploitation of cislunar space will provide significant military, scientific and economic benefits.

The military benefits of operating in cislunar space can be grouped into three broad categories: persistence, maneuver and cost. Persistence, in this context, is the ability to place assets into space and then keep them there indefinitely, or at least until they are obsolete. As it stands today, the lifespan of an object placed in earth orbit is governed by the amount of station keeping fuel on-board or its ability to remain functional. While the U.S. had a limited capability to access low-earth orbit satellites when the space shuttle was operational, at present, we have no capability to refuel or maintain space-based assets. The opening of cislunar space and the corresponding access to moon-based resources of water and volatile organic compound provide the opportunity to produce virtually unlimited amounts of prepollent.<sup>14</sup> Fuel produced on the moon and the ability to distribute that fuel throughout cislunar space without inducing the cost of moving resources out of earth's gravity well is a potential game changer for the persistence of military assets in space. Now, assets launched from Earth will no longer need to include large fuel reserves to maintain station-keeping. The ability to launch assets without station-keeping fuel can either reduce the overall cost of launch, permitting more assets to be launched or it can enable the launch of larger, more capable assets. Additionally, the ability to fuel assets while operating in space will increase their lifespan and open the possibility of performing in-flight maintenance or upgrades to space-based assets which again, can eliminate the need to research, develop and deploy costly replacement assets needed to when existing assets become obsolete or broken.15

The ability to maneuver is as critical a capability to military operations in space as it is to any other domain in which the military operates. Maneuver provides the ability to engage an adversary at a place and time of your choosing while minimizing the opportunity for the adversary to observe or predict your movement. "Cislunar space offers a vast maneuver space that is difficult to surveil and for which surprises can then emerge, analogous to deep-sea submarine warfare."<sup>16</sup> Expanding operations into cislunar will provide the U.S. military a maneuver capability in space that it currently does not possess. The refueling capability that this system would provide would free space-based assets from the restriction of continuously operating in single, predictable earth orbits. Instead, space vehicles would be free to alter orbits on demand or transit between lunar and earth orbit making their movement much less observable or predictable.<sup>17</sup> This freedom of maneuver could provide military capabilities to defend assets in predictable orbits from adversary interference or offensive capabilities that deliver both kinetic and non-kinetic effects against other space vehicles, onto the Earth's surface or even on the Moon or other celestial body.

The cost benefit to the military associated with maintain a permanent cislunar presence is one that would take more time to achieve, but would potentially provide the greatest benefit. As was previously mentioned, the ability to refuel assets in space will have the effect of reducing the cost of launching space assets from Earth. This savings could be reinvested in other space-based capabilities or used to offset costs in other areas. Additionally, a natural derivative of reduced launch costs would be the increase in number of and variety of space-based capabilities. This increase in asset volume should theoretically reduce the unit cost of particular capability. For instance, the cost associated with data transmission could be reduced if, for a given unit of data, there were 4 satellites capable of transmitting that data versus two. A final, more far-reaching cost benefit would be the utilization of Moon derived resources to manufacture military assets either on the moon or in orbital factories. Producing and deploying space-based military assets in and from space would eliminate the high cost associated with launching space assets out of earth's gravity well. Production of assets in space could also benefit from the ability to produce novel materials in low gravity that would either be prohibitively expensive or impossible to produce on the earth's surface.

Beyond the military benefit, there are also significant scientific and economic benefits to expansion of space operations into cislunar space. The obvious benefit to science will be the increased access for scientists to cislunar space, to include the lunar surface. This access will undoubtedly lead to scientific discovery and advancements in our knowledge and understanding of the earth-moon system. Furthermore, the access to fuel, resources and a manufacturing capability outside of Earth's restrictive gravity-well will provide a convenient and efficient jumping-off point for further exploration and scientific discovery in the solar system beyond cislunar space.<sup>18</sup> In fact NASA's current plan for extending manned exploration beyond the Earth-Moon system includes a Lunar Gateway that will make use of lunar produced fuel and other resources to equip planned exploration missions.<sup>19</sup>

The economic benefits of operations in cislunar space have already been alluded to and are natural extensions of the military and scientific benefits. Today, analysts have determined there is an approximately \$75M/year demand for a spaced-based refueling capability enabled by the production of moon-based propellant.<sup>20</sup> While this figure does not warrant a profit-making venture by commercial interests, it is predicted that once in-space refueling capabilities are fielded, the market could grow "…by at least an order of magnitude in the foreseeable future."<sup>21</sup> Additionally, access to cislunar space will facilitate the extraction of resources from near earth

asteroids and potentially the outer planets. Access to these resources will enable not only spacebased manufacturing but could lead to economically feasible alternatives to our current reliance on fossil fuels in the form of space based solar power or the development of clean fusion power utilizing elements such as helium-3 harvested from the moon's surface or from one of the outer planets.<sup>22</sup>



#### Recommendations

This paper has only scratched the surface regarding the benefits associated with the United States' pursuit of cislunar space-based capabilities, while making the case that having those capabilities will serve the United States' interest in maintaining its leadership while promoting its expanded utilization and exploitation of space. Fortunately, the two principal U.S. government stakeholders in space-based operations, the Department of Defense and NASA, have started to implement plans and policies that are moving each of these organizations in the right direction. NASA has committed to return to the Moon within the next decade as part of a planned Lunar Gateway capability that would utilize cislunar resources as a springboard to manned exploration of the solar system. For its part, the Department of Defense has created the Space Force which, in theory, will place the planning, development and employment of all military related space capabilities under a single military service. While these moves are certainly steps in the right direction, more can and should be done to fully integrate the resources and capabilities of NASA and the Department of Defense in order to maintain U.S. leadership in space. The following paragraphs will offer recommendations and propose milestones that the United States might implement in the pursuit of an integrated approach to cislunar exploration and exploitation.

Pursuing an endeavor as broad as the development of a cislunar space operating capabilities is one that will require significant investment on the part of the United States and expertise derived from multiple government and private entities. The size and scope of this endeavor necessitates the utilization of a deliberate process for outlining objectives and assigning stakeholders, both within government and industry, to efficiently and effectively achieve the objective. The Department of Defense Unity of Effort Framework is one such method that

would effectively coordinate the efforts of all stakeholders toward the goal of developing a National Space Strategy and developing a plan of action that would prioritize the United States' pursuit of a permanent cislunar presence.<sup>23</sup> This paper will not attempt to outline the entire framework approach it will provide some recommendations on how it should be structured. First, an overall lead integrator for the effort should be identified. This would be the organization assigned responsibility for coordinating among all stakeholders, facilitating the development of a plan of action and ultimately held accountable for achieving the objective. For the purpose of planning and executing the development of a cislunar space capabilities, the Department of Defense, and more specifically, the Space Force would be the best candidate for two reasons. First, the military has more resources, in the form of manpower, materiel and budget, than any other branch of the federal government. Leveraging these resources to the greatest extent practicable will be necessary to achieve this objective. Secondly, the military necessity outlined previously will be the most compelling justification for fielding this capability and will make the vast expenditure of necessary resources to achieve the objective more likely. There is an added benefit to identifying the Space Force as the lead integrator for this effort. In much the same way that the strategic bombing campaigns of World War II confirmed the legitimacy for a separate independent Air Force, assigning the pursuit of a pure space-based capability such as the development of cislunar space capabilities to the Space Force will provide much needed credibility to a nascent independent space service.

While the Space Force should be considered the natural choice to lead the development, integration and implementation of a new National Space Strategy focused on the development of cislunar capabilities, this would in no relegate NASA to the role of junior partner within the national space enterprise. The fact is, NASA has, and will likely continue to carry the

preponderance of the burden associated with developing the technology and procedures necessary to exploit cislunar space. Placing the Space Force in the lead for developing and implementing the National Space Strategy would not change NASA's role, but would base the rationalization and prioritization driving the development of cislunar capabilities on the needs and objectives of the United States' national security with scientific discovery becoming a secondary benefit of this endeavor. Beyond the lead integrator, the identification of other stakeholders will also be necessary to effectively plan and execute the development of a cislunar transportation and logistics system.<sup>24</sup> This would obviously include other relevant government agencies such as the Departments of Transportation and Commerce who already exercise significant responsibility and authority within the space enterprise. Additionally, it will be necessary to leverage the resources and creative talent resident in private industry for this endeavor to be successful. Capital investment in the form of research and development of the cutting edge technologies necessary to achieve cislunar space objectives would be the primary benefit derived from private industry. While the risks for private industry are understandably large, the potential profits associated with cislunar resource exploitation will likely be persuasive enough to ensure their willing participation.

With the Space Force partnered with NASA, other relevant government agencies, and private industry, the stage will be set for much detailed planning necessary to successfully develop a National Space Strategy that prioritizes the exploration and exploitation of cislunar space. It is not possible in the space of this paper to produce a complete outline for this planning endeavor. However, there are two milestone recommendations that should be near-term priorities for achieving the United States' cislunar objectives. First, the United States must get a manned mission to the moon, and more specifically, the lunar poles as soon as possible. These

future manned lunar missions should not be one-off publicity stunts, but should be part of an iterative plan that will expand our understanding and capability to operate in the cislunar domain. The Artemis program currently being pursued by NASA has objectives that appear to mirror this recommendation. Every effort should be made to adequately resource the Artemis program and integrate national security objectives to include the assignment of Space Force personnel within the Artemis program as soon as possible. Beyond Artemis, the United States should commit to developing the technologies and the processes necessary to harvest lunar resources, produce propellant on the moon, and transport that fuel back into earth orbit or to fuel depots stationed at the Earth-Moon Lagrange points. Developing, testing and fielding these technologies and procedures will provide the necessary framework for a cislunar transportation and logistics network that will lay the foundation for all future cislunar and deep space endeavors.

Second, the United States must rapidly expand its population of astronauts and develop the astronaut skills necessary to develop cislunar resources. One of the key enablers to this recommendation will require a significant paradigm shift in how the United States selects, trains and retains its astronauts. To this point, astronaut candidates are selected based on their physical fitness, ability to pilot aircraft or for their scientific, medical or engineering expertise. In most cases, astronauts possess advanced degrees in the physical sciences, medicine or engineering prior to their selection and then are placed through years of intense training before they are deemed capable of operating in space. While robotic capabilities will likely play an integral role in the day-to-day operations within cislunar space, it will be necessary to put people into space with varying technical skillsets to achieve the necessary level of development on a reasonable timeline. For the purposes of building bases on the moon to accommodate resources extraction, fuel production and manufacturing operations, something akin to a Space Corps of Engineers

will be needed with expertise in designing, constructing and maintaining lunar facilities. Similarly, technical expertise will be needed to operate propellant plants, fuel depots and satellite maintenance stations. These manpower requirements lend themselves to personnel credentialed with classic trade skills such as heavy equipment operations, refinery technician or HVAC repair rather PhD's in astrophysics or aeronautics.

Similarly, the scale of cislunar operations will require significantly more operators and technicians capable of sustained in-space operations than NASA's current astronaut pool or training program could likely accommodate. As was previously mentioned, the primary purpose behind the expansion into cislunar space will be national security related. Consequently, the majority of the personnel that will be responsible for manning these efforts in space should be members of the Space Force. Initially, the Space Force will need to leverage NASA's training experience to produce skilled space operators, but a Space Force specific training program will need to be quickly developed and implemented to ensure projected space operations are sustainable. Initial efforts should be focused on identifying the skills necessary to establish and sustain the variety of cislunar missions and capabilities. Next, a manpower model should be developed that accounts for such variables as realistic duration for manned space activities and the length of a space operators' career in order to quantify the number of trained personnel necessary to accomplish planned cislunar objectives. Armed with the appropriate manpower requirements, planners will then be able to design a space operator training pipeline that equips personnel with the necessary skills in a timeline that ensures sufficient manpower is available to accomplish required missions.

#### Conclusion

For the United States to maintain its position of leadership in space and to facilitate the peaceful and just expansion of human activity into cislunar space, a new space strategy is needed that emphasizes an integrated, whole of government approach to planning, developing and implementing new space-based capabilities. These capabilities should be focused on extending space operations beyond Earth's orbit into cislunar space in order to capitalize on the numerous resources available for exploitation and the strategic advantage associated with a deep-space presence. Implementation of this strategy will enable the United States to outcompete its adversaries and lead its partners and allies to enjoy the full military, scientific, and economic benefits that cislunar space has to offer. In so doing, the United States will preserve its current position of leadership in all space-based endeavors and will be poised to lead the further expansion of mankind throughout the solar system and beyond.

#### Notes

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<sup>2</sup> *National Security Space Strategy*, (Department of Defense and Director of National Intelligence, January 2011), 1-14.

<sup>3</sup> *National Space Policy of the United States of America*, (Office of the President of the United States, June 28, 2010) 1-14.

<sup>4</sup> National Space Policy of the United States of America, 1-14

<sup>5</sup> National Security Space Strategy, 1-14

<sup>6</sup> "National Space Society Roadman to Space Settlement", adAstra, Third Edition, (2019): 26.

<sup>7</sup> Diane Linne, Gerald Sanders, Julie Kleinhenz, Landon Moore, "Current NASA In Situ Resource Utilization (ISRU) Strategic Vision" June 2019, accessed February 12, 2020,

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<sup>8</sup> Paul Spudis, The Value of the Moon: How to Explore, Live, and Prosper in Space Using the Moon's Resources.

(Washington, DC: Smithsonian Press, 2016), 138-139.

<sup>9</sup> Spudis, *The Value of the Moon*, 176.

<sup>10</sup> Alexander Bowe, "China's Pursuit of Space Power Status and Implications for the United States", U.S.-China Economic and Security Review Commission Staff Research Report (April 11, 2019), 8

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<sup>11</sup> Spudis, *The Value of the Moon* p. 113-114.

<sup>12</sup> Spudis, The Value of the Moons p. 48-49

<sup>13</sup> Spudis, *The Value of the Moon*, p. 181.

<sup>14</sup> Loren Grush, "Why Mining the Water on the Moon could open up space exploration" The Verge, Aug 23 2018, https://www.theverge.com/2018/8/23/17769034/nasa-moon-lunar-water-ice-mining-propellant-depots.

<sup>15</sup> Spudis, The Value of the Moon p. 173-174.

<sup>16</sup> Leonard David, "US Military Eyes Strategic Value of Earth-Moon Space", Space.com, August 29, 2019,

https://www.space.com/us-military-strategic-value-earth-moon-space.html.

<sup>17</sup> Spudis, *The Value of the Moon* p. 176.

<sup>18</sup> John Lewis, *Mining The Sky: Untold Riches From The Asteroids, Comets, And Planets* (New York: Helix Books, 1997) 122-123.

<sup>19</sup> "Q&A: NASA's New Spaceship", Nasa.gov, November 13, 2018, accessed February 12, 2020

https://www.nasa.gov/feature/questions-nasas-new-spaceship

<sup>20</sup> Aiden O'leary, Jason Aspiotis, "A Preliminary Estimate of Future Potential US Military Supply and Demand for In-Space Water-Based Fuel", Booze-Allen-Hamilton, June 2019,

https://isruinfo.com/public/index.php?page=srr\_20\_ptmss

<sup>21</sup> O'leary and Aspiotis, US Military Supply and Demand for In-Space Water-Based Fuel

<sup>22</sup> Lewis, *Mining The Sky*, 137-139, 204-21.

<sup>23</sup> Unity of Effort Framework Solution Guide (Unity of Effort Guide), Joint Staff, 31 August 2013 [electronic resource], 19.

<sup>24</sup> Unity of Effort Framework Solution Guide, 7.