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An Atlas for Navigating the Innovation Ecosystem: Hybrid Airships as a Use Case to Engage the Commercial Sector

March 2022

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Prepared for the Naval Postgraduate School, Monterey, CA 93943

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ABSTRACT

The Chief of Naval Operations and Commandant of the Marine Corps have stated the need to streamline innovation practices for faster adoption of emerging technologies to support force design initiatives. However, the Department of Defense (DOD) innovation ecosystem is difficult to navigate. This research develops an atlas to guide interaction and engagement for DOD personnel to navigate the innovation ecosystem while assessing commercially-developed, large-capacity transportation platforms. Using hybrid airships as the use case, the authors employed two research methods while developing the atlas: 1) technology progress and cost modeling and 2) market analysis through research and interviews with industry leaders. The results confirm that early DOD engagement with commercial partners can positively influence long-term procurement options. The authors believe that the atlas can guide timely and productive engagement with the commercial sector for the sustainable development of large-capacity platforms, but must have a framework that protects commercial intellectual property. We recommend that the DOD utilize the atlas to explore how commercial markets will affect future hybrid airship development, while creating a more complete picture of the function and utility of these versatile platforms.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACLS	air cushion landing system
ADM	Admiral
AFIT	Air Force Institute of Technology
AiDA	Acquisitions in the Digital Age
ARPA	Advanced Research Projects Agency
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
BOR	body of revolution
BRI	Belt Road Initiative
CAC	common access card
CAT	cumulative average theory
CCP	Chinese Communist Party
CNO	Chief of Naval Operations
COI	community of interest
CRADA	Cooperative Research and Development Agreement
CRS	Congressional Research Service
CSET	Center for Security and Emerging Technology
DARPA	Defense Advanced Research Projects Agency
DAS	defense acquisition system
DC CD&I	Deputy Commandant for Combat Development and Integration
DIB	Defense Innovation Board
DII	Defense Innovation Initiative
DIU	Defense Innovation Unit
DMO	distributed maritime operations
DOD	Department of Defense
DTIC	Defense Technical Information Center
EABO	expeditionary advanced basing operations
EU	European Union
FDDA	Future Deployment and Distribution Assessment
FMF	Fleet Marine Force
GAO	Government Accountability Office

GPC	Great Power Competition
HAV	Hybrid Air Vehicles
HBR	Harvard Business Review
IPT	integrated planning team
ISR	intelligence, surveillance, and reconnaissance
ITARS	International Traffic in Arms
JLOTS	joint logistics over the shore
LEMV	Long Endurance Multi-Intelligence Vehicle
LOCE	logistics in a contested environment
LTA	lighter-than-air
MAGTF	Marine Air-Ground Task Force
MIT	Massachusetts Institute of Technology
MS&A	modeling, simulation, and analysis
MVM	mounted vehicle maneuver
NASA	National Aeronautical and Space Administration
NDAA	National Defense Authorization Act
NDS	National Defense Strategy
NPS	Naval Postgraduate School
NSF	National Science Foundation
NSS	National Security Strategy
O&S	operations and sustainment
ONR	Office of Naval Research
OUSD(A&S)	Office of the Under Secretary of Defense (Acquisitions and Sustainment)
OUSD(P)	Office of the Under Secretary of Defense for Policy
R&D	research and development
RCAT	Rapid Course of Action Analysis Tool
USCG	United States Coast Guard
USINDOPACOM	US Indo-Pacific Command
USMC	United States Marine Corps
USN	United States Navy
USTRANSCOM	United States Transportation Command

I. INTRODUCTION

The Department of Defense (DOD) innovation ecosystem is large and complex, in part because of the commercial sector's aggressive development of emerging technologies for more than 20 years. Rooted in the post-World War II (WWII) race for global technological dominance, the U.S. innovation ecosystem has experienced significant evolution, especially in the past 20 years. There are no signs to suggest this momentum will slow any time soon. To explore, capture, and adopt commercially developed emerging technologies, the DOD and its five service branches have encouraged a rapid build-up of organizations to interact with the commercial sector. Particularly regarding large-capacity transportation systems, the commercial sector has been prototyping new platforms with increasing frequency. This explosion of growth and development has partly been to drive down costs, but also to capitalize on other complementary technologies, while recognizing the need to be more sustainable.

Developing a new large-capacity mobility platform is never cheap or simple. Traditionally, the DOD has spent enormous sums of money in the research, development, and acquisitions of systems like the C-5 Galaxy, the largest U.S. aircraft currently in used for military purposes. The DOD now has the capability to engage with a larger commercial audience beyond the defense industrial base through its growing innovation ecosystem. We can collaborate with the commercial sector to inform the development and delivery of mature and proven platforms for the U.S. military.

A. PURPOSE

The purpose of this research is to begin outlining what a flexible pathway for interaction and engagement between the DOD and the commercial sector can look like in the development of a large-capacity mobility platform.

The first objective of our research is to understand what milestones would be important in this interaction. The resulting atlas is not intended to be rigid and structured but instead a living document that should be edited, adjusted, and improved as a technology proceeds forward. Our second objective is to demonstrate how commonplace tools and research capabilities can be used to achieve early milestones in the atlas, by prototyping the atlas with hybrid air vehicles.

B. SCOPE AND RESEARCH METHODS

Our research approach followed three steps. First, we became familiar with innovation ecosystems and how they tend to function. Next, we identified an emerging large-capacity mobility platform that we felt could be reasonably analyzed in the time frame available. The final step was to explore potential qualitative and quantitative analysis tools for use in the creation of the atlas to demonstrate the value of early engagement with the commercial sector. We chose hybrid airships as the strongest use case for this atlas.

C. WHY HYBRID AIRSHIPS?

Currently the United States military employs a wide range of large-capacity mobility platforms. These platforms work in one of three domains: air, land, and sea. In the air, the DOD relies on the C-5, C-17 and C-130 airframes to move the majority of its tactical cargo but does rely on contracted airlift for a handful of services. On land, cargo moved by contracted rail is the only large-capacity capability. Finally at sea, contracted cargo ships carry the bulk of the military's prepositioned forces and its bulk freight. While effective, these platforms have only been capable of operating on either the land, sea, or air. Additionally, many of these platforms are reaching the end of their life cycle and there are forthcoming decision points about whether to maintain or replace them (Trunkey, 2018).

Hybrid airships come from the family of lighter-than-air (LTA) vehicles. Although they travel through the air, they are best described "as a fast ship, rather than a slow airplane" (R. Boyd, Lockheed Martin Hybrid Airship Program Manager, personal communication, November 18, 2020). In their baseline configuration, hybrid airships have the ability to conduct on-load and off-load operations not only on land, but also on water and in remote and austere locations with little to no infrastructure. This represents a potentially dramatic change in the way the U.S. military plans and executes its mobility operations in the future. Hybrid airships can also be a pioneering platform by incorporating alternative energy propulsion in the baseline configuration. As we explored the evolving global security climate, and the climate concerns currently faced by the DOD, we decided that this platform may have significant impacts in both the commercial and military sectors of the future.

The DOD has a significant history with hybrid airships, spending approximately $1 billion dollars between 2007 and 2012 on multiple programs (Chaplain, 2012). Although the DOD funding was closed off and the programs were shut down, several companies continued their exploration with hybrid airships. Over the past ten years, the development of these platforms has continued, funded entirely by the private sector, with the possibility of entering multiple markets in the next five years. The DOD now has a renewed opportunity to explore these craft and their capabilities without having to provide the bulk of the funding.

D. RESEARCH QUESTIONS

Our primary research questions were:

1. What are the key markets that hybrid airships intend to enter and how do those markets view the viability of hybrid airships?
2. In what way can cooperative modeling, simulation, and analysis (MS&A) efforts with commercial organizations accelerate the development of hybrid airships?
3. Are there potential collaboration milestones between the DOD and commercial manufacturers that can improve or accelerate the maturation of the technology?
4. To what degree must the DOD understand the development and sustainment of the supply chain and production practices of commercial manufacturers?

E. ASSUMPTIONS AND LIMITATIONS

The atlas is still in development. The major limitations were time, experience, and manpower. The atlas requires an interdisciplinary analysis.

During this research, we interacted with multiple commercial entities who trusted us with proprietary information and intellectual property (IP) to further our research. To protect that trust and information, we did not use this protected information specifically to create some of our models nor did we publish any of it as part of this research, unless first approved by the commercial partners and annotated appropriately.

F. BENEFITS

This research project ideally enables DOD personnel to guide their interaction with the commercial sector, through the innovation ecosystem and existing tools. The DOD may find cost-savings while improving capability and function as a platform nears adoption and acquisition. In return, the commercial sector can gain early and valuable feedback on what elements of a platform may become requirements for acquisition. This research also incentivizes engagement with more than just commercial manufacturers of hybrid airships. There are a host of complementary technologies identified from which future research projects can be derived. Finally, this atlas aspires to encourage innovators not currently in a perceived position of influence to explore the art of the possible while maneuvering within the bureaucracy that is the U.S. military.

II. BACKGROUND

A. A COMPLEX THREAT

The United States is facing an increasingly complex security environment around the globe. Although, the global population is more connected than ever before, it also finding itself more fractured than previously experienced. The *Interim National Security Strategy* (NSS) defines this environment in part by rapid technological changes, pacing threats from adversaries in multiple domains, and a level of inter-state competition that is threatening global democratic foundations like never before (White House, 2021a). The strategy further describes how many of the greatest threats bearing down on the United States are not constrained by traditional borders or walls. This makes them hard to categorize and harder still to prepare for. The first step in understanding this new environment is to acknowledge how the distribution of power across the world is changing. But this is not a threat that the United States faces alone. The NSS reinforces the need to improve, strengthen, or rejuvenate alliances, agreements, and cooperative efforts to counter malicious actions of authoritarian nations like China, Russia, and North Korea. Of course, the NSS requires that long-term strategic thinking is applied in many areas, including diplomacy, economics, finance, information, and more. The military's role in the NSS is only one piece of what must be a seamless integration of many focus areas, continuously balanced for optimal response.

The summary of the *National Defense Strategy 2018* (NDS), published under former Secretary of Defense James Mattis, is currently guiding much of the strategic direction to which the U.S. military is aligning itself. The landscape in which the U.S. military currently finds itself operating is one of global competition, commonly referred to as Great Power Competition (GPC), with the Chinese and Russian governments fielding the immediate threats. The NDS outlines three distinct lines of effort to expand capability in this competitive space; improve the lethality of the joint force by rebuilding military readiness; strengthen alliances to attract new members.; remake the DOD's acquisitions and business practices to maintain technological superiority (Mattis, 2018). Secretary Mattis reminds all service members in this summary that "we must use creative approaches, make sustained investment, and be disciplined in execution to field a Joint Force fit for our time. One that can compete, deter, and win in this increasingly complex security environment" (p. 18).

Over the last twenty years, as we have been fighting wars in the Middle East, our competitive advantage over peer adversaries has eroded and the development of other military technologies suitable to compete against a peer adversary suffered (Goure, 2015). Mattis (2018) believed that inter-state strategic competition, not the global war on terrorism, had to become central theme of the NDS. Many experts agree that the U.S. is falling behind both technologically and operationally as the world has become progressively more complex. Our competitors are now operating in virtually every domain: land, air, maritime, space, and cyberspace (Clark et al., 2020).

The immediacy of a joint force that is capable of operating in all five domains (sea, land, air, space, and cyber) is echoed in the 2020 strategic document *Advantage at Sea: Prevailing with Integrated All-Domain Naval Power*. Written and published by the U.S. Navy (USN), Marine Corps (USMC), and Coast Guard (USCG), it is commonly referred to as the Tri-Service Maritime Strategy and its problem statement is:

> China and Russia's revisionist approaches in the maritime environment threaten U.S. interests, undermine alliances and partnerships, and degrade the free and open international order. Moreover, China's and Russia's aggressive naval growth and modernization are eroding U.S. military advantages. (2020)

The strategy states that the U.S. military does not have maritime dominance across the world, and certainly not in the areas where China and Russia operate. Through five lines of effort, the maritime components of the DOD hope to counter the pacing threats and avoid an armed conflict. The Joint Force, and particularly those of the maritime component, have a great deal of work they must accomplish to regain and maintain dominance across the globe. In particular, the Pacific regions and Arctic regions pose the most immediate challenges (Department of Defense, 2020).

B. CHALLENGES IN INDO-PACOM

During the Global War on Terror, an irregular warfare conflict concentrated in the Middle East, U.S. forces became habituated with a predictable mission and deployment cycle in a common region. While the U.S. gained valuable experience fighting an unconventional enemy, other near-peer competitors took advantage of the US's hyper-focus. The Chinese Communist Party (CCP) exploited the regular lack of U.S. naval presence within the U.S. Indo-Pacific Command (USINDOPACOM) to maneuver China into a dominating position. China has emerged as a regional juggernaut that has precipitously expanded its diplomatic, economic, and military power through gray zone activism below the threshold of armed conflict (Freier & Schaus, 2020). The U.S. now requires a more resilient, hypercompetitive USINDOPACOM Joint Force. Currently, the United States is out of position, both geographically and conceptually, to support and sustain forces over this vast region, limiting the ability of Combatant Commanders (COCOM) to deter the CCP. These disadvantages support the push from the DOD to develop and experiment with concepts such as technological innovation and cultural performance, which will generate a decisive military advantage (Mattis, 2018).

To put its sheer size into perspective, the USINDOPACOM area of responsibility (AOR) covers half of the earth's surface and more than 50% of the world's population. This AOR extends from the west coast of the U.S. to the western border of India and from Antarctica to the North Pole. There are 36 nations within the AOR, including several of the world's largest militaries and two of the three largest economies (US Indo-Pacific Command, n.d.).

Currently, U.S. forces are primarily postured in Northeast Asia, with a heavy concentration of assets on large bases in Japan, Korea, Guam, and Hawaii. The CCP's advancement of precision weaponry has placed U.S. forces in these areas in immediate danger. In the event of armed conflict, the Navy and Marine Corps must navigate over long distances to augment and sustain these forces. The current capabilities cannot sufficiently conduct all-domain operations to halt China's campaign to control this region (Freier & Schaus, 2020).

C. CHALLENGES IN THE ARCTIC CIRCLE

In 2018, President Xi Jingping of the CCP outlined an Arctic extension of the Belt and Road Initiative (BRI) (Lim, 2018). President Xi set forth the resolve of his party to build a "polar silk road" that would increase access, while decreasing transit time, to more than 75% of the world's countries. However, China does not have any land or borders that fall within the Arctic Circle, and instead must rely on relationships and a dominant presence to establish and maintain this polar silk road. As a nation with little to no Arctic equipment or experience, the CCP has a long road ahead to become a dominant player in the Arctic. But both the CCP and the Russian government of Vladimir Putin have other reasons for wanting to establish dominance in the Arctic. Beneath the ever-changing, fragile Arctic eco-system is an almost unimaginable treasure chest.

According to the U.S. Navy's arctic guidance "the region holds an estimated 30% of the world's undiscovered natural gas reserves, 13% of global conventional oil reserves, and one trillion dollars' worth of rare earth minerals" (Department of the Navy, 2021, p. 6). If the polar ice caps continue to melt as they do, these vast caches of valuables will become easier and cheaper to remove from the under the ice pack. While the U.S. military does maintain some units in Arctic regions full-time, it is simply not equipped conducted sustained combat operations within the Arctic circle. The guidance advises that Arctic environments pose singularly unique challenges for vehicles, personnel, and energy. In some cases, our existing equipment can be adapted to function in the Arctic, but in other instances, this is simply not cost effective and time efficient. To meet the changing climate conditions, posture forces for sustained operations, and maintain uninhibited freedom of movement in the Arctic region, the U.S. military will need to consider what new capabilities it can leverage in short order, while maintaining awareness of its sustainability and climate impact (Department of the Navy, 2021).

D. CLIMATE SECURITY

Climate security has recently become a priority for the military. *The Department of Defense Climate Adaptation Plan* has identified climate change as an existential threat to U.S. national security that will influence our force operationally and financially. Climate change is reshaping the strategic, operational, and tactical battlespace, adding a layer of uncertainty that can contribute to global political, economic, and social instability that the DOD may be called upon to address (Office of the Under Secretary of Defense for Policy, 2021).

In Figure 1, the DOD identifies climate change hazards and mission impact with increased requirements for transportation capabilities in harsh and constrained environments.

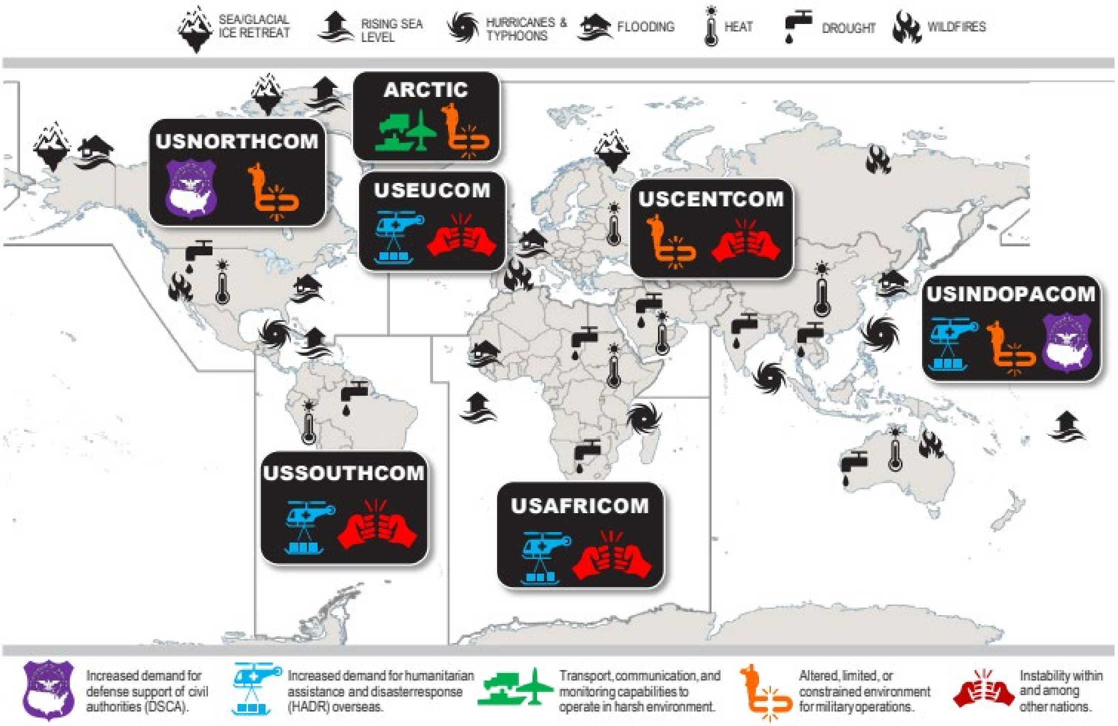

Figure 1. Climate Change Hazards and Potential Impacts of DOD Missions. Source: Office of the Under Secretary of Defense (Acquisition and Sustainment) [OUSD(A&S)] (2021).

In preparation for an increased requirement to support these unique missions, the DOD has the challenging task of identifying platforms capable of meeting current and future operational needs while ensuring they reduce adverse effects on the environment compared to existing assets. The DOD has generated the climate adoption framework, depicted in Figure 2, to address these requirements.

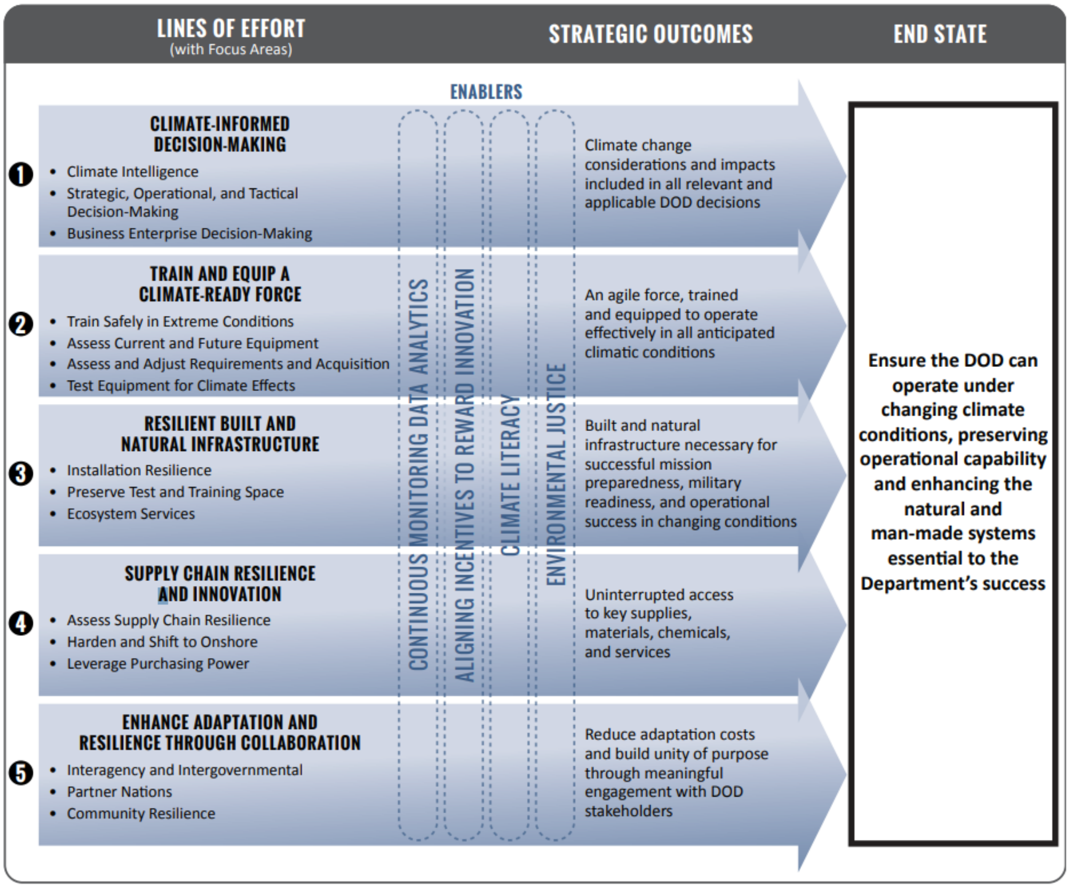

Figure 2. DOD Climate Adaptation Strategy Framework for Current and Future Force Decision. Source: OUSD(A&S) (2021).

A key enabler to operating under these changing climate conditions is the DOD's commitment to allocate resources to accelerate the growth and development of new, eco-friendly capabilities (OUSD(A&S), 2021). Emphasis is placed on partnering with industry to stimulate the progress of dual-use technologies. With aging mobility platforms and turbulent fuel prices, the DOD is at a pivotal moment where partnerships with industry to capitalize on emerging technologies are critical to maintaining a technological advantage over adversaries. We must place more emphasis on capturing the full costs of greenhouse gas emissions when evaluating current and new platforms (Exec. Order No. 13990, 2021).

This presents a significant challenge, as the DOD consumes more energy than any other federal agency, accounting for 77% of the federal government energy consumption (Greenley, 2019). As we identify unique mission requirements for the DOD, we can expect the energy requirements to increase if we do not invest now in technologies to reduce our carbon footprint.

E. MARINE CORPS OF THE FUTURE

After more than 20 years of combat operations in the Middle East, the United States Marine Corps must now shift its focus to GPC with a revived emphasis on the Indo-Pacific region. However, the current force structure and mobility platforms cannot support future operating concepts (Berger, 2019). Specifically regarding mobility, there is a shortfall in "affordable, distributable platforms that will enable littoral maneuver and provide logistical support in a very challenging theater for the kind of operations envisioned in our current concepts" (Berger, 2019, p. 2). In September 2019, the Deputy Commandant for Combat Development and Integration (DC CD&I) established twelve Integrated Planning Teams (IPT) to assess current and future force design recommendations. Per General Berger's guidance, one of the twelve areas to be evaluated was logistics capabilities supporting the Fleet Marine Force (FMF). With a renewed focus on the USINDOPACOM, the Marine Corps faces the daunting challenge of logistically supporting sustained distributed operations.

In response to these geographical challenges, the Marine Corps created the Expeditionary Advanced Basing Operations (EABO) and Logistics in the Contested Environment (LOCE) concepts (Marine Corps Warfighting Lab, 2018). Based on the well-proven Marine Air-Ground Task Force (MAGTF) structure that is used to organize all Marine forces, EABO and LOCE allow the Marine Corps to maintain a forward presence in contested environments.

To regain a competitive advantage over our adversaries, the Marine Corps' Deputy Commandant, Installations and Logistics (DC I&L) began adopting a new model of hybrid logistics (Deputy Commandant, Installations and Logistics, 2016). The advancement of our adversaries' defensive capabilities has reduced our superiority in the sea and air freedom of navigation, which means we can no longer rely on sustained dominance in each domain. The FMF now requires high levels of mobility, survivability, and lethality. Forces must now function disaggregated over multiple regions with the ability to rapidly reposition, requiring modular logistical capabilities that can still move heavy equipment loads to support a distributed force design (Haines & Jones, 2017).

In future military operations, adequate logistics support will require mobility, resiliency, and sustainability in austere environments to extend our operational reach with a blend of "old and new" logistics (Deputy Commandant, Installations and Logistics, 2016). The ability to sustain forces ashore is a determining factor in the operational reach and influence of a combatant commander (Morgan III, 2013). Our current platforms are more advanced and more capable than ever before. However, these tactical platforms, like the F-35C, require a resilient network of supply chain throughout the region to keep them in fighting shape. Hybrid logistics must meet these enduring requirements and strive to improve distribution to enhance the endurance of the MAGTF (Haines & Jones, 2017).

F. NAVY OF THE FUTURE

The U.S. Navy is transitioning its forces to face what it believes will be the adversaries of the future. In January of 2021, the Chief of Naval Operations (CNO), Admiral (ADM) Michael Gilday established the strategic direction that he sees for the USN. He opens his guidance by reminding sailors that America is a maritime nation and both her prosperity and security depend on control of the seas (Gilday, 2021). He further identifies China as the most significant long-term threat and establishes how the men and women of the U.S. Navy must be ready to meet that pacing threat. To achieve a naval force with the capacity to synchronize lethal and non-lethal fires across all domains, innovative approaches are required to harness emerging technologies and processes.

In creating the Navy of the future, emphasis is placed on the integration of unmanned platforms into the current air, surface, and subsurface fleets. ADM Gilday sees a crucial point of fusion in this area:

> A larger, hybrid fleet of manned and unmanned platforms—under, on, and above the sea—that meets the strategic and operational demands of our

> force. We will deliver the Columbia-class program on time; incorporate unmanned systems into the fleet; expand our undersea advantage and field the platforms necessary for distributed maritime operations. (2021)

To support the Distributed Maritime Operations (DMO) and LOCE concepts, the future Naval force will need to increase the number of ships in the fleet, while decreasing their size. A larger pool of more affordable, all-domain integrated manned and unmanned systems will enable distributed operations to occur in a faster cycle.

Like Gen. Berger, ADM Gilday references the Tri-Service Maritime Strategy as the principal document directing much of the Navy's preparation for the future fight. One of the primary drivers will be the integrated all-domain naval power contribution of the Navy. Like the Marine Corps, the future Navy will need a more robust and resilient way to support its fleet, especially if it becomes smaller and more numerous. The Navy is currently developing a plan to upgrade the infrastructure that services its fleet, which requires significant fiscal investment (Gilday, 2021). While this investment at home may improve the maintenance and sustainment of the overall fleet, it does not solve the problem of replenishment at sea. No matter the technology that is adopted, the ability to replenish and rearm vessels at seas remains a continuing challenge.

G. SUMMARY

The maritime Joint Force of the future must be agile, resilient, and integrated in order to conduct the distributed operations envisioned in the NSS, NDS, and the Tri-Service Strategy. Although the U.S. military has shifted the majority of its focus to USINDOPACOM, new operational requirements and threats shifting towards the Arctic region will press our forces with new challenges. To provide the type of All-Domain, Integrated Joint Force called for by Navy and Marine Corps leadership, new and unfamiliar pathways will have to be forged. Resilient, sustainable platforms will become crucial to a world that somehow seems bigger than ever before. But unlike decades past, the DOD now has the added responsibility of being very aware of its impact on climate security. The DOD now has the social responsibility to be hyper aware of how it's weapon systems and platforms impact the physical ecosystems in which they operate and be able to articulate the long-term effects of its choices.

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III. LITERATURE REVIEW

A. THE EARLY BATTLE FOR THE SKIES

Although they were not the first lighter-than-air (LTA) contraptions to take flight, airships made a surprisingly early appearance in the pursuit of powered flight. But since the first flight of Count Ferdinand von Zeppelin's Luftschiff Zeppelin (LZ-1), seen in Figure 3, almost 120 years ago, the airship industry has risen, struggled, faltered and all but vanished (Rose, 2020). Regardless, airships have fascinated and amazed humanity for more than a century.

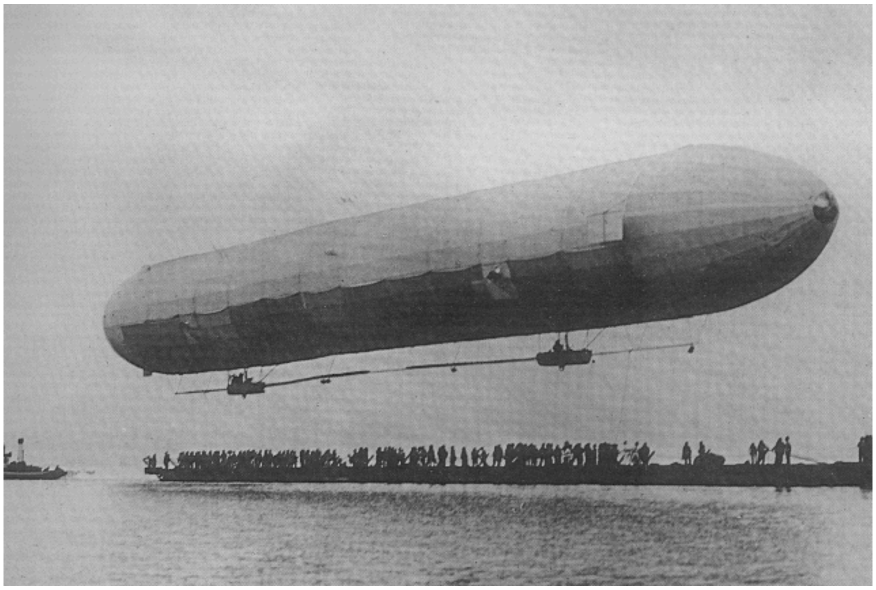


Figure 3. Luftschiff Zeppelin LZ-1, Friedrichschafen, Germany, 1900. Source: www.airships.net (2021).

For many casual observers, it is easy to see why the airship is not the titan of transport that it was expected to be. Although airships, and primarily those of Count Zeppelin's design, logged many firsts far before airplanes did, they are still not considered competitive platforms for the speed and necessity of today's global economy (Rose, 2020). For decades, the perspective and public optics of airships have been a significant contributor to its lack of adoption. Most people will identify an airship as either the

Goodyear Blimp, or the *Graf Hindenburg*. One is an understandable, if uninformed, explanation and the other a disaster that has held sway over the commercial airship industry since 1937. The hydrogen-fueled inferno that claimed the lives of 36 passengers and crew, subsequently broadcast on televisions across the U.S., was one of the most common references to the danger of airships. For years, the destruction of the *Graf Hindenburg* was synonymous with the death of airships in the eyes of the general public (Rose, 2020). But the path to their demise has been oversimplified, which has frustrated their return to the world stage for almost 80 years. Rose (2020) describes how Juan Trippe, the founder of Pan-American Airlines, skillfully manipulated the air mail market to build an airline that rapidly forced out Zeppelin's designs in the 1920s and 30's. As he slowly turned lucrative government air mail contract routes into cargo and then passenger routes, he bought or forced out his competition along the way. In the end, Juan Trippe's business practices, not the loss of the *Graf Hindenburg*, had far more influence in driving the giants of the sky away from public view.

With hydrogen currently outlawed as a lifting gas in most countries, non-flammable helium is now the buoyant gas of choice. The science behind LTA flight dynamics, known as hydrostatics, is universally accepted. According to the *2011 Future Deployment and Distribution Assessment* (FDDA) released by U.S. Transportation Command's (USTRANSCOM) Joint Distribution Process Analysis Center, "an airship generates lift from gases contained in an envelope. It can be steered or controlled by rudder or thrust from engines" (p. 2-1). In the design of powered LTA craft, as seen in Figure 4, hybrid airships fall into the non-body of revolution (BOR) category, meaning that their designs are unconventional. In this case, conventional design, or BOR, refers to the common cylindrical shape with which airships have historically been designed.

In their research publication, Pant and Manikandan M. (2021) present a very thorough history of hybrid airships. Their research primarily focuses on the design methodologies of hybrid airships, of which there are multiple variations. However, the researchers outline several key advantages that hybrid airships have over conventional LTA craft. Among these, the authors identify heavy-lift capability, better controllability, and a lesser dependence on ground infrastructure as key attributes. Within the design methodologies, the research paper describes the multi-lobed design, which can be seen in Figures 5 and 6. Multi-lobed hybrid airships inherently support several design aspects that are crucial for the U.S. military to consider. Multi-lobed airships have an air cushion landing system (ACLS), instead of landing gear or skids, which enable the airship to land on most surfaces, including unprepared ground, ice, and water. Multi-lobed designs are also extremely large, which allows for the installation of "huge cargo bays with loading ramps at each end" (M. & Pant, 2021, p. 8). Pant and his colleague complete their research paper by noting that future design challenges for hybrid airships include an extensive market analysis to understand market size and segments, as well as an analysis of the design process that accounts for existing ground infrastructure that could support craft of the airships size. Both areas informed our research.

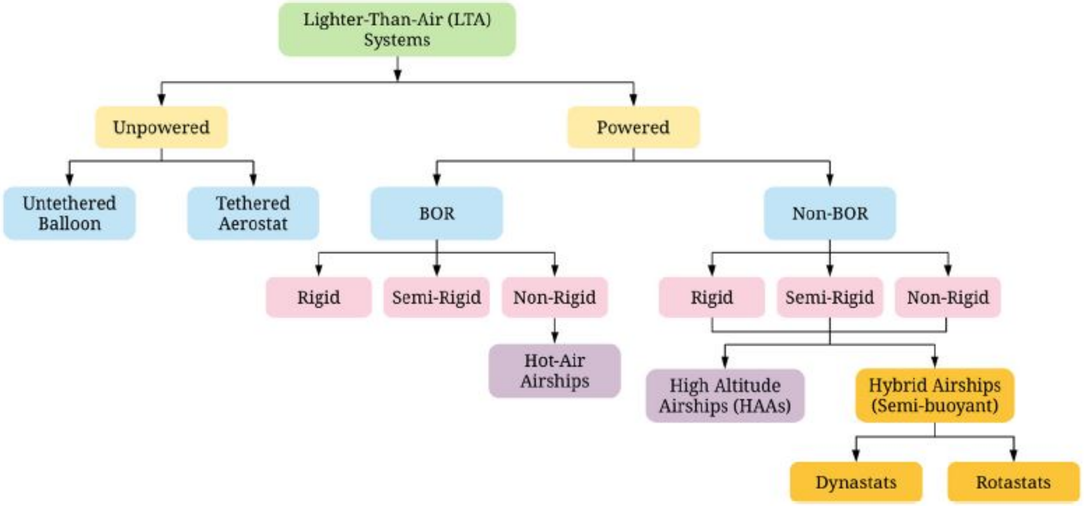


Figure 4. Airship Categorization. Source: M. & Pant (2021).

Figure 5. Multi-lobed Hybrid Airship Design, Lockheed Martin P-791 Prototype. Source: M. & Pant (2021).

B. HYBRID AIRSHIPS AND THE DOD

When USTRANSCOM conducted its assessment, it was not interested in the entire family of airships. Instead, the FDDA was evaluating hybrid airships specifically. The assessment (2016) explains:

> Conventional airships are lighter-than-air vehicles and fly because they are buoyant—that is, they weigh less than the air they displace. In contrast, airplanes are heavier-than-air and fly because of aerodynamic forces over the wings. Hybrid airships combine the characteristics of lighter-than-air and heavier-than-aircraft. Hybrid airships achieve lift from lighter-than-air gas, such as helium, and from aerodynamic forces. Sometimes, a third means of generating lift comes from vertical thrust—direct propulsive lift. Unlike conventional airships, hybrid airships ascend and descend heavier-than-air. (USTRANSCOM)

It is this key difference, that hybrid airships are heavier-than-air, that makes them unique in the LTA family and a promising future mobility platform for the DOD.

The FDDA (2011) was conducted in two phases and aligned to future DOD operational concepts that spanned from 2017–2030. Phase I of the assessment "identified capability gaps and developed assessment conditions that focused on 3 theme areas: austere access and speed, mounted vertical maneuver (MVM), and seabasing" (p. iii). To accomplish Phase I, USTRANSCOM looked at private (commercial) sector technologies that could be used to address the capability gaps. Hybrid airships were among the five platforms identified. Phase II "evaluated the technologies to assess their utility in satisfying the future capability needs represented by the selected themes. (They) conducted both qualitative and quantitative assessments" (p. iv). The assessment determined that "hybrid airships were the most promising platform type. Their highly positive performance in the quantitative assessment was bolstered by a fairly positive qualitative assessment" (p. iv).

Among the outputs of the FDDA (2011) was the intention of shaping an atlas for "future deployment and distribution" (p. 1-3). To further support this, the assessment recommended three follow-on actions, two of which influenced our research. The first was "investment in the development and integration of critical Airship Technologies, culminating with building and testing a cargo carrying demonstrator" (p. 4-6). The second recommendation was "form a public-private partnership to share development costs and risks" (p. 4-6). Although the goal of the FDDA was not to map how the DOD could better engage with the commercial sector, it places heavy emphasis on the need to work with manufacturers to bring hybrid airships to maturation.

A 2012 U.S. Government Accountability Office (GAO) report stated that between 2007 and 2012, close to $7 billion dollars was invested in airship research and development across 15 different programs, with close to $1 billion dollars of that dedicated to hybrid airship programs (Chaplain, 2012). The report also identified that the DOD did not have a comprehensive picture of these research efforts, nor was there a coordinated attempt to include hybrid airships in strategic documents or policy. The GAO (2012) report identified that many stakeholders within the DOD had an interest in seeing hybrid airships and other LTA platforms come into service. There was enough interest that in June of 2012, at the direction of the National Defense Authorization Act (NDAA), that the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) was designated as the oversight and coordination office for all DOD airship-related efforts (Chaplain, 2012).

Lynch (2011) showed that hybrid airships would be more cost-effective, with less total cargo movement time, than traditional airlift and sealift platforms in humanitarian aid and disaster relief missions. Several years later, Morgan's (2013) research focused on the feasibility of hybrid airships' ability to support supplies being delivered to an inland area from an amphibious force, also known as joint-logistics-over-the-shore (JLOTS). He determined that hybrid airships can increase throughput compared to water vessels and land-based systems. Most recently, Gilbert (2020) used the Rapid Course of Action Analysis Tool (RCAT) and simulations to study the optimal number of hybrid airships that can be used to augment current strategic lift assets. Using the deployment scenario of a Stryker Brigade Combat Team (BCT) from Washington State to the Philippines, Gilbert determined the optimal combination of planes, ships, and hybrid airships. Each of these studies relied on assumed payload capacities, usually in excess of 100 tons, that the DOD had identified as being useful. Very little input from the commercial sector was used for these research papers. In addition, these studies did not address hybrid airships as a dual-use technology and the implications of commercial development instead of military development.

One of the most commercially impactful hybrid airships programs funded by the DOD was the Long Endurance Multi-Intelligence Vehicle (LEMV). Funded primarily by the U.S. Army's Space and Missile Defense Command, the LEMV was supposed to be an unmanned, long-endurance, intelligence, surveillance, and reconnaissance (ISR) platform for use in Afghanistan (SAIC, 2016). The LEMV project attracted the attention of major defense contractors Lockheed Martin and Northrup Grumman. Northrup Grumman ultimately won the contract. In partnership with their subcontractor, Hybrid Air Vehicles (HAV) of the United Kingdom and produced a full-size aircraft, seen in Figure 6. According to the comprehensive SAIC report commissioned by USTRANSCOM, a $517 million dollar contract was awarded in June of 2012, but then cancelled in February of 2013. The project was declared to be 10 months behind schedule, with issues in fabric production, customs delays with parts, work delays due to inclement weather, and challenges with first-time integration and test processes (SAIC, 2016). Although there were other projects, like the U.S. Air Force's Blue Devil 2, that closely mirrored LEMV, few had such measurable impacts on the future development of hybrid airships by the commercial sector as did the LEMV project. Although the cancellation of the LEMV was a significant blow to the DOD's adoption of hybrid airships, it did not signal the end of the commercial industry's pursuit. The commercial hybrid airship industry as it exists today is explored more in Chapter IV.

Figure 6. Long Endurance Multi-Intelligence Vehicle (LEMV). Source: Szondy (2013).

C. INNOVATION ECOSYSTEM CONSTRUCT

Understanding the history of a technology and the DOD's interest and investment in that program is crucial to define what the future of that technology or program may look like. As of February 2022, the DOD innovation ecosystem looks vastly different than it did in 2012, when the LEMV contract was out for solicitation. In both the SAIC (2016) and GAO (2012) reports, there was a repeated emphasis on the need for DOD to engage with the commercial sector more proactively for the development of a platform as large as a hybrid airship. Today, there are more DOD organizations facilitating research and development pathways with the commercial sector. However, to utilize these innovation organizations to the maximum extent possible, servicemembers must understand how an innovation ecosystem comes to be and what factors may influence its growth.

1. Porter's Five Forces

In 1979, the Harvard Business Review (HBR) published an article by Michael Porter titled *How Competitive Forces Shape Strategy* which catalyzed a revolution in business strategy theory. Porter's article, his first ever in the HBR, was intended to give an organization tools to understand and cope with competition, which Porter describes as the essence of strategy formulation (Porter, 1990). What followed from this initial article was a slew of expansive writings from Porter on the topic of strategy for not just business, but nations as well. His landmark publication, *The Competitive Advantage of Nations* (1990), brought out the models that Porter believed any organization, including governments, could use to identify and manage their competition in a given market. Figure 7 shows the most common model, which is often referred to as "Porter's Five Forces."

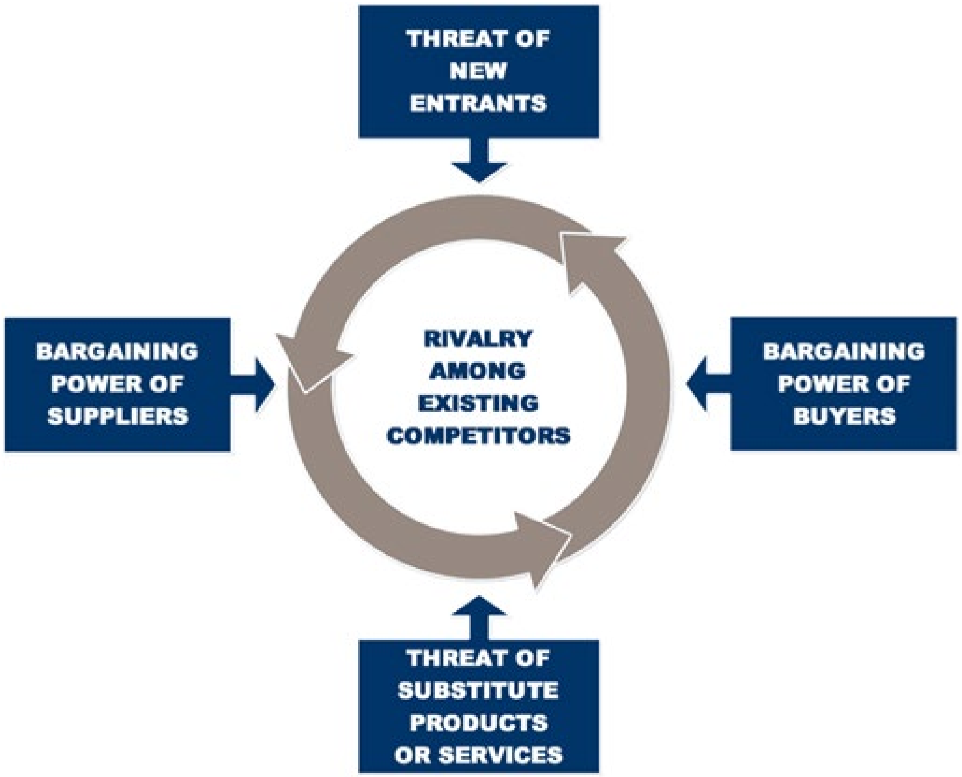


Figure 7. Porter's Five Forces Model. Source: Porter (2008).

At its core, the five forces model is a qualitative analysis tool. Porter (2008) posits that an understanding of these elements allows an organization to determine which market forces are the most prominent. Each industry is obviously different and cannot be simply or consistently quantified. However, the five forces tool can allow the most significant factors to percolate to the surface for consideration and action in the development of a strategic market plan. In using the five forces model, DOD leaders can consider how a technology or capability may evolve, grow, or change through influences that are prevalent in both the commercial and government sectors. Although DOD personnel are not expected to fully understand or act as economists, the five forces model nonetheless offers a window into the commercial sector and how it may affect a future platform. If used in collaboration with the commercial sector partners, it can certainly bring illumination to pathways within the atlas, as shown in Sections V and VII.

2. Barriers to Entry

In the same 2008 article, Porter also identifies what he considers the six major barriers for entrants into a market. Barriers to entry constitute the most significant hurdles that will likely dissuade or prevent new manufacturers from entering a market (Porter, 2008). However, Porter's perspective is built from analysis of commercial markets and firms and did not include a consideration of firms doing business with the DOD or the DOD itself.

The GAO delivered a report to the U.S. Senate Armed Services Committee that outlined the findings of interviews with 12 small but innovative companies that have avoided pursuing business opportunities with the DOD (Sullivan, 2017). In these interviews, the report compiled what barriers or risks these smaller companies identified. A comparison of these barriers as identified by Porter and the GAO are found in Table 1.

Table 1. A Comparison of the Barriers to Entry

Michael Porter's Barriers to Entry	**Challenges that Deter Companies from Developing Products for Military Use**
Economies of scale	Complexity of DOD's process
Capital requirements	Intellectual property rights concerns
Access to distribution channels	Inexperienced DOD contracting workforce
Product Differentiation	Unstable budget environment
Cost disadvantages independent of size	Government-specific contract terms and conditions
Government policy	Long contracting timelines

3. Disruptive Innovation

Christensen and Bower (1995) introduced disruptive innovation, defined as "a process whereby a smaller company with fewer resources successfully challenges established incumbent businesses" (p. 1). New entrants will target market segments considered too small or unprofitable by incumbent firms. Working in this smaller target segment, the entrant can build an understanding of the consumers in the market and begin making improvements to their product. A new entrant has achieved disruption when their product offerings have risen to the quality of their incumbents but have maintained the original market segments. At its core, disruptive innovation refers not necessarily to a technology, but instead to a business model. DOD personnel can analyze and understand the risk that may be faced by a market entrant to determine potential pathways within our atlas.

4. Evolution of Technological and Market Developments

When a new technology is invented, it is only the beginning of a long journey to achieve adoption and widespread acceptance in the marketspace (Bayus et al., 2007). The number of sales in an industry can indicate when a product has reached acceptance. While creating an atlas for the DOD's interaction with the commercial sector, we must be aware of this general pattern leading to market adoption. If the DOD sees great potential in an emerging technology, it must be willing to consider stimulating the market as part of a more rapid adoption strategy, while simultaneously reducing risk for commercial developers. DOD stimulation of the market potentially speeds up the technology progress and subsequently reduce risk of the technology however, decisions to stimulate a market must be made carefully and ethically.

For a technology to form a new market, there is a critical point in the relationship between the price, the number of competitors, and the overall number of sales in an industry. There is an initial incubation period between the development and commercialization of a product (Bayus et al., 2007). Sales are low during this period and there is relatively little competition. As more firms enter the market, the increasing competition pushes prices down, which typically increases sales. While past research has demonstrated that sale will take off based on new firm entries and price decline, Bayus et al. (2007) found that sales will significantly increase in a new market when there is an increasing innovation activity in addition to the entry of large firms. This may mean that DOD innovation efforts can have longer term market impacts, known as downstream effects.

Modeling the downstream effects that the DOD can have on the hybrid airship's commercial market growth is similar to the idea of a demand-side strategy to spur innovation in critical areas for the DOD. Dew's (2012) research on the strategic acquisitions of unmanned systems for the Navy presents an argument for enabling demand-side factors that may help defense transportation sustainability. If it pursues significant procurement, the DOD can find itself in the role of venturesome user, meaning they become a lead user of the technology (Dew, 2012). If the DOD becomes that lead user, it can contribute to the market demand. The DOD is generally viewed as a source of stability through long-term commitments, and could do the same for hybrid airship production. The by-product of the DOD being a lead user is the potential to attract a critical mass of other users (Dew, 2012). If that comes to pass, the result could be improvements in the learning curve rate and reduction in cost

a. Technology Impacts on New Markets

The driving forces behind a new technology reaching the market can broadly be classified as either a technology push or demand pull (Geroski, 2003). Demand will often "pull" the innovation out of R&D labs to the market if the newly developed technology meets an existing need. In a growing market, strong demand signals can stimulate the industry to invest more in product development. Alternatively, Geroski explains that supply can "push" the new technology into a market space because it better meets a current need or addresses a new need, creating a new market altogether. Duysters (1996) proposes that technology development is an endogenous factor influenced by firms' existing market structure and actions, allowing for new technologies to destroy existing industries and create new markets.

b. Technology Trajectories

Technological innovation follows a pattern called a technology trajectory where a string of innovations will follow one another, based on the previous engineering efforts (Geroski, 2003). Figure 8 represents the trajectories that follow-on technologies may take after a breakthrough idea. He explains that progress along the main technology trajectory results in more research opportunities, which in turn create various additional technology branches, all based upon the engineering efforts of the initial breakthrough technology. Geroski establishes that even if the discovery of a technology may seem accidental, it is rooted in a specific technology that received traction from interested parties. Throughout the atlas, we see examples of these technology trajectories, particularly in alternative energy analysis.

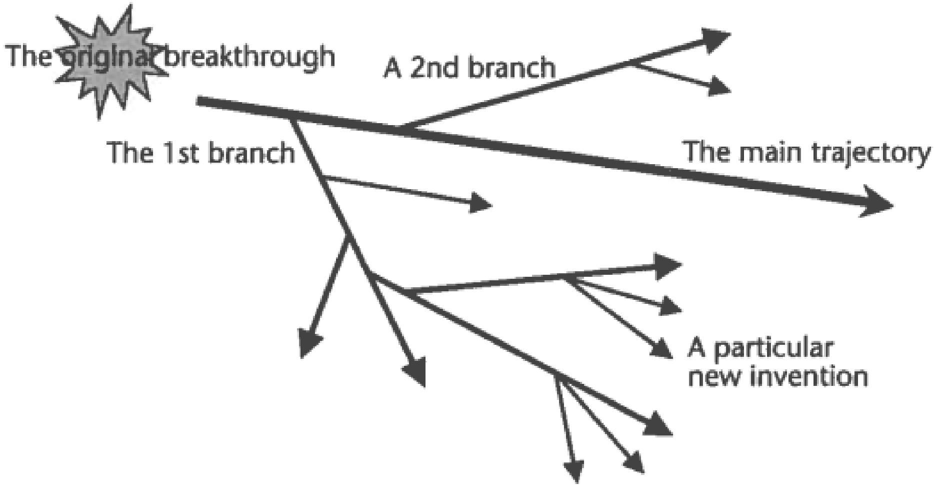


Figure 8. Technology Trajectories. Source: Geroski (2003).

c. Role of Incubators for Breakthrough Technology

The DOD and academia play an essential role in stimulating these technological trajectories (Duysters, 1996). A new technology and its potential market can make incumbent firms hesitant to support early development. In these moments, Duysters suggests that academic and government entities can act as "incubators," which will stimulate competitive firms to invest in developing the technology. With an increased level of competition comes a natural drive for firms to want to stay ahead and capture as much of their market share as they can. This naturally drives these firms to increase the quality of the product, which results in technology progress overall. It is reasonable to assume that if the DOD identifies a technology of interest early enough, engagement with emerging firms will stimulate the technology's growth. For example, the requirements of the Apollo program at the National Aeronautical and Space Administration (NASA) lead to the miniaturization of computers. This government-led effort had significant spillover effects, as the miniaturization of these systems into the 1960s resulted in commercial firms being able to afford and utilize these computer systems. (Mazzucato, 2021)

D. TECHNOLOGY ADOPTION AND PROGRESS

There is never a guarantee of any technology being adopted in either the commercial or military sectors. However the DOD can utilize proven theories and models for a degree of predictability when determining the viability of a new technology (Nagy et al., 2013). Understanding and applying these principles gives context to the development of our atlas.

1. Dynamics of Innovation in Industry

Utterback (1994) theorizes that the "rate of major innovation for both products and processes follow a general pattern over time, and that product and process innovation share an important relationship" (p. xvii-xviii). Utterback's model has proven helpful in explaining the rate of technological innovation as an aspect of industrial competition over time. His model encompasses three phases: fluid, transitional, and specific. Figure 9 provides a visual description of the Utterback model.

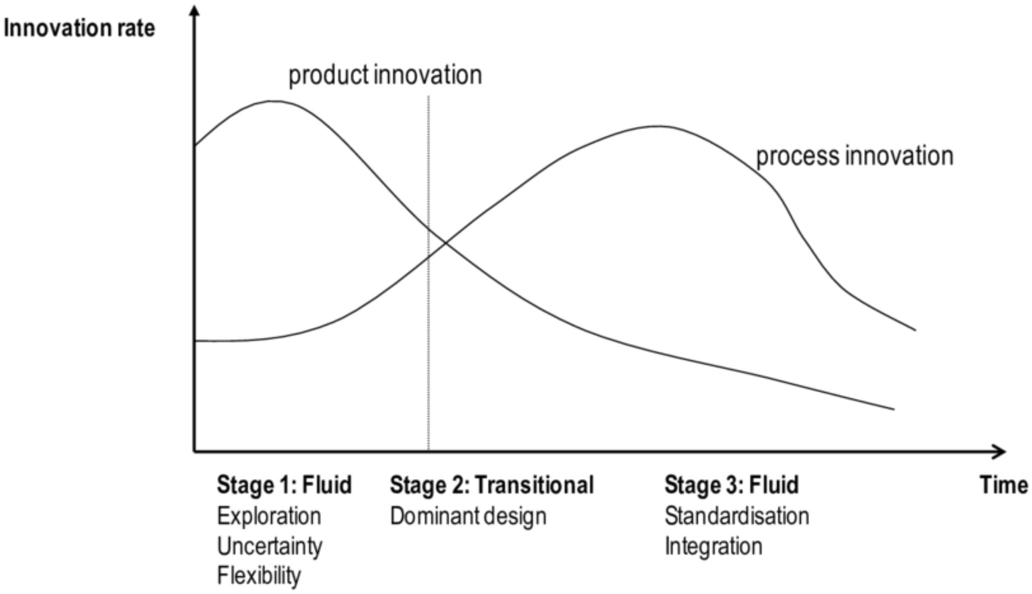


Figure 9. Utterback Model of the Dynamics of Innovation. Source: Utterback (2004).

The fluid phase occurs during the foundational years of a new product when there is a large amount of design experimentation. This phase is defined by significant uncertainty and much of the focus is on the product rather than process, which creates rapid advancements in product innovation (Utterback, 1994). The fluid phase leads to the transitional phase when major product innovation begins to slow and process innovation rapidly gains momentum.

At the intersection of product and process development, there emerges a dominant design, which Utterback (1994) describes as the product that wins the affinity of the market. This is the beginning of the transitional phase. As a dominant design is accepted, the process innovation curve steepens while competing parties rush to produce their product as quickly and cost-efficiently as possible, without a loss of performance. Competing firms begin focus on adapting their strategy to meet the consumer's needs, which leads to the final phase (Utterback, 1994).

In the specific phase, Utterback (1994) asserts that both the product and process innovations have reached a certain level of maturity. The focus for industry competitors now becomes cost and volume of product. According to Utterback, technological innovation slows and design improvements incremental. The phases of the Utterback model demonstrate a pattern of technological innovation though not all industries will fully participate in each phase. Utterback (1994) believes that a company's strategy may differ depending on at what phase they enter a market. The introduction of a radically new technology can completely change the dynamic of a market, shuffle the industry leaders, and start a new cycle of product innovation.

2. Technology S-Curve Defined

Christensen (1999) defines a technology S-curve as, "an inductively derived theory of the potential for technological improvement in the performance of a product or process over a given period of time or resulting from a given amount of engineering efforts differs as technologies become more mature" (p. 392). Figure 10 depicts the technology S-curve, which presents an "S" shape because initial advancements in the technology are relatively slow. As more knowledge is gained about this new technology, the curve steepens, and performance begins to improve as the technology is diffused throughout the industry (Sahal, 1981). Eventually the technology reaches its mature stage, where it's natural limit is met. Christensen (1999) explains greater levels of time and engineering effort are required in this maturity stage to make incremental improvements in the technology's performance. Foster (1986) uses the technology S-curve to explain this decision as the reason why new technologies are often brought into an industry by an entering firm, rather than an incumbent firm. If the leading incumbent firms fail to identify or respond to a new technology in a timely manner, they can lose their position of dominance within an industry.

The information technologies and disk drive industry provided empirical evidence to support this theory, demonstrating its validity as a robust tool that is used in multiple industries to help forecast technological maturity (Scillitoe, 2013). Becker and Speltz (1983) reference commercial sector applications of the technology S-curve for industry leaders to understand how to manage technology and allocate resources to maintain a competitive advantage. If applied appropriately and objectively, it can be a powerful analysis tool and one that the DOD should employ frequently.

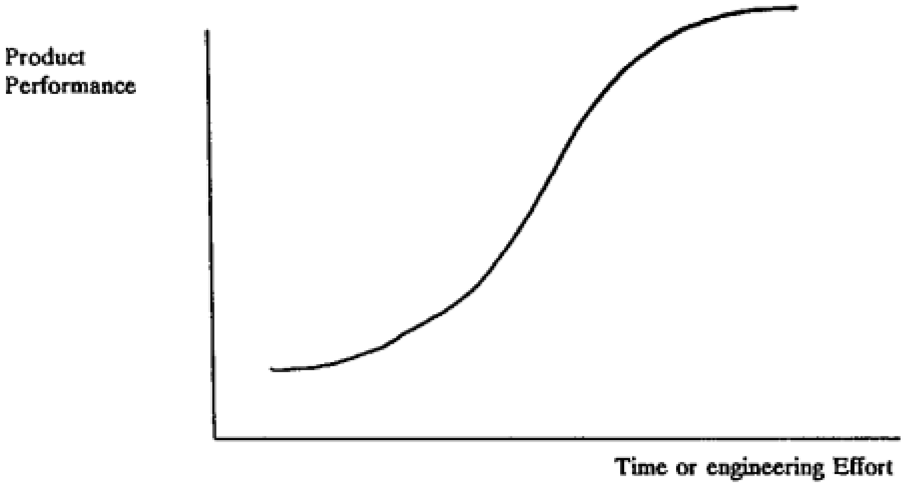


Figure 10. Technology S-curve. Source: Christensen (1999).

Like all theories, the technology S-curve does have limitations, namely that the true limits of a technology are simply unknown (Schilling & Esmundo, 2009). This makes it difficult for firms to identify when the right time is to switch from an old to new technology.

> Decisions about whether to extend the performance of a given technology for another product generation or to switch to a new and more promising technology must be made component-by-component, year-by-year, in the real world of technology and product development. (Christensen, 1999, p. 385)

Complex systems, like a hybrid airship, have multiple components which will be in various stages of maturation. The DOD cannot accurately assess the airship without considering the capabilities and potential improvement of these components along the way.

3. Typologies of Technological Change

Overall performance improvements stem from the interaction of component and architectural technologies, which Christensen (1992) explains as a factor in new technologies eventually being favored over mature technologies. He employed four typologies of technical change which were initially proposed by Henderson and Clark in 1990. The first typology, architectural change, involves rearranging how components relate within a product's design, while their design remains unchanged. Modular innovation, the second typology, is a fundamental change in the technological approach, while the architecture remains unchanged. The third typology is incremental change, where components are improved within the system design without significant changes in their relationships. Finally, radical innovations indicate where both the system design and the components are changed. Christensen (1992) explains that these typologies are neither sequential nor mandatory, but instead what could be experienced in the process.

To understand a single technology's development, we must understand which individual components are critical to the system's overall ability to meet performance requirements. Figure 11 from Christensen (1992) demonstrates technology extensions and substitutions at the component and architectural level. There are numerous incremental improvements to a particular technology, represented by the dots above the S-curves. When a new dominant technology is developed, a firm will transition to this new technology, making the first technology inferior.

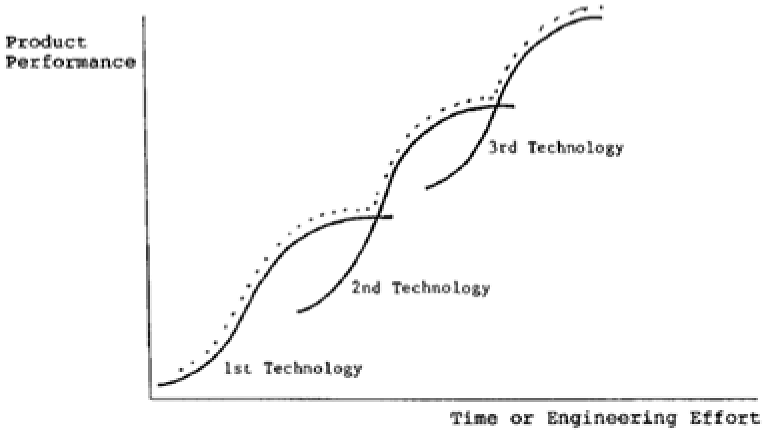


Figure 11. Prescriptive S-curve Strategy. Source: Christensen (1992).

For the DOD to keep pace with cutting-edge technologies, military professionals must be aware of the architectural trajectories of technology while also maintaining awareness of which individual components are critical to the system's overall ability to meet performance requirements.

4. DOD Application of Learning Curves

The GAO Cost Estimating and Assessment Guide (2020a) states a learning curve occurs in production based on the premise that:

> As people and organizations learn to do things better and more efficiently when performing repetitive tasks, a continuous reduction in labor hours from repetitive performance in producing an item often results from more efficient use of resources, employee learning, new equipment, facilities, or improved flow of materials. (GAO Cost Estimating and Assessment Guide 2020a, p. 119)

Typically, when the government conducts cost estimates for a new platform, a specific quantity is expected to be bought over time. The guide explains that earning curves are used to determine the first unit, average, and individual unit costs for a clearer picture of the overall costs (2020a). Figure 12 from the guide depicts how different learning curve rates affect the cost and time it takes to produce a product.

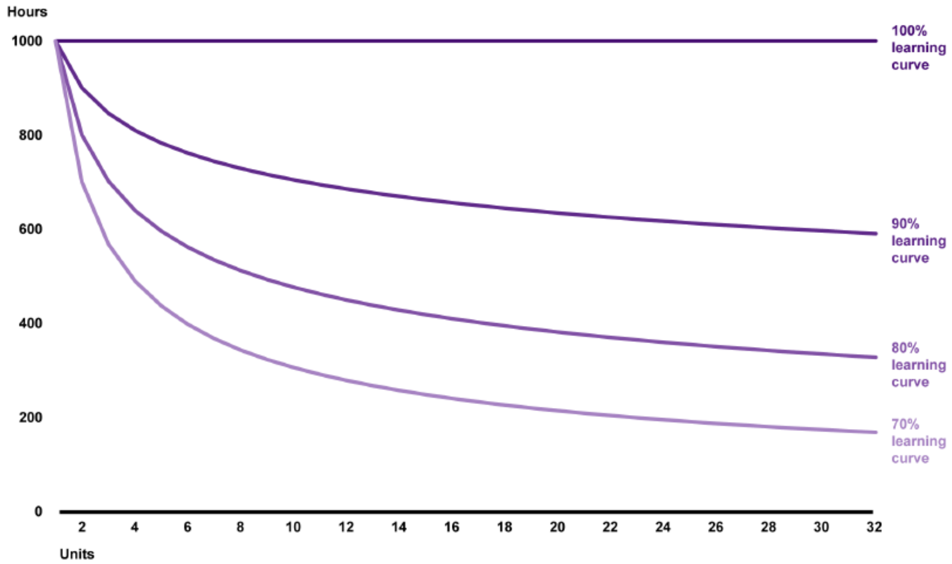


Figure 12. Learning Curve Rates. Source: GAO Cost Estimation Guide (2020).

DOD cost estimators typically use either unit theory or cumulative average theory (CAT). Unit theory suggests that as production units double, cost is reduced by a constant percentage. CAT is essentially the same as Wright's Law. The main difference is that unit theory calculates each lot produced individually, while the cumulative average theory calculates the cumulative average cost of all units. The GAO (2020a) guide explains there are no firm rules when choosing one method. However, some factors to consider when determining the approach to use are analogous systems, industry standards, historical experience, or expected production environment.

Loerch (1999) explains the correlation between learning curves, also called learning behaviors, and procurement programs:

> Each government contractor must submit a form quantitatively describing the anticipated learning behavior of their manufacturing process. These data are used by cost analysts throughout the acquisition process for determining

> contract prices, for budgetary projections, and for performing cost and effectiveness analyses. (p. 257)

The overall quantity produced determines the overall unit cost of the platform because of the learning curve effect. Loerch (1999) uses the B-2 bomber budget cuts to demonstrate how the overall quantity produced affects the cost. He explains that when the amount of bombers procured was reduced due to budget cuts, it inadvertently increased the unit cost. Due to the learning curve effect, the decrease in costs would have reduced the overall cost later in the production process. In this case, cancelling some of the bomber orders did not save as much money as anticipated. The opposite can also be true, as was the case with the B-47 bomber. In 1954, the labor hours required per pound of the airframe had been reduced to just 7% of what it initially was for the first production aircraft (Hartley, 1965). When estimating the cost of new ships, the CBO will adjust their costs if the same ships are being built simultaneously (Labs, 2018). Simultaneously building two surface combatant vessels reduced the cost by close to 20% due to efficiencies gained in production.

5. Explanatory Models for the Technology S-curve

Multiple models explaining and quantifying the technology S-Curve have been developed, with engineering effort or time being the driving factors for predicting technology growth. Nagy et al. (2013) conducted a comparative study that ranked different postulated laws to determine which models best predict the future cost of new technologies. Their study applied six different laws to the historical data from 62 different technologies to determine which model would be most accurate in predicting future costs. The six laws chosen for analysis were Moore’s, Wright’s, Lagged Wright’s, Goodard’s, Sinclair-Kepper-Cohen’s, and Nordhaus. The study determined that it is not possible to quantify performance changes in differing technologies with a single metric, but performance improvements can be measured by the inflation-adjusted cost of one unit. Wright’s Law and Moore’s Law produced the best forecasts, and demonstrated a degree of predictability in technological progress (Nagy et al., 2013).

6. Moore's Law

In 1965, Gordon Moore accurately predicted that the speed of computer processing power would improve as the number of transistors per integrated circuit doubled every two years, without specifying how it would be accomplished (Mollick, 2006). Moore's Law therefore suggests that the cost of a given technology will decrease exponentially over time (Nagy et al., 2013). Jovanovic and Rousseau (2002) claim that Moore's law is an example of efficiency improvements that will occur among producers in a market. The market size will play a role in the rate at which a technology improves as competition can increase firm's investment in their engineering and R&D efforts.

> Predictions made using the law become the basis for future production goals, which in turn reinforces the validity of the law as a measurement of industry progress. In a rapidly changing environment, Moore's law has been described as "the only stable ruler" on which companies can rely. (Mollick, 2006, p. 62)

7. Wright's Law

In 1936, T.P. Wright examined World War I aircraft production to better understand the predictive nature of lowering production costs as airplanes were produced at greater quantities (Mislick & Nussbaum, 2015). Wright found that "If there is learning in the production process, the cumulative average cost of some double units equals the cumulative average cost of the un-doubled units times the slope of the learning curve" (Mislick & Nussbaum, 2015, p. 182). Wright's Law states that as cumulative production increases, the cumulative average cost will decrease (Nagy et al., 2013). Also known as the cumulative average theory or "learning by doing" model, the law postulates that more effort put into a product inherently increases the level of knowledge gained, reducing production costs.

Many factors can reduce cumulative average cost, including improving efficiency in the labor force and streamlining processes in the production facility through continuous improvement (Wright, 1936). Other generalities that impact cost include the design's simplicity, the number of parts required, design structure, and materials. If a system is overly complex, we can expect a much slower decrease in cost because the level of complexity involved will have a slower rate of improvement for both the technical performance and production process (McNerney et al., 2011). Changes to the final product in production will also significantly impact the cost, as will the market conditions, dependent on demand (Wright, 1936).

8. Dual-use Technology

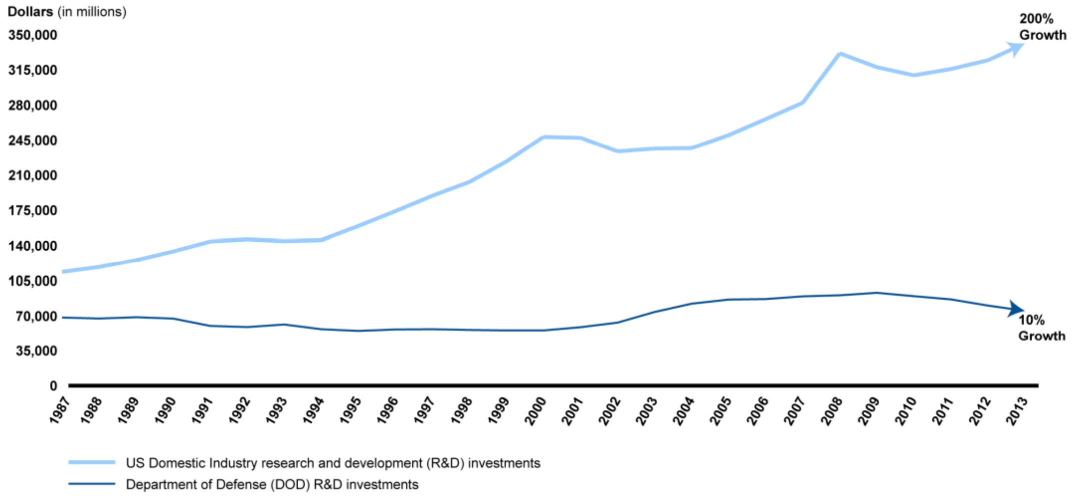
Ultimately, the DOD must understand how new technologies, capabilities, and platforms are being developed. Some technologies are found to have application in both the military and commercial sectors and are referred to "dual-use." Flagg and Corrigan (2021) point out that the concept of dual-use technologies is certainly not new but they have taken a more central role as the commercial sector continues its rapid R&D efforts. This means that more responsibility is placed on the DOD to identify commercially developed technologies that can be militarized than in years past (Gagnon & Van Remmen, 2018). However, dual-use technologies are inherently a double-edged sword. Technologies that are developed for commercial markets have the potential to be militarized or even weaponized. The commercial partners must be comfortable with that possibility, which may not always be the case. For both the commercial sector and the DOD, understanding and predicting the possibilities of dual-use technologies remains a necessity, which is no easy task. To enable this, the DOD has begun to bolster its innovation ecosystem.

E. THE DOD INNOVATION ECOSYSTEM

Shortly after WWII, a race for technological dominance laid the groundwork of what soon became the DOD innovation ecosystem. The establishment of NASA, ARPA, the Office of Naval Research (ONR) and the National Science Foundation (NSF) between 1946 and 1958 propelled R&D rapidly forward in the post-war era. Flagg and Corrigan (2021) explain:

> In the post-war period, most global R&D was conducted within the borders of the United States, most U.S. R&D was funded by the federal government, and most federal R&D dollars were doled out by the military. In 1960, roughly one-third of worldwide research funds were devoted to U.S. national defense. (p. 2)

As the U.S. came out of the Cold War, the military found it was no longer the primary R&D funding source. Having benefited from healthy military R&D funding streams, commercial firms had become profitable enough to begin funding their own research interests (Flagg & Corrigan, 2021). The rapid adoption of the internet, and the increasing affordability of personal computers, put the commercial sector in a position to recruit the best and brightest minds for their own profitable goals. The military watched as many researchers who had been supporting government projects took more lucrative positions in rising technology companies. A steady decline in the military's influence over the broader national innovation ecosystem followed. By 2018, Flagg and Corrigan (2021) explain that the U.S. government had only 22% of the total R&D spending focused on its interests, of which the DOD received barely half. Figure 13 demonstrates the widening gap between commercial and DOD R&D spending between 1987 and 2013.



Source: GAO presentation of National Science Foundation and Office of Management and Budget data. | GAO-17-644

Note: Expenditures have been adjusted for inflation in accordance with DOD National Defense Budget Estimates for Fiscal Year 2017. Industry research and development spending may include funding provided by DOD for research performed by industry.

Figure 13. DOD and Private Sector Research and Development Spending. Source: Sullivan (2017).

1. Fresh Momentum

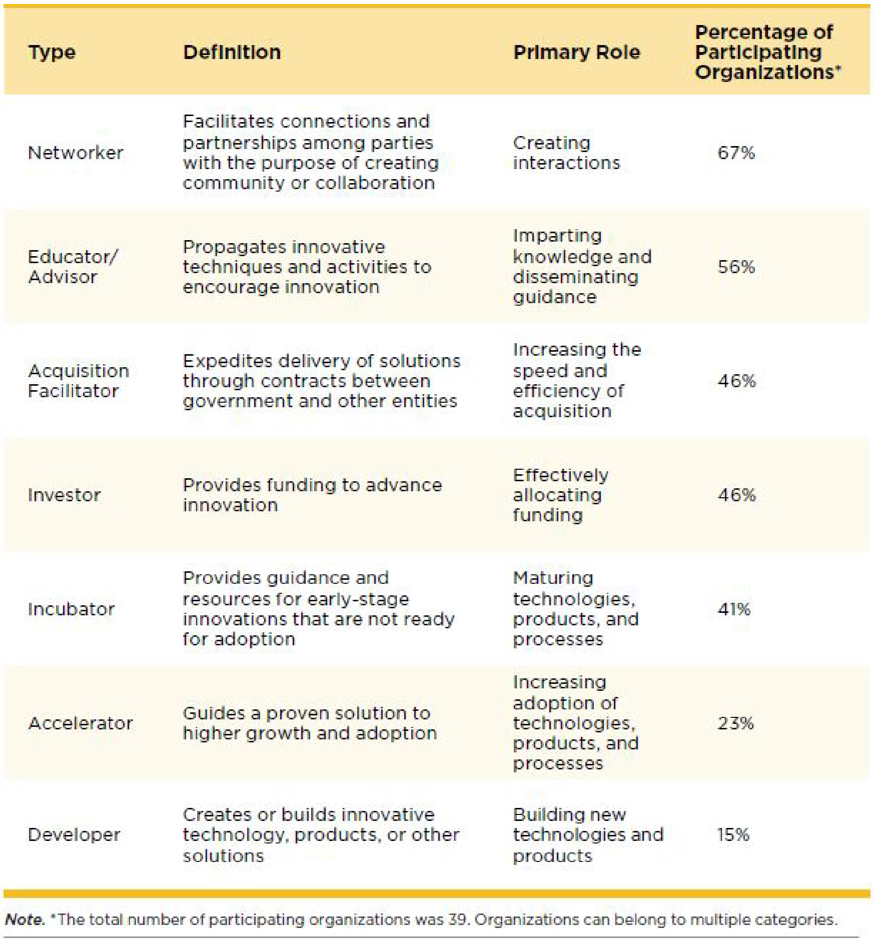
In 2014, recognizing the need to be make broad and bold changes to the DOD's innovation ecosystem, then-Secretary of Defense Chuck Hagel announced the Defense

Innovation Initiative (DII). The DII was intended to catalyze a new approach to innovation within DOD by forming a stronger relationship with innovation and technology hubs in the U.S.. The first action taken within the initiative was the formation of the Defense Innovation Unit (DIU) in 2015 (Hummel & Wurster, 2016). Based at Moffett Field in Mountain View, CA, Hummel and Wurster clarify that it was the first DOD organization created with the mission of giving the DOD access to innovative technologies and processes being pursued by smaller companies in innovation hubs, like Silicon Valley. DIU has the secondary mission of teaching the DOD how to understand and implement the best innovation adoption practices of the commercial sector.

Many other defense-based organizations have been created, expanded, or combined since 2015 to harness the innovation momentum that was catalyzed by the DII. As of October 2021, the MITRE report had confirmed 28 DOD innovation organizations. Figure 16, published in 2019, provides a visual generated by DIU that groups together some of these organizations. However, there is not a current map of the DOD innovation ecosystem and connected network.

2. An Initial Framework

As government innovation organizations proliferate, their parent agencies expect to see results from their resource investments. Innovation organizations are therefore tasked with determining how to effectively measure themselves (Brunelle et al., 2020). The MITRE Corporation's 2020 report set out to assess how government organizations, including the DOD, define innovation and what metrics they use to measure and quantify their impact. A survey was sent to every known innovation organization in the U.S. government, though only 19 government agencies completed the survey. The MITRE report (2020) identified seven types of government innovation organizations from the survey responses. Figure 14 describes these seven types, defines their primary role, and shows the percentage of respondent organizations within each category.



Type	Definition	Primary Role	Percentage of Participating Organizations*
Networker	Facilitates connections and partnerships among parties with the purpose of creating community or collaboration	Creating interactions	67%
Educator/ Advisor	Propagates innovative techniques and activities to encourage innovation	Imparting knowledge and disseminating guidance	56%
Acquisition Facilitator	Expedites delivery of solutions through contracts between government and other entities	Increasing the speed and efficiency of acquisition	46%
Investor	Provides funding to advance innovation	Effectively allocating funding	46%
Incubator	Provides guidance and resources for early-stage innovations that are not ready for adoption	Maturing technologies, products, and processes	41%
Accelerator	Guides a proven solution to higher growth and adoption	Increasing adoption of technologies, products, and processes	23%
Developer	Creates or builds innovative technology, products, or other solutions	Building new technologies and products	15%

Note. *The total number of participating organizations was 39. Organizations can belong to multiple categories.

Figure 14. Types of Innovation Organizations. Source: Brunelle et al. (2020).

3. DOD Innovation

The MITRE Report (2020) led the way for the creation of a DOD-specific evaluation. Although they were not the first to analyze the DOD's innovation ecosystem, MITRE was the first to produce a more comprehensive analysis. Working from the original seven types of innovation organizations, MITRE identified six categories of DOD organizations that worked in and around innovation (MITRE, n.d.). Figure 15 shows the six categories and the known organizations that fit within each category. It is important to note that the categories are not exclusive, and many organizations operate in more than one, such as AFWERX, the Air Force's primary innovation hub.

Accelerator. Accelerators offer competitive and structured programs focused on scaling the growth of an existing company. Accelerators typically provide some amount of seed money and a network of mentors. Programs are typically a few months in duration culminating in an opportunity to pitch to investors at the conclusion of the program.

AF Techstars Accelerator | Allied Space Accelerator | Catalyst Accelerator | Starburst Accelerator | T3 Accelerator

Challenge. A challenge can be a single or recurring contest or competition aimed at solving problems where emerging technologies have the potential to provide non-traditional solutions, or to expand the pool of participants to address critical issues. Challenges may offer cash prizes or may be part of a broader Challenge-Based Acquisition (ChBA) strategy that may result in a government contract.

AFWERX | Challenge.gov | ERDCWERX | Hyperspace Challenge | MGMWERX | NSIN | SOFWERX | STRIKEWERX | xTechsearch

Connector. The objective of connector organizations is to build networks and create relationships between government organizations, industry, private equity firms, and academia to facilitate partnerships to solve challenging problems by generating new solutions.

AFWERX | Defense Innovation Marketplace | DEFENSEWERX | Doolittle Institute | ERDCWERX | MGMWERX | NSIN | NavalX | RRTO | SOFWERX | STRIKEWERX

Funding Opportunity. Funding opportunities are offered by organizations that seek to invest in and enhance the chances of success of entities (often start-ups or small businesses) pursuing advancements in technology. These are not government contracts or agreements.

AF Techstars Accelerator | Allied Space Accelerator | Catalyst Accelerator | In-Q-Tel | RRTO | Starburst Accelerator | T3 Accelerator

Government Contracting Authority. An organization with government contracting authority can execute contract awards or agreements for government projects. These organizations have warranted Contracting Officers who are authorized to execute awards and agreements on behalf of the government.

AFRL | AFWERX | Army Applications Lab | ARL | Army SBIR/STTR | DARPA | DIU | DoD Labs | NRL | Navy SBIR/STTR | RIF

Incubator. Incubators focus on start-up and entrepreneurial entities with innovative ideas. They may provide seed funding and a collaborative physical environment to grow ideas, brand identification, and business plans. Not-for-profit and government or university operated incubators seek to enhance the economy and/or advance the state of the art of the US industrial base for government stakeholders.

IQT | SOFWERX

Figure 15. DOD Innovation Ecosystem. Source: MITRE Acquisitions in the Digital Age (AiDA) (2022).

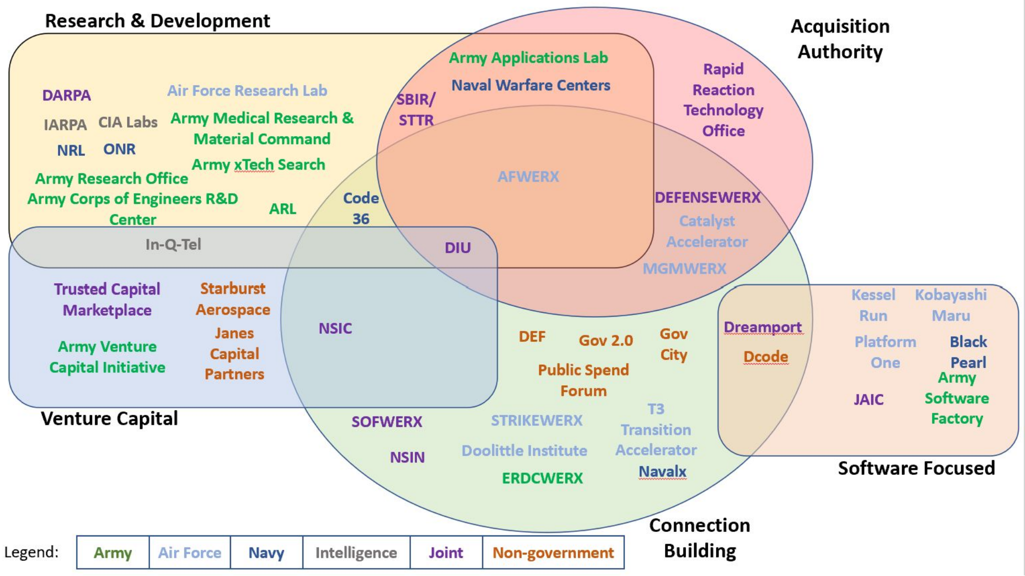


Figure 16. Defense Innovation Unit (DIU) Network Diagram. Source: DIU (2019).

a. *Innovation Culture*

In 2018, Eric Schmidt, then head of the Defense Innovation Board (DIB) and Chief Executive Officer of Google, delivered an address to the House Armed Services Committee. Although he delivered this address in a personal capacity, not as the head of the DIB, the impact was powerful. Schmidt (2018) stated "Early on, I reached a fundamental conclusion that has been borne out over time: DOD does not have an innovation problem; it has an innovation *adoption* problem" (p. 1). Flagg and Corrigan (2021) elaborate on this point:

> We find the military's current approach to engaging with small tech companies, or nontraditional vendors, is more akin to innovation tourism—with the DOD sampling the local fare of the United States' various tech hubs—than a bona fide strategy for bringing emerging technologies into the department. To integrate the activities of innovation offices into the broader defense procurement pipeline, the DOD must change the incentives that drive its acquisition ecosystem. (p. 1)

Former Secretary of Defense Jim Mattis prioritized innovation as one of his critical objectives for the DOD. To deliver performance with affordability and speed, we must "change Departmental mindset, culture, and management systems; and establish unmatched twenty-first century National Security Innovation Base that effectively supports Department operations and sustains security and solvency" (Mattis, 2018, p. 4). Like Mattis, Hagel believed that for America's strategic dominance to continue, innovation and adaptability would play a significant role in the military force's long-term lethality and resiliency (Lyngaas, 2014).

b. *Dual-use Technology*

Because dual-use technologies are seen as one of the more prominent ways for the DOD to rapidly acquire new capabilities, many innovation organizations have placed emphasis on early cooperation and coordination with commercial partners. However, an interest in dual-use technologies also forces the DOD to acknowledge that a shift in its business model is necessary. A report from the Massachusetts Institute of Technology (MIT) Lab for Innovation Science and Policy explains:

> This makes the capability to 'innovate/experiment for Innovation' a key one—enabling defence systems to create new business models that at once reflect and engage with the evolving wider economy and its ecosystem stakeholders. This current interest in so-called 'dual-use' technologies is a particular focus (e.g., in the UK, USA, FRA and ISR), as the civilian economy outpaces the military in technological sophistication in key domains (especially digital) and in new enterprises (particularly new ventures). (Budden & Murray, 2019, p. 8)

As dual-use technologies will likely continue to be a theme in DOD innovation, there are steps that must be taken to reduce risk and incentive more commercial collaboration within and around the DOD. The existing defense industrial base is a complex challenge the DOD must address soon if it wants to capitalize on these emerging dual-use technologies and the commercial innovators responsible for them.

4. Connecting the Large and the Small

The defense industrial base today is composed primarily of several large prime defense contractors. These organizations, like Lockheed Martin and Boeing, hold significant influence and pedigree with the DOD. As mentioned in the GAO (2017) report, smaller innovative companies avoid doing business with the DOD because of the complexity of the acquisitions process and the long contract awarding timelines. The defense primes, more familiar with these challenges, are often reluctant to bring aboard smaller subcontractors who lack the experience and resources necessary to interface with the larger primes on DOD contracts (Flagg & Corrigan, 2021).

DIU was specifically seeded in the Silicon Valley area because it allowed access to growing number of technology start-ups. To fully engage the innovation that is growing out of these hubs, DIU and other DOD innovation organizations may need to create the equivalent of safe spaces for smaller organizations and defense primes to interact and collaborate with the DOD's unbiased support (Flagg & Corrigan, 2021).

As we look to integrate and capitalize on the commercial sector's innovation, the DOD has no choice but to take a hard look at our current procurement process and how we can leverage commercial advancements and innovation to support national defense (Barnett & Buss, 2016). The DOD does not have to shoulder every cost of R&D, but it can foster and stimulate the commercial sector's investment. The current contracting process provides barriers for small companies that have developed technology that can significantly benefit the DOD (Barnett & Buss, 2016). Small but essential demand signals to the commercial sector, like more accessible contract and lease options, can have significant primary and secondary effects on developing and integrating future technology (Barnett & Buss, 2016). As the DOD continues to shift both its strategy and its acquisitions model, commercially developed hybrid airships offer a unique opportunity for the DOD to capture a large-scale, billion-dollar program at a reduced cost. A defense stimulus to the hybrid airship industry now will yield exceptional results thirty years in the future. The DOD can continue to benefit from this maturing commercial industry (Taylor, 2021).

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IV. METHODOLOGY

A. MARKET ANALYSIS

To analyze a commercially developed platform, the DOD must understand the market which commercial developers intend to enter. This is critical if the mobility platform has dual-use potential. Manufacturers will undoubtedly make decisions to remain competitive within the market they target, and these decisions will affect the development of the initial platform and subsequent generations.

In order to acquire more timely data and further advance our research, we initiated a Cooperative Research and Development Agreement (CRADA) with one of the leaders in the hybrid airship industry. Hybrid Air Vehicles (HAV), based in the United Kingdom, has been involved in hybrid airships since the late 2000s and competed in the LEMV contract. The CRADA allowed for the exchange of proprietary information and intellectual property that would have otherwise been inaccessible to us.

In our conversations and interviews with hybrid airship manufacturers, the transportation industry was identified as the largest and most profitable market to pursue. The Global Industry Classification Standard (GICS), developed by Morgan Stanley Capital International (MSCI), classifies transportation as a group within the industrial sector, and its sub-groups are air freight and logistics, airlines, marine, road and rail, and transportation infrastructure (Morgan Stanley Capital International (MSCI), n.d.). Because of the unique operational capabilities of hybrid airships, an analysis of just one of these subgroups would be insufficient for this research. However, a thorough analysis of the entire transportation industry is a significant undertaking that should be conducted in scope that narrows from macro to micro. We have identified these proposed points in the road map. While this research can and is commonly conducted by private sector organizations or resources important for market analysis to be conducted by members of EU S military not only for education on the platform itself, but also to understand how the market is evolving and what role the DOD may play in its evolution.

We used the Porter's Five Forces model to conduct our initial market analysis. The transportation industry is massive and consequently has a wide variety of influences and factors that must be considered for a robust and thorough market analysis to accomplish our mission of a cursory market analysis, we identified one to two key factors or influences in each of the five forces. To complete this qualitative analysis, we interviewed personnel in the commercial airship sector as well as reviewed a variety of papers published from a multitude of sources.

B. COST ANALYSIS

Since the early 2000s, multiple government studies have evaluated hybrid airships' ability to support operational requirements, either through augmentation or replacement of current conventional airlift or sealift assets. Most of these studies concluded that hybrid airships offer a unique capability for transportation to multiple locations globally at a potentially reduced cost. However, the hybrid airship market is not mature, and technological progress in the near term will substantially affect the costs to DOD.

To further evaluate the cost implications of the military adoption of a dual-use technology like hybrid airships better understand how the market size and DOD procurement strategy will affect the procurement costs and potential cost savings, we use a technology progress model. Our technology progress model allows us to investigate how the market size and learning curve rate, in interaction with DOD procurement strategies, will affect hybrid airship's average unit procurement cost (AUC). One of the benefits of hybrid airships relative to current cargo aircraft is the greatly reduced O&S costs partly due to lower fuel demand. We develop an operations and sustainment (O&S) cost model that accounts for variability in fuel prices to estimate potential net costs savings when a hybrid airship fleet is used in ways typical of current cargo aircraft. The cost savings are measured as the O&S savings, less total procurement cost. We also calculate barrels of fuel saved, which also reduces CO_2 emissions. Our model provides an example of an analysis that can be used to support the atlas for evaluating future large-scale commercial technologies for military application and DOD procurement.

1. Transportation Platforms Performance Characteristics

The unique capabilities of a hybrid airship make it difficult to compare to a specific platform because it can function within both the sea and airlift realms. To measure potential cost reduction, we estimated the cost and fuel savings for a hybrid airship fleet in comparison with the existing USN and USMC KC-130J fleets, normalizing by ton-km transported. Table 2 provides the parameters of the hybrid airship relevant to our model and is not specific to any hybrid airship company's specific platform to protect their intellectual property and proprietary information. Table 3 gives parameters for KC-130J's.

Table 2. Hybrid Airships Parameters

Cost Data	**Cost**	**Source**
First unit procurement cost	\$140,000,000 (FY21\$)[1]	Adapted from Lockheed Martin (2016).
Cost per ton-kilometer (ton-km)	\$0.43[2]	Adapted from SAIC (2016).
Performance Data	**Metrics**	
Maximum payload capacity	50 tons[3]	Adapted from SAIC (2016).
Annual flight hours per airship	4200 hours[4]	Adapted from SAIC (2016).
Cruise speed	150 kilometers per hour (k/hr)[5]	Adapted from Gilbert (2019).

*O&S costs include fuel; consumables; helium, mid-life re-hulling; maintenance personnel; life-limited parts; and scheduled maintenance. Excludes crew, system sustainment, and infrastructure support.

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[1] 2016 Lockheed Martin had a sale of 12 airships for 480 million dollars however the deal fell through. (563 million dollars (FY21$).

[2] . "However, with these caveats in mind, and realizing that the cost per ton/mile efficiency for a 20 ton lift airship will be different than that for a 200 ton lift airship, a general cost for cargo airship transport on a per ton/mile basis is estimated to be in the range of $.75 to $1.00" (SAIC, 2016 p.133).

[3] "The desired airship payloads follow a bell curve from 10 tons through to 100 tons. The middle of this curve is around 45 to 50 tons" (SAIC, 2016).

[4] Range from approximately 2500 to 5760 operating hours a year depending on the platform and size (SAIC, 2016).

[5] Based on data available, the SkyCat speeds are either 80 knots or 105 knots. The HULA speeds are either 70 knots or 105 knots" (Gilbert, 2019)

Table 3. KC-130J Data

Cost Data	Cost	Source
Cost per ton-kilometer (ton-km)	$1.65	Adapted from McGarvey et al. (2013), USAF (2018), Defense Logistics Agency [DLA], (2021)
Performance data	**Metrics**	
Maximum payload capacity	41,333lb (20.66 tons)	Lockheed (2015)
Annual flight hours per aircraft	600 hours	Globalsecurity.org, (n.d.)
Cruise speed	593 kilometers per hour (k/hr)	NAVAIR (2018)

2. Technology Progress Model

To assess technology progress in the hybrid airship industry, we measured technology improvement by the decrease in the AUC. Cost is a reasonable metric to measure technology progress and production process advancements over time (Nagy et al., 2013). We estimated the AUC of a hybrid airship in future years by applying Wright's Law, which has proven useful to predict production costs in aircraft manufacturing and shipbuilding. As described in Section IID7, according to Wright's Law, the production cost, and therefore procurement cost, of each successive airship will decrease according to Equation 1. The cost-reduction parameter, *w*, describes the rate of progress - unit cost declines by a factor of 2^{-w} when cumulative production doubles, i.e., average unit cost declines by a constant percent as the total number of units produced doubles.

$$y_t=Bx_t^{-w} \tag{1}$$

where:

t = Time measured in years since year 0
y_t = Average unit cost per airship procured in year t (all costs are in FY21$ unless otherwise specified)
B = Unit procurement cost of first airship (in year 0)
x_t = Cumulative number of airships manufactured through year t
w = Cost reduction parameter

Often, the factor 2^{-w} is expressed as a percent—e.g., when cumulative production doubles, the unit cost declines by 15% or to 85% of the original cost, and therefore the second unit costs 85% as much as the first unit. This corresponds to $w = \ln(.85)/\ln(2)$. Table 4 shows typical parameters expressed as a percent as defined by Delionback (1975). We use 85% ($w = 0.234$) as our base case.

Table 4. Typical Learning Curve Parameters

Industry	Cost of 2nd unit as % of first unit
Aerospace	85%
Shipbuilding	80 to 85%
Complex machine tools for new models	75 to 85%
Repetitive electronics manufacturing	90 to 95%
Repetitive machining or punch-press operations	90 to 95%
Repetitive clerical operations	75 to 85%
Repetitive welding operations	90%
Construction operations	70 to 90%
Raw materials	93 to 96%
Purchased parts	85 to 88%

Table 5 shows the number of hybrid airships is projected for delivery to the DOD and non-DOD organizations. The estimate of the projected delivery quantity is based on conversations with commercial leaders, open-source reporting on commercial orders, and analysis of additional markets segments targeted for penetration. An additional factor is the current and forthcoming carbon dioxide emission regulations that will affect the transportation industry heavily.

Table 5. Number of Hybrid Airships Delivered to DOD and Non-DOD Organizations by Year

Year	Hybrid airships delivered to DOD	Hybrid airships delivered to Non-DOD organization	Total hybrid airships delivered by year	Cumulative number of hybrid airships delivered	Average unit production cost without DOD procurement (FY21$ millions)	Average unit production cost with DOD procurement (FY21$ millions)
0	0	1	1	1	$160.00	$160.00
1	4	4	8	9	$102.53	$89.33
2	4	6	10	19	$79.65	$70.07
3	4	8	12	31	$65.49	$58.38
4	4	8	12	43	$56.36	$50.54
5	4	8	12	55	$49.57	$44.58
6	4	10	14	69	$43.67	$39.50
7	4	10	14	83	$38.94	$35.35
8	4	11	15	98	$34.87	$31.78
9	4	12	16	114	$31.33	$28.67
10	4	12	16	130	$28.32	$25.98
Total	**40**	**90**	**130**			
Average					**$48.27**	**$44.74**

The unit procurement cost (discounted to FY21$) in each year is calculated as in Equation 1, based upon the cumulative number of hybrid airships delivered to the market, and the average cost per unit for the DOD fleet procured over 10 years—the AUC—is calculated as shown in Table 5. As a comparison the unit procurement cost in each year if DOD does not participate in the market is also shown. We see that changing the number of procured airship does not have a significant impact on the overall cost of the platform.

3. Operation and Sustainment Cost Model

To better understand the potential cost reduction of supplementing or displacing our current transportation assets with a hybrid airship, we estimate the difference in cost per ton-km when transporting cargo with an airship versus KC-130J's. Through discussions with leaders in the hybrid airship industry, we developed an estimate of operating capability, fuel consumption, and cost per ton-km. The operating costs for the hybrid airship include fuel, consumables, helium, mid-life re-hulling, maintenance personnel, life-limited parts, and scheduled maintenance. They exclude crew, system sustainment, and infrastructure support costs. USTRANSCOM's Airship study project (2016) estimates a general cost per ton-km of $0.51 to $0.62 (FY21$) for 20 ton to 200 ton cargo capacity.

USTRANSCOM (2016) explains that the desired payload for resource extraction and providing essential supplies to areas lacking infrastructure is between 45 and 50 tons.

However, in order to make the cost comparison with KC-130J more direct, we assume an average transportation weight of 12 tons. Given that 12 tons is on the lower end of 50-ton airships capabilities, we use an average cost per ton-km of $0.43 for airship transport.

The KC-130J cost estimate is shown in Table 6. Numerous factors could impact the fuel burn rate, which can range between 672 to 800 gallons of fuel per hour (Myers et al., 2020). We use 750 gallons per hour as our average fuel burn rate. McGarvey's (2013) study provides the average fixed and variable costs per flight hour. The fuel cost was determined with DLA's (2021) standard fuel pricing of $3.38 dollars multiplied by 750 gallons burned per hour. Based on this data, the cost per ton-km for a KC-130J is $1.65 (FY$21), with approximately 20% to 35% being attributed to fuel costs.

Table 6. KC-130J Cost Per Ton-KM Calculations (FY21$). Source: USAF (2018), McGarvey (2013), Meyers et al. (2020).

Fuel Burn Rate per hour	4500	lb/hr	750	gallons/ hour	
Gallons per KM			1.50	gallons/ hour	
Fixed Cost per flight hour			$ 5,800.00		
Variable Costs per flight hour			$ 4,100.00		
Total Cost per flight hour (without fuel costs)			$ 9,900.00	**$ 1.65**	
Cost of fuel per flight hour			$ 2,535.00		
	Fuel Price/ gallon	3.38			
Percent of O&S that is fuel			26%		

Hybrid airships require less fuel for operation per ton-km. For the hybrid airship, a multi-lobed lifting design allows for static gas to account for 60% of the lift, with the remaining 40% generated by airflow underneath the hull (SAIC, 2016). Hybrid airships also have four engines available for take-off but the capability to cruise with only two engines, allowing for less fuel consumption. Many factors can determine how much fuel an aircraft or an airship consumes. M. and Pant's (2021) hybrid airship study compared different modes of transportation to carry 10,000 kilograms of cargo with one gallon of fuel. They found that an airship will use about 50% less fuel for regional transportation than an aircraft. An airship will use about 80% less fuel than an aircraft for global transportation. We assume that hybrid airships will burn about 30% of the fuel compared to a KC-130J. Our assumptions are conservative; however, the fuel burn percentage will be important for O&S costs as well as emission calculations. A more precise measurement in the future will critical.

To compare hybrid airships and KC-130J's O&S costs, we estimate each platform's total distance traveled based on annual operation hours and average cruise speed. Since the KC-130J and hybrid airships have significantly different cruise speeds, we could not solely use operating hours to make a like comparison. The estimate for one hybrid airship's annual operating hours is 4200 hours, with an estimated cruise speed of 150 km/hr based on SAIC (2016), Gilbert (2020), and conversations with industry leaders. Based on these metrics, one hybrid airship is estimated to be capable of covering 630,000 km annually. The annual operating hours of a single KC-130J is approximately 500 hours. With an estimated cruise speed of 500 km/hr, the total distance covered per aircraft is 250,000 km per year. To calculate cost reduction, the following equation was used, identified as Equation 2:

$$\text{O\&S cost reduction} = \text{Hybrid Airship annual fleet distance traveled (km)} \tag{2}$$

$$*12 \text{ tons payload } *(\text{KC-130J cost per ton-km} - \text{hybrid airship cost per ton-km.})$$

4. Fuel Price Model

Fuel consumption is an important variable to include for analysis. With significant uncertainty in future fuel prices, service branches have implemented initiatives to reduce fuel consumption. In the Annual Energy Outlook (2021), the U.S. Energy Information Administration forecasts that over the next 28 years, the price of jet fuel will continue to rise, as displayed in Figure 17.

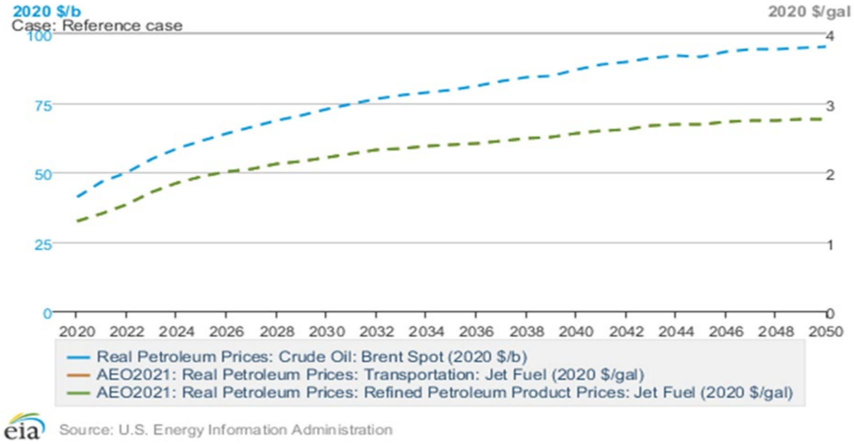

Figure 17. Real Petroleum Prices of Transportation Jet Fuel. Source: U.S. Energy Information Administration (2020).

Historical standard fuel prices of Jet Propellant 8 (JP-8) and Jet A-1 (JA1) were collected from the Defense Logistics Agency’s (2021) “standard fuel prices for petroleum products” from October 2011 to January 2022. Before 2011, JP-8 and JA1 had different fuel prices, and we could not differentiate how much of each type of fuel is consumed by KC-130Js. Figure 18 is the historical data of JP8 and JA1 standard fuel pricing adjusted to FY21$. A Crystal Ball simulation is used to account for uncertainty in future fuel prices using a lognormal distribution with a mean value of $3.47 and a standard deviation of $1.29. We used a single realization of that value for all 10 years.

Date Published	$ Per Gallon		$ Per Barrel (42 gallons)		Per Gallon (FY21$)	Per Barrel (FY21$)
1-Jan-22	$ 3.08	FY2022	$129.36	FY2022	$ 3.36	$141.12
1-Oct-21	$ 2.82	FY2022	$118.44	FY2022	$ 2.82	$118.44
1-Oct-20	$ 2.37	FY2021	$ 99.54	FY2021	$ 2.54	$106.68
1-Jun-20	$ 2.36	FY2020	$ 99.12	FY2020	$ 2.55	$107.10
1-Oct-19	$ 2.96	FY2020	$124.32	FY2020	$ 3.21	$134.82
1-Oct-18	$ 2.98	FY2019	$125.16	FY2019	$ 3.29	$138.18
1-Apr-18	$ 2.76	FY2018	$115.92	FY2018	$ 3.07	$128.94
1-Oct-17	$ 2.15	FY2018	$ 90.30	FY2018	$ 2.43	$102.06
1-Jul-17	$ 2.15	FY2017	$ 90.30	FY2017	$ 2.45	$102.90
1-Oct-16	$ 2.26	FY2017	$ 94.92	FY2017	$ 2.61	$109.62
1-Feb-16	$ 2.61	FY2016	$109.62	FY2016	$ 3.07	$128.94
1-Oct-15	$ 2.95	FY2016	$123.90	FY2016	$ 3.46	$145.32
1-Feb-15	$ 3.26	FY2015	$136.92	FY2015	$ 3.87	$162.54
1-Oct-14	$ 3.70	FY2015	$155.40	FY2015	$ 4.34	$182.28
1-Oct-13	$ 3.62	FY2014	$152.04	FY2014	$ 4.32	$181.44
1-Oct-12	$ 3.73	FY2013	$156.66	FY2013	$ 4.50	$189.00
1-Jul-12	$ 2.31	FY2012	$ 97.02	FY2012	$ 2.81	$118.02
1-Jan-12	$ 3.82	FY2012	$160.44	FY2012	$ 4.70	$197.40
1-Oct-11	$ 3.95	FY2012	$165.90	FY2012	$ 4.86	$204.12

Figure 18. Defense Logistics Agency Fiscal Year Standard Fuel Prices for JP8 and JA1. Source: DLA (2021).

Per the Office of Management and Budget Circular A-94 (1992), a discount rate of 7% is used to calculate a year-end discount factor. The discount rate reflects the time value of money as it is necessary to discount future benefits and costs to compute a net present value and assumes that costs and benefits occur as a lump sum at year-end.

V. AN ATLAS TO NAVIGATE THE ECOSYSTEM

Innovation is a term commonly found in national strategy documents, service level guidance, and frequently discussed at NPS. However, context or direction for capturing innovation is often ambiguous. For our purposes, we used the definition provided by Denning and Dunham (2010) which describes innovation as “the adoption of a new practice in a community” (p. 5). When we started our research, we had almost no familiarity with any part of the DOD innovation ecosystem. As our exposure to people and organizations increased, it became almost overwhelming to understand and navigate. While we were encouraged to engage with the commercial sector to explore emerging technologies, we did not understand how do so productively and legally. The potential tools available for use were not always apparent and it was incorrectly assumed that because we were selected to attend NPS, we were familiar with a range of tools and processes. In fleet units, where we both served prior to NPS, exposure to the innovation ecosystem is even more rare and convoluted.

As noted in Section IIIE3, there are some visualizations of the existing innovation ecosystem. Unfortunately, there is nothing currently available that tells DOD personnel specifically where to start. For most DOD personnel, connecting to the innovation ecosystem is a matter of knowing someone who is already connected. The atlas provides not only a beginning, but also direct links to organizations that can further assist. We built the atlas to illuminate the vast network of the innovation ecosystem without being overwhelming.

A. DESIGN

This atlas is intended to be flexible, except for the first step in Phase I, the background. The accompanying visualizations should enable understanding of various pathways and the follow-on actions. A user can identify the elements that are most beneficial and engage where appropriate. The atlas describes multiple pathways for research that supports innovation and could applied to a large program that has several major research areas. For instance, research related to hybrid airships could cover propulsion systems, advanced materials and composites, maintenance and sustainment, and avionics, to name a few. However, this first version of the atlas was designed through our available time and experience with this technology.

The atlas, which intentionally has no definitive timelines, is organized into three phases as seen in Figure 19. Each phase is divided into sections drawn from *The Innovator's Way* (Denning & Dunham, 2010) which outlines foundational practices of essential skills to achieve the adoption of innovation at a higher success rate. The phases begin and end with critical milestones to assess the value of the research for both commercial and government stakeholders, as well as the researcher. At the end of each section and phase, we encourage the user to ask, "why should this research continue?"

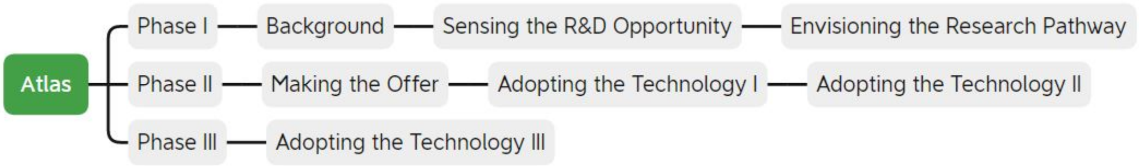

Figure 19. Atlas Overview

Before beginning to navigate the atlas in earnest, we encourage asking several questions to calibrate the research pathway.[6] Catalogue the answers; they will be important for reference in later phases, and they are considered the beginning of Phase I:

1. What are the current technology focuses of your service branch or organization?
2. What can I legally do in the position I'm in and where is that documented?
3. How much time is available for research?
4. What is my sphere of influence?

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[6] By calibrate, we are suggesting that by establishing the baseline information inherent in these questions, the researcher can consistently refer back to how the roadmap has influenced or changed the original perspective of the technology.

5. Who are my personal or professional champions[7]?
6. What makes this technology dual-use?
7. If the technology was discarded by the military before, why?
8. How could this technology impact your professional community, which can be defined as your military occupational specialty (MOS) or rate?
9. How well do I understand U.S. military Technology Readiness Levels (TRL), further defined in Appendix E?

B. PHASE I

1. Background

Conduct the background research for the technology. As shown in Figure 20, we recommend beginning with Google Scholar, which searches a broad range of academic articles, journals, publications, and databases. This initial search will yield a variety of material from government, academic, and commercial sources. Google Scholar will also search the Defense Technical Information Center (DTIC), contingent upon classification levels. DTIC catalogues a wide range of DOD and government publications and has a robust search engine. DTIC has also begun to organize its database around communities of interest (COI), which will further expand the researcher's network who may already be looking into the technology.

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[7] Champions in this instance are defined as senior leaders, decisionmakers, or influencers who can and will support the research and showcase the efforts underway. These do not always have to be general officers or servicemembers.

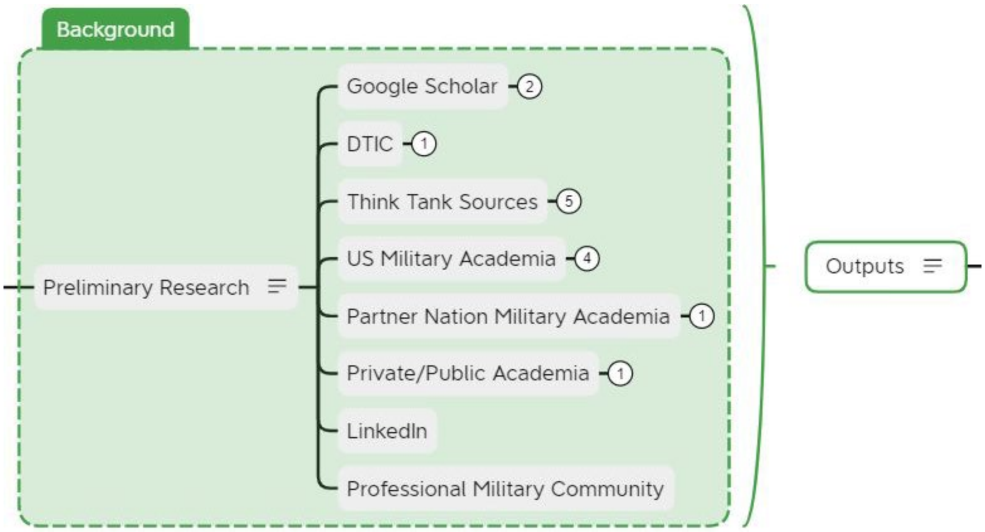

Figure 20. Phase 1: Background Section

Other research organizations may include what are commonly referred to as "think tanks." Among the more common of these is the RAND Corporation, but other organizations include Science Applications International Corporation (SAIC), the Center for Strategic and Budgetary Assessments (CSBA), and the Center for Security and Emerging Technology (CSET), to name a few.[8] Many of the publications from these organizations can found through either Google Scholar or DTIC, but for academic students, it is important to check with your library for access through organizational subscriptions. The Air Force Institute of Technology (AFIT), NPS, the Army's War College, and others are examples of academic institutions that enable further research. Likewise, consider military academic sources outside of the U.S. through allied nations, as well as public and private academic institutions, especially your alma mater. Be sure as well to check professional military publications, like Proceedings or the Marine Corps Gazette for any related articles or subject matter experts.

Lastly, use LinkedIn and professional community engagement as research repositories. LinkedIn can provide considerable connections and engagements for military service members and may allow a researcher to see more current research. Engaging the

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[8] RAND is derived from "research and development"

professional military community can also be beneficial as others may be aware of, if not actively pursuing, the technology. Once complete, the background analysis should generate four outputs that lead into the next section. Ensure that the results of the background are well documented and organized.

2. Sensing

The four key outputs seen in Figure 21 that should result from the background are an understanding of the DOD's previous engagement and investment in the technology, who key military stakeholders may be, who the commercial stakeholders may be, and a very broad view of the existing or potential technology market.

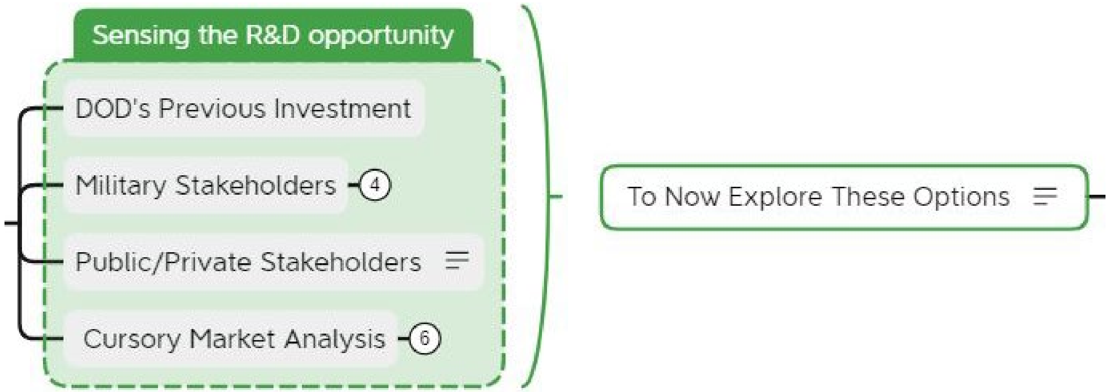

Figure 21. Phase I: Sensing Section

The DOD's previous research and investment will likely identify who may have been stakeholders in the past. It is always worth reaching out to these stakeholders, as we did with USTRANSCOM and several authors of the papers that we reviewed, to develop more context for the DOD's previous interest. These conversations were valuable to understand the mindset of those who may become stakeholders, or even more importantly, why others abandoned the technology pursuit.

For the market analysis, this does not necessarily mean that a Porter's analysis needs to be conducted, but the research will likely have identified some commercial and potentially government organizations that have assessed the market.

3. Envisioning

The envisioning section begins with identifying potential innovation organizations, further explained in Appendix A, to align the technology research efforts with, if there is not already a program or research effort underway. Innovation organizations can be explored by either branch of service, purpose, or capability. Referring to Figure 15, multiple innovation organizations span more than one of the six categories, indicating they can fill multiple roles and be engaged with the research at more than one juncture. The goal of engaging an innovation organization is to not only exploit their capabilities, but to build relationships that can be leveraged when the research hits challenges or roadblocks, which will absolutely occur, by tapping into the broader network associated with the organization. Applying for military fellowships is an exceptional way to find and connect with not only innovation organizations, but also potential mentors. Figure 22 outlines the envisioning section.

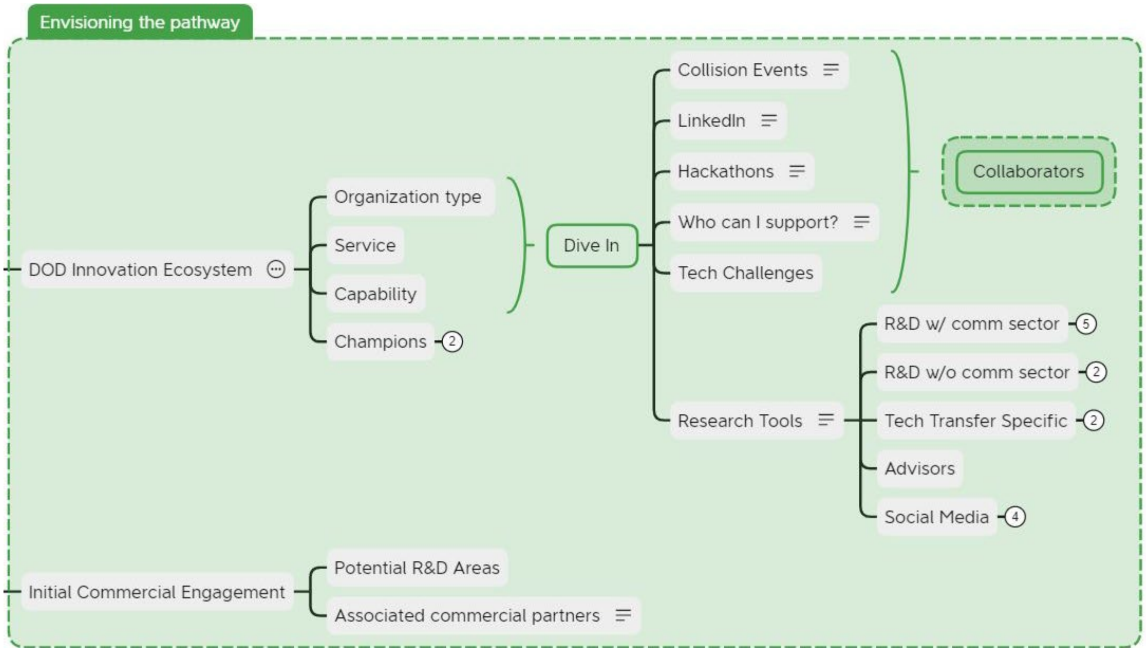

Figure 22. Phase I: Envisioning Section

At the same time, consider the commercial players in the technology space. Consider who stands to benefit from a potential collaborative research opportunity with the

DOD, and what would bring value to their organization. Be aware that all organizations, large and small, may be reticent to commit resources to an effort if funding is not involved upfront. Research potential partners to determine whether they would even have an interest in working with the DOD on any level. Research of this type generally only takes a few hours and can be conducted through news agencies and on social media platforms, like LinkedIn, where the organization or its employees may comment on or have a reaction to military use of their technology. This is also the window to begin making professional connections to these organizations to develop an initial relationship. However, ensure that the communication with the commercial partner is legal and supported by your parent organization, champions, and/or mentor.

Considering who the potential DOD and commercial partners will be can also illuminate the types of research tools that may be available for collaborative research. There are a multitude of tools, beyond CRADAs, that can be used to further research and these are described in Appendix F. It is not crucial to have selected the right tool at this stage, but to be aware of the options, especially in relation to the innovation organization with which partnership is sought. Depending on whether there is a plan to involve a commercial organization will also have an impact on the right tools, and if IP will need to be transferred between partners.

As these potential collaborators begin to crystallize, it is time to consider whether transition to Phase II can begin. The end of Phase I is generally characterized by being able to confirm that these milestones have been attained:

1. Confirmed value in this technology for the military and for your professional community.
2. An innovation organization has been contacted and has expressed interest in joining the research by assigning a specific action officer, even if funding has not been allocated.
3. The security and classification requirements for the technology have been identified.

4. Potential commercial technology partners have been identified and contacted. If they are foreign-owned or controlled, International Traffic in Arms (ITARS) has been reviewed for any conflicts.
5. Research champions have been approached and confirmed interest in supporting the research.
6. The technology is at the mature end of TRL 5, headed towards TRL 6.

Lessons we learned in developing Phase I:

1. Stakeholders may come from strange places and seemingly unrelated organizations. Be open to all offers that may come your way.
2. Keep a "failure" log. Failures are learning, but sometimes failures are a result of incorrect timing. Do not assume a failure means that the event can never be repeated.
3. Seek a mentor, separate of the champions and stakeholders, ideally one who is familiar with the innovation ecosystem and the technology
4. Always be asking "what can I do to support others" just as frequently as asking "what value can others bring to my research."

If the research pathway has led to a clear transition to Phase II, the researcher should refer to the original calibration questions. Documenting the changes and evolution of the research is critical to helping advocates generate the narrative that may support further research and potential adoption.

C. PHASE II

Phase II is where the bulk of the focused research efforts will occur. The first section, shown in Figure 23, is where an offer for collaborative research to both the proposed DOD innovation and commercial technology partners, if applicable, must be made. This offer will form the cornerstone of the proposed partnership and will also be the foundation of trust that is necessary for this collaborative research. The offer can take many forms, but it must be within the researcher's capability to deliver. It must also be flexible and ready to address counter offers. For instance, the offer to form a CRADA as part of this thesis played out over four months.

The initial offer for our research, to create USINDOPACOM-based scenarios for detailed operational analysis of the hybrid airship, quickly evolved into a conversation that spanned three departments and grew well beyond the initial intent. Because students cannot be the principal investigator (PI) for a CRADA, the scope and scale had to be approved by the IP. The scale at which the CRADA expanded had to be carefully considered to not overwhelm the researchers, the PI, and the commercial partner.

An unexpected negotiating point with the CRADA partners became oceanographic data, in the form of historical wave data. Thanks to fellow students and faculty in the oceanography department at NPS, we were able to deliver on this request. In return, the Modeling and Virtual Environment Simulations (MOVES) Institute at NPS joined the CRADA and received detailed aircraft design information and data that could be used in live virtual environments. In this instance, NPS served as an excellent innovation organization to support the research, as these departments all had an interest in collaborating.

Regardless of the final details of the offer, there must be a clear definition of the research areas and actions taken. Additionally, a clearly understood and agreed upon plan for the collection, management, and ownership of all data generated during the research effort must be published. This becomes essential for IP concerns and considerations with commercial technology partners. This atlas is designed to avoid forcing the commercial partners to turn their intellectual property (IP) over the U.S. military, seen as one of the six barriers to adoption identified in Table 1.

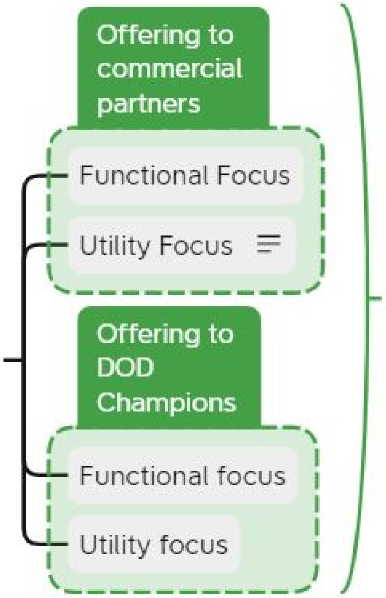

Figure 23. Phase II: Offering Section.

There are considerations in negotiating the offering. Even if the DOD researcher is working alone, there are other researchers working with the partner organizations, which suggests that research in both utility and function can be considered. This is important because this portion of the atlas is designed to consider where the function and utility of the technology may intersect, and what that intersection means for the DOD. Here are suggested areas of broader collaboration that relate to both function and utility:

- Simulator development
- MS&A of the platform's performance in real-world scenarios
- Development of scale and full-size prototypes and components
- Integration of platform's systems
- Structural design of the platform
- Human machine interface or human systems integration

This section is also the beginning of engagement with potential early adopters within the DOD. Even if an innovation organization has accepted the offer, that does not guarantee that actual end-users of the platform are included. Leveraging the innovation organization's connections to larger program offices is important. As research is being conducted, engaging these potential early adopters must be well-timed and should involve the advocacy stakeholders. For something as large as a hybrid airship, it is unlikely that any innovation organization will have the budget and resources to maintain an R&D effort for too long. Therefore, a larger service program office will need to be pursued as an early adopter and critical stakeholder. This early engagement is intended to improve familiarity with the platform and open the door to mainstream adoption. Having confirmed stakeholders and champions in Phase I to assist with this effort, the engagement of a larger program office can begin. Researchers should know that the effort to engage a program office will be a lengthy process that will align to the fiscal year funding cycles.

Once the offer is confirmed, the research can begin, using some of the tools identified in Figure 24 and further explained in Appendix F. This research can last for days, weeks, month, or longer. No matter the time allocated to the research, the goal is actionable data.

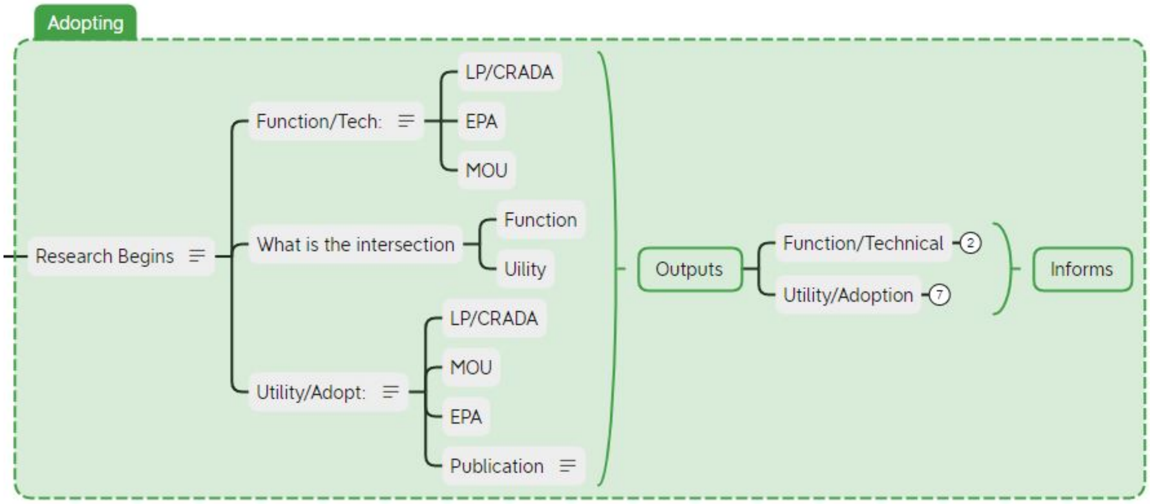

Figure 24. Phase II: First Adopting Section.

Even before the first iteration of research concludes, the next steps should already be coming into focus. Figure 25 outlines these considerations. Identifying the next R&D line of effort (LOE), if there is a need for one, is important. An additional stakeholder analysis should be conducted towards the end of each research period, as stakeholders will likely change or fluctuate over time. Continued awareness of IP concerns and protection measures should be maintained. New topics to consider would be any rising regulatory measures that may impact the technology or a discussion to further de-risk the efforts being undertaken by all partners. Consider also whether any complementary technologies may begin to impact the platform as this stage, and whether those invite additional research effort.

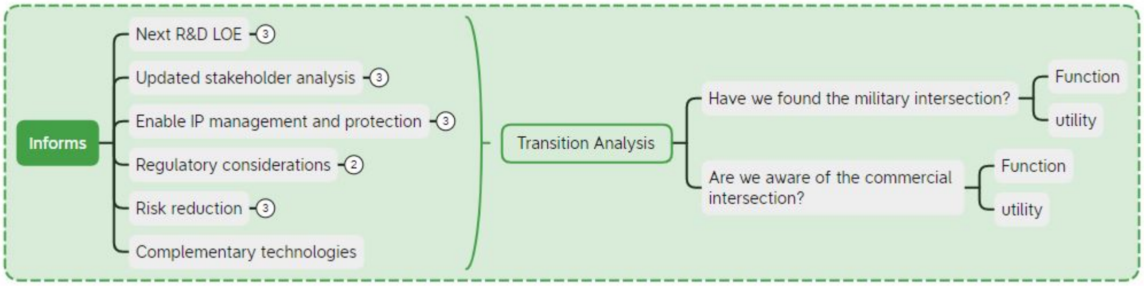

Figure 25. Phase II: Second Adopting Section.

The end of this phase is characterized by these milestones:

1. Clearly defining the detailed intersection of military utility and function of the platform in a way that stakeholders agree with.
2. Explain, but not define, the commercial intersection of utility and function of the platform as defined by the commercial market analyses.
3. Confirm the intersections have enough overlap for the DOD to continue researching the technology with commercial partners.
4. The platform is maturing out of TRL 6 and is either in or about to be in TRL 7.

Being able to answer these with little to no uncertainty may mark the beginning of transition towards Phase III. However, Phase II can be repeated as many times as necessary to progress the research to a point that value is gained for all parties.

Lessons we learned in developing Phase II:

1. Protection and awareness of IP is crucial with commercial partners. It is also important that military researchers not find themselves in a compromising position by holding too much IP from multiple entities without formal agreements.
2. Understanding how to personally engage with the commercial partners, both in the early stages of offering and well into the research, takes finesse and mentorship. Seek guidance early and often, as you are ambassadors and representatives of your service.
3. Maintain awareness of the impact that the research agreement had on the commercial partner and be sure not to abuse the direct communication line to their leadership.
4. Maintain an awareness of what value is being provided to the commercial partner.
5. Stay focused on the research goals and do not get distracted by too many exciting opportunities, no matter how interesting they may be.

The decision to transition into Phase III comes with more consideration than Phase I into Phase II. Phase III proposes that the researchers shift away from a focus on the platform itself and redirects majority focus to what long-term adoption and sustainment of the platform may look like.

D. PHASE III

Large-capacity platforms of the future will likely not be able to run solely on fossil fuels, as noted in Section IID. Our belief is that not only should the platform be sustainable, but the pathway to its production should be sustainable as well. The focus with many emerging technologies is the need to get it funded, fielded, and "into the hands of warfighters" immediately. For a large-capacity mobility platform, like a hybrid airship, there will not be the opportunity to rush the platform into service. To be functionally ready for military service, more than just the platform's capabilities require research, and this occurs in Phase III.

As with the previous phases, another stakeholder and market analysis should be conducted at this stage, primarily because of the amount of time that has likely passed between Phase II and III.

This phase begins with the following transitional questions:

1. Are commercial manufacturers beginning production planning and supply chain development?
2. Has enough research been completed on platform performance that platform sustainment can now become a research focus?
3. Has a market analysis revealed the incumbents and potential new entrants of the markets that the platform will likely enter first?

The first section of Phase III is still considered adopting as seen in Figure 25, but with the focus shifting towards the sustainment of the platform, beginning with the development of the supply chain. For example, the recent global supply chain disruption caused by a massive container ship becoming stuck in the Suez Canal provides a cautionary tale of why supply chain resilience is so crucial. A single vessel being stuck for six days resulted in an estimated $10 billion dollars a day in trade being lost (Yee & Glanz, 2021). Supply-chain complexity continues to be one of the most significant concerns for many companies, as globalization has actually made many supply chains more susceptible to anomalies, both large and small (Bratton, 2020) It is reasonable to question what impact another event like the grounding of the Ever Given in Suez might have on a hybrid airship supplier. The resilience of a commercial manufacturer's supply chain is essential to its ability to deliver on-time. Beyond the supply chain, there is research and analysis into the production methods that commercial suppliers intend to put in place. A start-up that has focused solely on its prototype's success may not have given much thought to how it will organize its production facility to meet the increasing demand of its orders. As a result, that start-up may find that it is unable to scale for contract requirements and is therefore unable to be competitive for government contracts and programs.

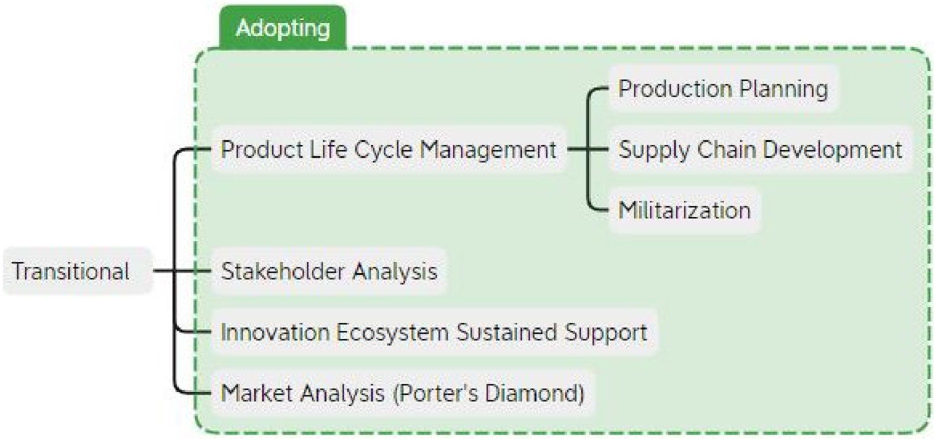

Figure 26. Phase III: Adopting Section.

Through our CRADA, we engaged in detailed and frank conversations regarding HAV’s planned production process. While we cannot publish the details of that conversation due to proprietary information protection concerns, we can confidently say that our commercial partners identified some gaps in their supply chain and production process because of our engagement. These are gaps they are now seeking to close. In addition to resilience and scale, supply chains and production processes should be assessed for their environmental impact. Assessing the carbon footprint of a hybrid airship in flight has tremendous value. However, the manufacturer has additional impacts in building the platform and these should be quantified if the platform is to be considered a truly sustainable platform for the future. These estimates often fall into what is referred to as the social cost of carbon (SCC) and are highly controversial due the subjective nature of the variables that contribute to determining social cost. However, it is still pertinent to assess how the manufacturers are considering the sustainability of their production models and supply chains.

Phase III was designed to further push researchers outside of a comfort zone and delve deeper into an area of the commercial sector that is not commonly seen outside of the major acquisition groups that serve the DOD. However, we had far less time to develop a complete Phase III due to graduation limitations and timelines.

E. CONCLUSION

Although the description that we have provided of our journey through the atlas would suggest a linear pathway, we want to emphasize that was not the case. In fact, the pathway that materialized for us was non-linear and circuitous. The atlas is intended to provide illumination of the pathways that potential researchers may use or follow as they pursue a new technology. We encourage all researchers not to see the atlas as a checklist but instead as a series of interconnected opportunities that can be explored as they become available or timely.

VI. COOPERATIVE RESEARCH AGREEMENT

We wanted to conduct collaborative research with a commercial technology partner. Based on limited previous experience we understood that a CRADA could be a valuable part of an offer to a potential commercial technology partner. The Naval Postgraduate School has an office dedicated to the formation and management of a variety of research tools for both faculty and students. NPS, which is classified as a National Laboratory, also has world-class facilities that could be leveraged to support and augment our research priorities.

Lockheed Martin's hybrid airship division was the first commercial group that we engaged with. The program manager, Dr. Robert Boyd, who has led Lockheed Martin's hybrid airship program for more than 15 years, extended an invitation to visit the famed Skunkworks branch in Palmdale, CA. At the time, Lockheed Martin still had their scale-model prototype hybrid airship in one of the hangars. During the visit, Dr. Boyd outlined the potential future of the division. Due to legal proceedings regarding a potential sale at the time, Lockheed Martin would not have been able to form a CRADA with NPS for research on this topic. Additional open-source research revealed that other partner nation manufacturers that could have been potential technology partners had ties to the CCP. As a result, we could not communicate with these organizations for operational security reasons.

Our introduction to the Hybrid Air Vehicle (HAV) company came in January of 2020, through our personal network which included retired and reserve officers. In the initial stages of engagement with HAV, we had not yet determined that a CRADA was a possibility, or the right tool. An early consideration was that HAV is a foreign owned organization. Although they had conducted business in the U.S. as part of the LEMV project, we still had to submit approval to the U.S. Trade Representative's office to allow the formation of a CRADA thaw did not violate ITARS.

A major benefit to the CRADA is that it does not require a confirmed source of funding prior to the framework being signed by both parties. Equally important, a CRADA protects the intellectual property and proprietary information of the commercial technology partner from the moment it is signed and provides assurances to the commercial partner that what they provide to the U.S. military is lawfully protected. We found that a CRADA is regarded as a stamp of legitimacy for an organization interested in a research effort with the U.S. military but has limited or no prior experience. The CRADA took just four months to finalize and move through legal review.

A CRADA is a flexible tool and we found that not having immediate funding actually allowed more flexibility for the needs of both the military researchers and the HAV team. Although funding cannot be passed from the government to the commercial group through a CRADA, funding can still be legally applied to the research itself.

After consulting our mentors and several potential thesis advisors we made an initial offer to the HAV team about how a CRADA could potentially be formed and what the combined research tasks might be. A CRADA requires that both organizations have responsibility for individual and joint tasks. Initially our primary research interest was exploring how the Airlander family of aircraft could be contextually applied to real-world mobility operations. At the time we considered a model to be a visual representation of the aircraft traveling between selected points within a specific theater of operations. We believed that this simulation would highlight the performance characteristics of that aircraft that would further our research interests of the time. Initially, we believed that through the CRADA, we would receive data related to the airship's performance and then build our own simulations and models of the airship.

Soon after the CRADA was finalized, our research team traveled to Bedford, England to meet with the HAV leadership team. The four-day visit was essential to solidifying the working relationship between NPS and HAV. During the visit, we met with the marketing and sales team, production team, flight test team, and various members of the company's senior leadership. After touring the company headquarters, the technology center, and the flight simulator, it became clear that our research goals and simulation interest needed to be adjusted.

The scenario modeling evolved as both partners gained more insight into each other's capabilities. The outcome was a phased approach to creating mobility and transportation scenarios, each based on real-world experience of the NPS personnel present. This collaboration leveled the understanding of what was in the realm of possible, but also generated momentum for the follow-on actions. Our initial impression was that the HAV team would want to use the Airlander 10, their first-generation airship, for most of the modeling. We were surprised to find that they were more inclined to use the scenarios to inform the design of the next generation airship. Collectively, we decided to create three scenarios, each with varying degrees of detail. The first to be completed was the Airlander 50 being the mobility platform to move a USMC infantry battalion from Camp Hansen, Okinawa to Camp Rodriguez, South Korea, which can be found in Appendix B. The other two scenarios were not intended to be a part of this research, but instead supported other efforts at NPS.

Although HAV had access to an array of open-source meteorological data, it did not have access to valuable oceanographic data, specifically wave height and frequency. We had not considered the depth to which HAV needed to understand this oceanographic information to provide realistic simulations of amphibious operations. The CRADA allowed for appropriate oceanographic data, provided through the NPS Oceanography department, to be passed to HAV. This was invaluable not only for the more realistic scenario that evolved, but also because the information shared helped HAV answer questions to one of its commercial clients. This simple exchange of information generated value for HAV as it could apply the data to further dual-use of the platform.

Prior to the formal scenarios developed to evaluate the airship as part of forward deployed mobility efforts, HAV also generated a simple simulation that proved unexpectedly powerful. The Airlander 50 was simulated in a movement of household goods (HHG) for USMC personnel changing duty stations between southern California and Hawaii. The resulting model was surprisingly insightful, demonstrating that the Airlander 50 could significantly decrease the time of moving service members between duty stations, which can be seen in Appendix B.

The HAV team arranged for us to visit one of their new partners on the last day of the visit. The Advanced Manufacturing Research Centre (AMRC) is a consortium of more than 150 commercial and government agencies around the world focused on advancing manufacturing and production capabilities around the world. Started as a research project between the Boeing Company and the University of Sheffield in 2007, AMRC is now partnered with HAV to develop their supply chain and production facility in Doncaster, England. It became clear that AMRC's capabilities, particularly in digital engineering, could provide tremendous research opportunity to NPS and future innovators. NPS is currently engaged with in preliminary talks with AMRC to discuss potential collaboration opportunities. Without the CRADA, NPS would not have been introduced to AMRC, nor been able to further expand its innovation network. As a result of the interaction with both HAV and AMRC, we found that another crucial area of research, outline in Phase III of the road map, would be supply chain resilience and production planning. Given some of the events currently in motion around the world, analyzing the proposed supply chain and production process of a large platform holds significant benefit and is recommended for further research.

To complete our research with HAV, we asked their leadership to answer several questions on the conduct and value of the CRADA and their research partnership with NPS. The value gained in scenario development was immense and it generated confidence and trust that DOD personnel can provide valuable insight into their program's development. Further, HAV indicated that dealing with specific individuals, as opposed to a larger program office, was more beneficial than anticipated, even if this interaction was outside of the normal acquisition pathways. The complete responses are found in Appendix C.

VII. PORTER'S FIVE FORCES

The U.S. military can and should correlate their own market analysis against those from the commercial sector, instead of relying solely on those from private firms. Although there are dozens of companies around the world that have, or are capable of, conducting a market analysis for hybrid airships, there are benefits to DOD personnel executing their own. First, it forces an analyst to consider the platform through a lens that is not DOD-centric. Secondly, it increases familiarity with the platform and its potential uses, whether military or commercial. Third, it expands understanding beyond just the platform by focusing on how commercial stakeholders may holistically see market influences, regulations, restrictions, and competing capabilities. Next, a market analysis may expose more about who is developing the platform and why, which can yield information into potential commercial partners, as well as adversary nation interest and investment. Finally, a market analysis conducted by DOD personnel will further bridge the gap between the commercial sector and the military. The effort necessary to conduct a market analysis is significant and doing so inherently signals a level of interest from the DOD to commercial firms. A bonus of a DOD market analysis is the professional growth and development that the analyst can experience through this research. Professional growth and development in market analysis is not commonly found in the DOD's educational pathways. However, as the U.S. military encourages more engagement with the commercial sector, while maturing and adapting its talent management strategies, a market analysis can prove to be a strong teaching tool.

The USTRANSCOM (SAIC, 2016) assessment of the airship market does identify major manufacturers. However, it fails to assess the market itself, instead focusing on the platform manufacturers, not the customers or market forces that may impact future development. Each time airships have been assessed from a DOD perspective, it has been how these platforms need to be designed to best function for the military. Instead, a market analysis can identify how manufacturers and consumers see the platform's development and may identify when the right time is for the DOD to begin inquiring as to its military applicability.

Market assessments can also reveal how manufacturers are addressing their supply chains and production process. Once a decision is made to acquire a platform, whether through military or commercial methods, it is important that the platform is delivered on-time and within the contracted requirements. The manufacturer must put significant thought, effort, investment, and coordination into the supply chain that will support the production of the platform. If the manufacturer is competing for a military contract, much of this supply chain needs to be outlined as part of a successful bid. This can be challenging for smaller companies that are competing for potentially large contracts to have the resources to rapidly scale production to meet demand.

While the Porter's analysis does not explicitly reveal the supply chain and production process, it can generate a learning environment for members of the DOD to engage the commercial sector with thoughtful and pointed questions. It is not uncommon for commercial organizations to consider information related to their supply chain and production process to be proprietary information. Having a cooperative research agreement, like a CRADA, enables the DOD and its commercial partners to share what may otherwise be sensitive information.

Our analysis of the transportation industry was conducted from the simple perspective of DOD personnel assessing the five forces impact on all hybrid airship manufacturers. During the analysis, we identified the top one to two factors in each force to analyze, as each sub-group would essentially require its own analysis.

A. THREAT OF NEW ENTRANTS

The threat of new entrants in the transportation industry is assessed as high, due in large part to a surge of emerging technologies already impacting transportation platforms globally. Autonomy will undoubtedly impact all areas of transportation. For example, autonomous technology being utilized in the trucking industry may reduce operating costs by as much as 45% between 2020 and 2027, resulting in somewhere between $85 billion to $125 billion saved (Chottani et al., 2018). Although full autonomy is still several years off, locally owned trucking companies can take advantage of this technology early. Consider that a small business owner, operating a single truck, could purchase a second truck and then install an autonomous package. Using a practice known as "platooning," the unmanned truck will simply follow the first manned truck. Without having the significant costs of a second driver, a small business owner can double or even triple their transport capability, and subsequent profits, in a matter of days. Autonomy can easily be applied to hybrid airships which can reduce operating costs by having fewer humans required for flight operations. Hybrid Air Vehicles, for instance, plans to make all of their airships "optionally manned," to give its customers flexibility in operation (Gee et al., 2020). Lockheed Martin has planned the same for their model as well. (R. Boyd, personal communication, February 2020)

Additionally, renewable energy sources are having noticeable impacts. While hydrogen propulsion systems for trucks and cars are being explored by companies like Nikola, others are building much larger platforms. The Flagship Project, a European Union (EU) partnership effort to deploy hydrogen-powered inland cargo ships, launched its first vessel in early February of 2022 to begin service in France along the Seine river (Flagships, 2022). The smaller and more agile start-ups that are developing these systems are finding that they can partner with incumbents to accelerate their digitization, or they can strike out on their own. There are incentives for both pathways.

When applying how hybrid airships could be utilized by new entrants, it is important to remember that they are simply platforms that enable a service. However, because they can operate from land and sea, they may allow an incumbent in one sub-group to enter another. An example may be that an incumbent in the rail industry may purchase or contract a hybrid airship and be able to compete in the marine industry at a relatively low cost. The potential for this "cross-pollination" between the sub-groups will be affected by a variety of factors and requires considerable future analysis. Even though the capital requirements are very high, there are still many organizations with the capability to purchase and contract hybrid airships.

Although a plethora of large, well-established organizations in each of the sub-groups of the transportation industry exist, new entrants now have incentive to enter the market. These large organizations will have to pay significant costs to not only upgrade their fleets with an autonomous capability, but also face the mounting increase of regulatory hurdles that are pushing out fossil fuels. The EU set ambitious climate goals that will see a reduction of carbon emissions by 55% in 2030, as compared to 1990 levels (European Commission, 2020). The United States enacted equally ambitious goals for 2030, planning to reduce greenhouse gas emissions between 50% to 52%, from 2005 levels (White House, 2021b). These impacts of these regulatory variables will have significant impacts on both the DOD and the commercial sector, but it will take several years before the effects can be tallied and analyzed.

B. BARGAINING POWER OF SUPPLIERS

The bargaining power of suppliers is assessed as moderate. There is a wide range of suppliers that can affect the transportation industry which suggests that suppliers have very little power because of the range of alternatives available. Airship manufacturers will need a range of suppliers, many of whom come from the well-established aviation industry. This includes avionics and navigation equipment, which will be important not only for safety, but also for regulatory considerations.

Engine suppliers for the early hybrid airships will have some bargaining power as well. For instance, the Airlander 10, seen in Figure 27, has custom-built diesel engines planned for its first production models. This indicates that the suppliers of these engines will be filling niche orders, not required by any other manufacturers. Although other engines may be available, the decision to pursue custom propulsion gives the suppliers some latitude. There would be very high costs to switch engine manufacturers in the next five to seven years.

Figure 27. Airlander 10 Prototype. Source: Gee et al. (2021).

For non-rigid hybrid airships, like the Airlander 10 in Figure 27 or the LMH-1 in Figure 28, the hull, where the lifting gas is stored, is the single most expensive element of the aircraft, at almost 20% of the purchase price. In conversations with leadership at both Lockheed Martin (R. Boyd, personal communication, February 2020) and Hybrid Air Vehicles (Gee et al., 2020), there are a limited number of companies capable of this production capacity, which require significant labor hours and special fabric. This gives the suppliers some leverage over the manufacturer as noted by Porter (2008). How much at this stage is unclear, as we were unable to communicate with any firms that had initiated full-scale production.

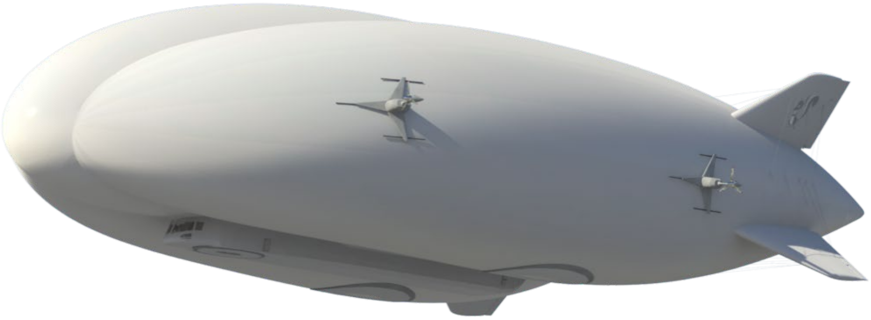

Figure 28. LMH-1 Prototype. Source: Boyd (2020).

C. BARGAINING POWER OF BUYERS

The bargaining power of buyers is assessed as low, due to large pool of existing buyers across the sub-groups of the transportation industry. However, this takes into consideration the wide range of platforms and businesses across the industry. Hybrid airships are new and unproven from a commercial standpoint, and the revenue potential is not confirmed. While this has made many buyers uncertain of the profit potential for hybrid airships, there is very little standardization across the transportation industry. As Porter notes (2008), buyers gain more power if there are fewer of them, and they face low switching costs. Purchasing or even leasing hybrid airships will be costly to any organization. Depending on the industry buyer, there are many considerations, from personnel to maintenance facilities to infrastructure adaption costs. However, the relatively low operating cost of hybrid airships, to include low part counts, reduced complexity, and reduced maintenance requirements, can offset the initial procurement costs.

In some instances, there are buyers powerful enough to influence the entire market. Recently, Amazon was considering using hybrid airships for package delivery (Coxworth, 2016). If Amazon were to decide to move forward with this concept, it would generate enormous ripple effects across the entire industry. While there are very few titans like Amazon with the resources to execute such plans, these buyers alone could impact the market singlehandedly which would increase the bargaining power of buyers and encourage other firms to follow suit.

Hybrid airship manufacturers themselves are described as intermediate buyers (Porter, 2008). Because they are not end-users, they may be able to build exclusive agreements with buyers or even end-users to capture more market share. On average, hybrid airship manufacturers are estimating they can initially produce approximately 11 to 14 aircraft per year for the early models. Large transportation firms could conceivably purchase all aircraft built in a single year. This would increase the buyer's power and likely impact an airships manufacturer's delivery options to other customers. For example, Air Lease Corporation announced its intent to purchase 116 aircraft from Airbus, the major European rival to Boeing (Singh, 2021). As of 30 September, Singh notes that Air Lease Corporation has an order backlog of 320 aircraft and only expected to get 25 of those aircraft, from both Boeing and Airbus, in the 4th quarter of FY21. This illustrates the impact that a single organization can have, even for the largest manufacturers.

Hybrid airship manufacturers that we spoke to are specifically targeting two industries within transportation. The first sub-group is marine transportation, and the other is regional air passenger and freight. Although there are other markets that have shown interest, these industries have made moves to place first orders but for use in vastly different geographic areas. To protect proprietary information, the specific names and geographic locations of these markets are not published.

D. THREAT OF SUBSTITUTES

The threat of substitutes is assessed to be high. As evidenced by the current construct of the transportation industry, there are many substitutes already in use and more on the way. Unless a buyer intends to use the hybrid airship to work across the spectrum of air, land, and sea, there will always be a strong substitute market. Across all the sub-groups of the industry, each transportation platform is considered an alternative.

In specific instances, airships may find that no cost-effective substitutes exist. From a geographic perspective, airships allow operation in very remote and austere locations that are currently inaccessible to other platforms or are very expensive to operate. The mining industry of northern Canada is an excellent example of a challenge that hybrid airships may be the only platform economically viable enough to employ (ISOPolar, 2020). Using airships as survey vehicles or even to carry in large equipment is a use case being actively explored by several manufacturers. If targeting end-users in these niche applications, airship manufacturers may be able to identify early adopters and establish a market foothold. However, marketing strategy will important so that potential buyers understand how airships can support augmentation of existing fleets, not just replacements.

In addition to existing platforms, like trucking and shipping, other emerging technologies are also taking hold. Wing-in-ground effect craft are another platform being developed by commercial manufacturers for high-speed, low-cost transportation in and around coastal cities (Welsh, 2022). Hybrid airships are not only competing with the incumbent platforms, but they are competing with other emerging technologies. It is worth noting that there will also likely be considerable hesitation for incumbent firms to make a significant shift to hybrid airships. This will encourage incumbents to lean towards substitutes until others have adopted and proven that hybrid airships are a viable and profitable option.

E. RIVALRY AMONG EXISTING COMPETITORS

Rivalry in the transportation industry is assessed as high. Intense competition in the transportation industry makes it difficult for competitors to capture new market share and it will be no different for hybrid airship operators. It is likely that the first adopters of hybrid airships will not be major global competitors. Examples of these companies would be Maersk SeaLand, United Parcel Service (UPS), and Knight Transportation. Instead, regional organizations seeking ways to expand into new markets are expected to be the first to pursue airships.

Some short-haul, middle-weight regional transportation firms might have enough capital to purchase airships but may be able to capture small enough market shares early on that allow them to gain and maintain a foothold in multiple markets. Others may not be able to outright purchase an airship, but can contract or charter the platforms and expand market share. Groups like Ryanair, easyJet, and Wizz Air are all European regional airliners that are competition with not only each other, but with larger global carriers like

Lufthansa and Air France-KLM Group (Hayward, 2020). These regional carriers own roughly 30% of the passenger airline market in Europe.

This intense competition may result in disruptive innovation taking place, where new entrants will look to move into markets they have not commonly operated in, using innovative business models (Bower & Christensen, 1995). Although hybrid airships can operate globally, their initial uses will be influenced by regional factors and their payload capacity. As they increase payload capacity, they will likely see more adoption as incumbent firms look to utilize the platform against new entrants, further increasing rivalry.

F. MILITARY FEEDBACK TO COMMERCIAL DEVELOPMENT

Although market analysis is recommended at multiple points in the atlas, the early use of the Five Forces has already yielded important considerations. The hybrid airship market appears to be evolving around regional transport of personnel and cargo. For the military, this can translate to regional transportation in locations like INDOPACOM. We used the results of this analysis to develop a simple mobility scenario, modeled on real-world requirements experienced by both authors on previous deployments. Through the CRADA, we were able to provide detailed information to Hybrid Air Vehicles who then simulated how the Airlander 10 would perform in supporting mobility operations between Okinawan and South Korean training facilities. The results of this can be found in Appendix B.

Although this initial market analysis is a macro-level view of a very large industry, it nonetheless provided excellent context and education to our own understanding of the many forces that influence the adoption of new platforms. Furthermore, it provided us more direction to generate our own technology progress models to conduct a quantitative analysis.

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VIII. COST ANALYSIS AND RESULTS

A. BASE MODEL

As described in Section IVB2 the baseline estimate of the AUC is based on DOD procurement of 40 hybrid airships in a medium-sized market, with an 85% learning curve rate. As shown in Table 5 in Section IVB3, the AUC for the commercial sector without DOD procurement is $48.27 million (FY21$). To understand how DOD procurement might affect the AUC, we compare the market without DOD procurement to the market with DOD procurement. Under the assumption that manufacturers can meet DOD demand, the AUC decreases by approximately $3.84 million to $44.43 million.

Figure 29 shows the learning curve effect on the AUC over ten years. The most significant reduction in AUC due to DOD participation in the market—the difference between the orange and blue lines—occurs in year two, with an approximately $7.78 million dollar difference. Starting in year two, additional DOD airships reduce the AUC by less each year. The market size and the learning curve rate can shape strategy for DOD procurement schedules to determine the right time to invest in a dual-use technology for maximum benefit at the lowest potential procurement cost.

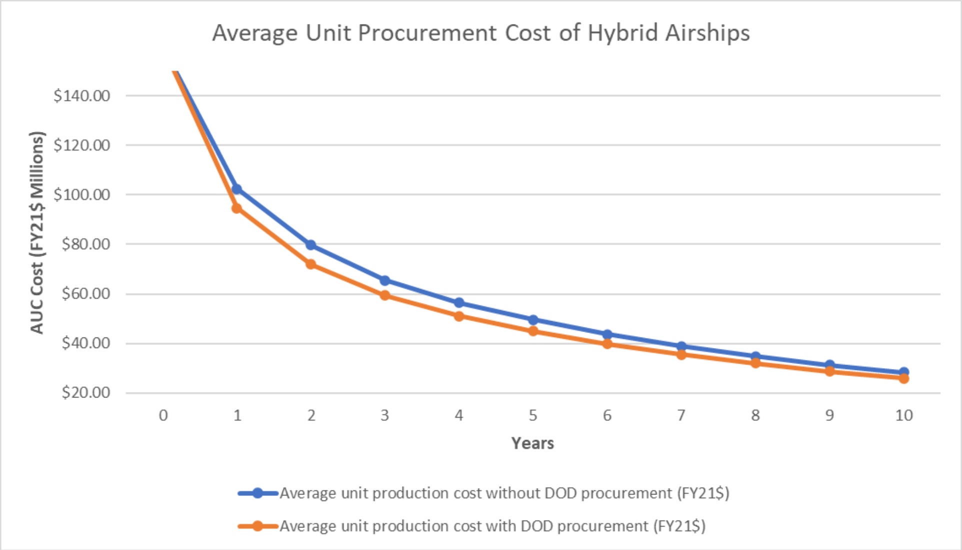

Figure 29. AUC Cost by Year in a Medium Size Market

B. SENSITIVITY ANALYSIS

Our initial model establishes a baseline for how the learning curve affects the hybrid airship market. We then adjusted the variables we believed might affect the AUC of the airship over ten years:

- The market size
- The learning curve rate
- The number of airships procured by the DOD
- The DOD’s time of entry and expected delivery timeline
- The variability in fuel prices
- Payload comparison

By manipulating these variables and observing the resultant change in AUC, we understand how they may impact technology progress and DOD costs.

1. Impact of Market Growth and Learning Curve

Our Porter’s analysis and conversations with industry leaders from Hybrid Air Vehicles and Lockheed Martin helped inform our assumptions about potential market growth. To create our technology progress model, we use Microsoft Excel. Equation 1 is applied with learning curve rates of 80, 85, and 90% to what we categorize as a small, medium, and large hybrid airship commercial markets. Table 7 shows the total quantity of hybrid airships delivered to commercial organizations (non-DOD) for each scenario. Three scenarios for DOD interest level—low, medium, and high—vary the number of hybrid airships delivered to the DOD for the 10-year period as shown in Table 8.

Table 7. Total Quantity of Hybrid Airships Delivered to Non-DOD Organizations

Market Size Scenario	Total 10-year Quantity of Hybrid Airships Delivered to Non-DOD Organizations
Small Market	40
Medium Market	90
Large Market	140

Table 8. Total Quantity of Hybrid Airships Delivered to the DOD

DOD Interest Level	Total 10-year Quantity of Hybrid Airships Delivered to DOD
Low	10
Medium	40
High	70

Each DOD interest level is applied to each commercial market size to assess changes in AUC based on market size and DOD procurement. The model is measured ten years after the initial production year 0. Table 9 displays our assumptions about the market growth and the number of hybrid airships delivered to non-DOD organizations over ten years. The delivery schedule for each procurement level is displayed in Table 10.

Table 9. Hybrid Airships Delivered to Non-DOD Organizations by Year

Total 10-year Quantity of Hybrid Airships Delivered to Non-DOD Organizations			
Year	**Small Market**	**Medium Market**	**Large Market**
0	1	1	1
1	2	4	8
2	3	6	9
3	4	8	10
4	4	8	12
5	4	8	12
6	4	10	16
7	4	10	16
8	4	11	18
9	5	12	18
10	5	12	20
Total	**40**	**90**	**140**

Table 10. Hybrid Airships Delivered to the DOD by Year

Hybrid Airships Delivered to DOD by Year			
Year	**Low Interest**	**Medium Interest**	**High Interest**
0	0	0	0
1	1	2	4
2	1	4	6
3	1	4	6
4	1	4	6
5	1	4	6
6	1	4	8
7	1	4	8
8	1	4	8
9	1	5	8
10	1	5	10
Total	**10**	**40**	**70**

Figure 30 depicts AUC as a function of market size and the number of hybrid airships procured by the DOD. DOD procurement has the biggest impact in a small market. The AUC is reduced by 18.18% when 70 airships are procured, as compared to ten. DOD's procurement has a smaller effect in a medium size market than the small market, with a reduction of only 10.79% and in a large market the DOD's procurement only a 7.71% difference in AUC.

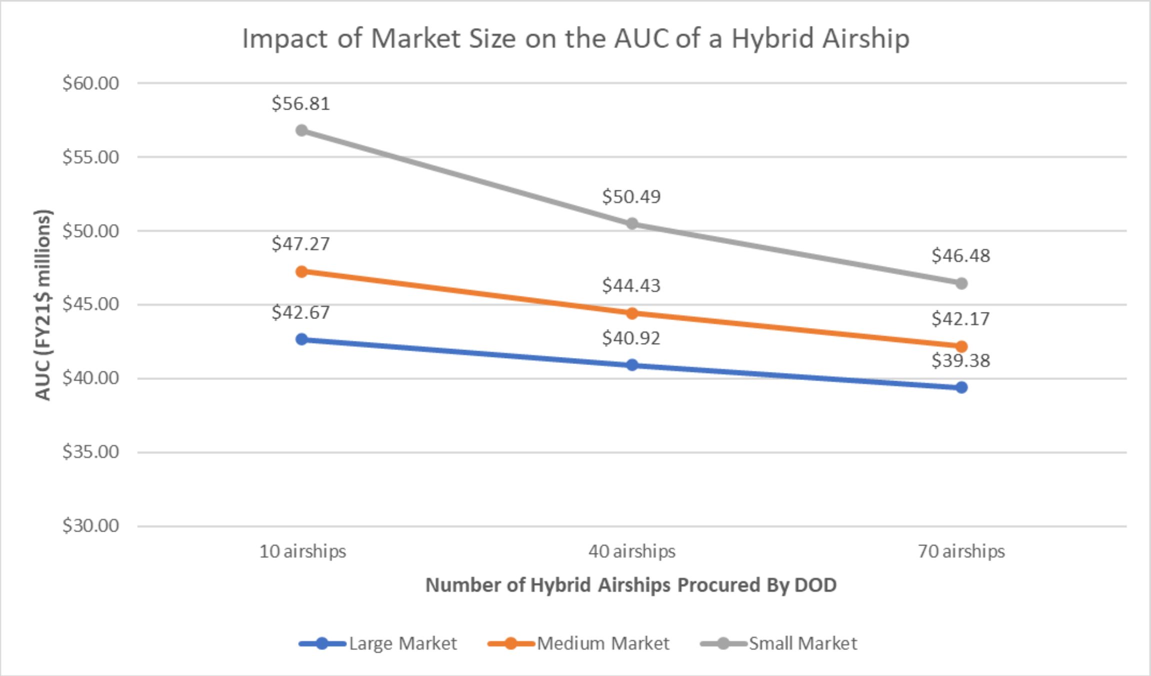

Figure 30. AUC Difference between Market Size and Number of Hybrid Airships Procured by the DOD

Figure 30 illustrates that DOD procurement quantity reduces AUC the most when DOD procures over 60% of the hybrid airships in a small market. The DOD should never cross the line of making procurement decisions for the best interest of any market. However, it can consider how the downstream effects of investing in a dual-use technology can improve the procurement costs for the future.

2. Impact of the Learning Curve

The forecasted learning curve rate has more influence on the AUC than market size. Table 11 displays how different learning curve rates will affect the AUC of various market sizes. A 5% shift in the learning curve rate can change the AUC by approximately $10 million dollars or more for each market size.

Table 11. AUC for Different Learning Curve Rates Applied to Different Market Sizes

	Total Hybrid Airships Delivered			Average Unit Cost (AUC) (FY$21 million)			AUC Difference		
Market Size	Total Non-DOD Hybrid airships delivered	Total DOD Hybrid airships delivered	Total Hybrid airships delivered	80% Learning Curve	85% Learning Curve	90% Learning Curve	80%	85%	90%
Large Market	140	40	180	$28.99	$40.92	$57.07	-$11.93	-	$16.15
Medium Market	90	40	130	$32.41	$44.43	$60.30	-$12.02	-	$15.87
Small Market	40	40	80	$38.39	$50.49	$65.88	-$12.10	-	$15.39

3. Impact of DOD Procurement Schedule on Total Costs

The Table 11 results indicate that market size and learning curve rates must be considered for more robust analysis when analyzing a dual-use technology. Based on this, we assessed how a procurement schedule can be utilized to generate the most significant cost savings, including both procurement and O&S costs.[9] Four different procurement schedules were analyzed in this model, using the O&S cost model described in Section IVB3. The result is a Crystal Ball Monte Carlo simulation estimating the net savings over 10 years—O&S cost savings minus procurement cost—associated with procuring and using hybrid airships in place of KC-130J's. Shown in Figures 31–34 are the probability distribution of net cost for different procurement scenarios. For each procurement schedule the learning curve rate is 85% and there is a medium size commercial market.

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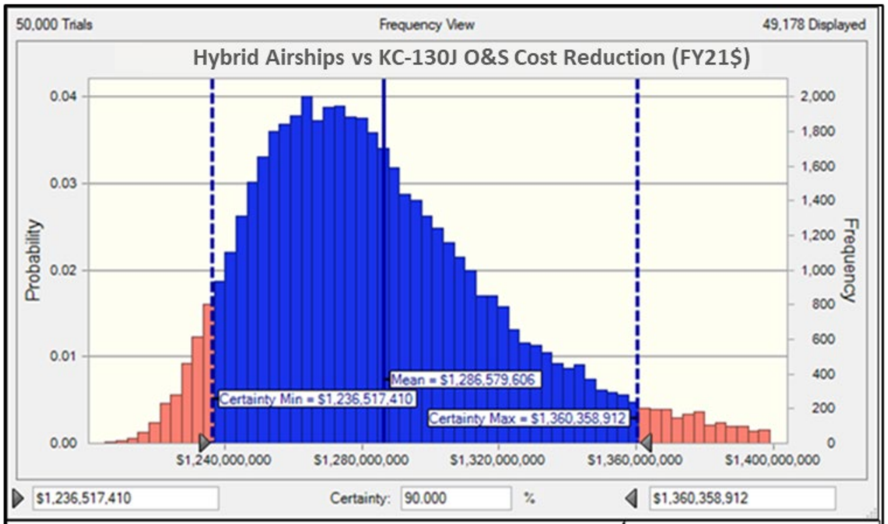
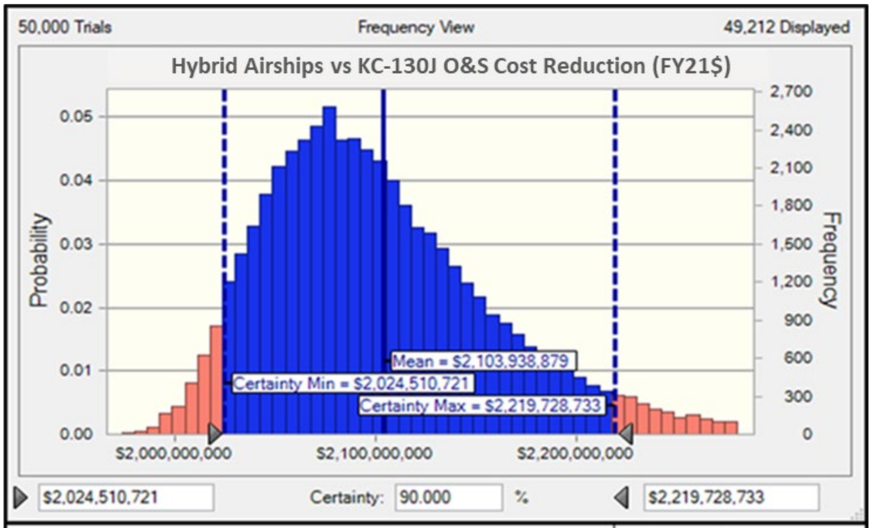
[9] While procurement is generally applied to both the DOD and commercial sectors here, it should be noted that DOD procurement estimations may demonstrate that contracting hybrid airship capabilities may be more effective for the future. This model still provides an awareness of what those costs might be to any buyer.



$1,236,517,410 Certainty: 90.000 % $1,360,358,912

	FY21$ Millions
Total procurement cost of hybrid airship fleet	$1,896.73
Mean O&S Cost Savings	$1,286.57
Net Cost	**$610.16**

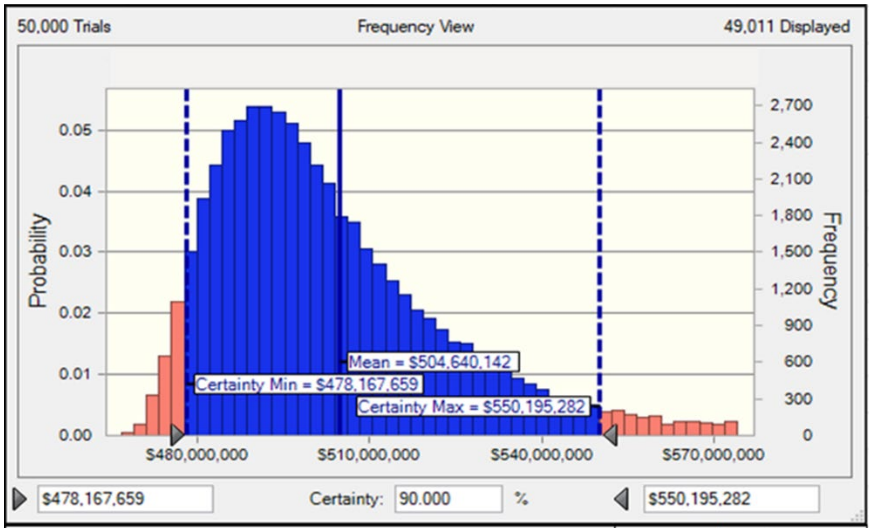
Figure 31. Steady Procurement: DOD Procurement of Four Hybrid Airships a Year



$2,024,510,721 Certainty: 90.000 % $2,219,728,733

	FY21$ Millions
Total procurement cost of hybrid airship fleet	$2,397.04
Mean O&S Cost Savings	$2,103.94
Net Cost	**$293.10**

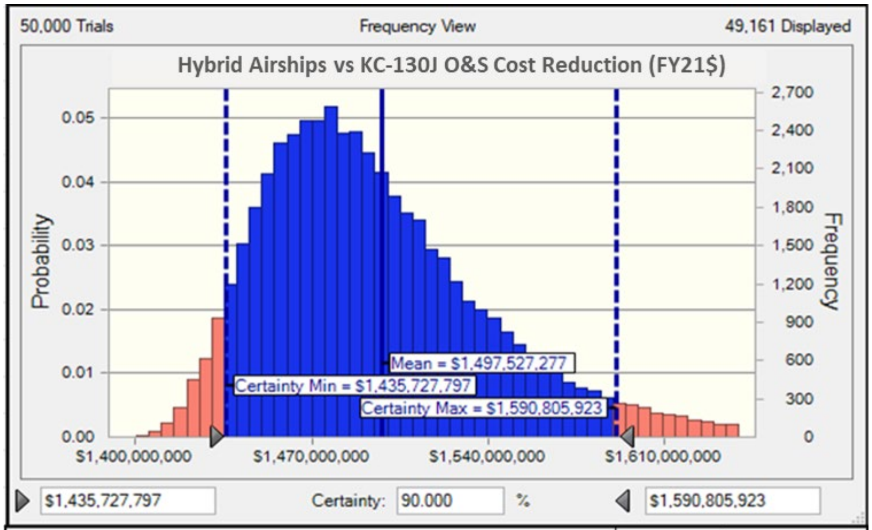
Figure 32. Early Procurement: DOD Procurement of Ten Hybrid Airships from Year One to Year Four



$478,167,659 Certainty: 90.000 % $550,195,282

	FY21$ Millions
Total procurement cost of hybrid airship fleet	$1,252.18
Mean O&S Cost Savings	$504.69
Net Cost	**$747.49**

Figure 33. Late Procurement: DOD Procurement of Ten Hybrid Airships from Year Seven to Ten



$1,435,727,797 Certainty: 90.000 % $1,590,805,923

	FY21$ Millions
Total procurement cost of hybrid airship fleet	$1,892.85
Mean O&S Cost Savings	$1,497.53
Net Cost	**$395.32**

Figure 34. Delayed: DOD Procurement of Ten Hybrid Airships from Year Three to Six

Among these four different procurement schedules, the DOD would get the greatest return on investment by procuring hybrid airships over the first four years. Procuring in the last four years has the highest net cost over the ten year horizon. These results suggest that time of entry into a market is a critical factor to consider for the DOD.

C. CARBON EMISSION CONSIDERATIONS

Airships' reduced fuel demand has value beyond the cost savings. The climate security implications of fuel savings are addressed in the Climate Adaptation Plan (2021). Barrels of fuel saved when using hybrid airships instead of a KC-130J is an additional output of our model that is essential to include. We calculated the barrels of fuel saved once the hybrid airship fleet is operational from the first four-year model. Assuming each hybrid airship operates 4200 hours per year, an estimated 4.57 million barrels of fuel will not be required over a ten-year period.

To better understand the adverse effects of climate change on the U.S., David Anthoff, a professor of Energy and Resources at UC Berkeley, highlighted the importance of economic analysis to shape and inform climate security decisions (New York University, 2021). EO 13990 (2021) calls for government agencies to capture the full cost of greenhouse gas emissions as accurately as possible to support policy development on climate issues. Recently, the U.S. government reinstated the economic cost of CO_2 emitted to be approximately $50 a ton, a metric they hope will better estimate the inequitable effects of climate change (U.S. Energy Information Administration [EIA], 2021).

We calculated the net benefit of reducing CO_2 emissions over ten years when the DOD procures 40 hybrid airships in years 1–4. For every gallon of jet fuel burned, 21.5 pounds of CO_2 is generated (U.S. Energy Information Administration [EIA], 2021). Given that a metric ton is 2204.6 pounds, Equation 3 outlines how we calculated this cost-benefit.

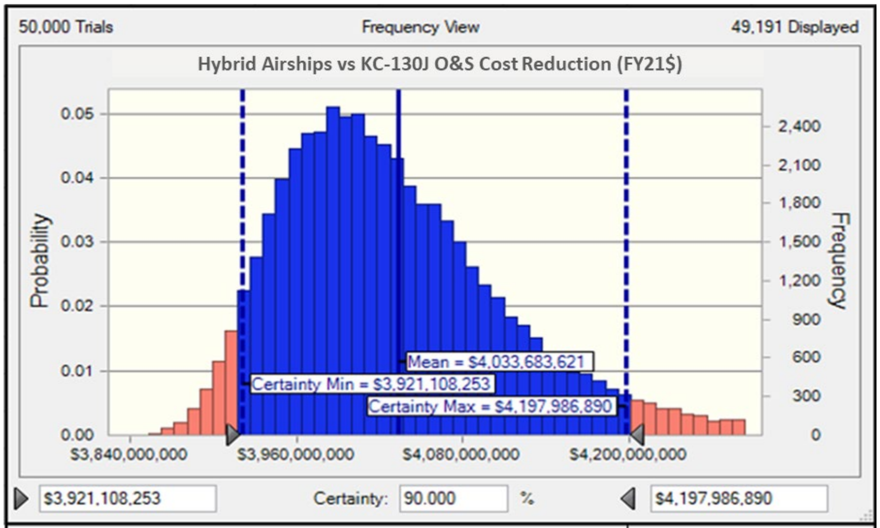
$$\text{Social cost of Carbon} = (21.5 \text{ pounds of } CO_2 \,/\, 2204.6 \text{ pounds}) * \text{Gallons of fuel saved} * \$50 \qquad (3)$$

Using the economic cost of CO_2 emitted of $50 a ton, the hybrid airship fleet net cost decreases an additional $93.52 million dollars to $199.58 million dollars. Since there is some uncertainty in the monetary estimate of SCC, we also calculated it at $20 and $80 dollars a ton which would decrease net cost by $37.41 million and $149.63 million dollars respectively. Despite some ambiguity and controversy on monetizing the social cost of carbon, it is a metric the DOD and commercial partners must be mindful of when building platforms for the future.

D. PAYLOAD COMPARISON

It is important to note that this cost model assumes a payload capacity of 12 tons, significantly less than the hybrid airship 50 ton variant is capable of transporting. The 12 ton assumption allows a direct comparison to the current mission set of a KC-130J. As part of our sensitivity analysis we estimated the potential cost savings when a hybrid airship is utilized to is maximum payload capabilities.

Figure 35 shows the results of the cost model when the hybrid airships and the KC-130J operate at their respective payload maximums. Since the hybrid airship can carry over twice the payload of the KC-130J, we assessed the cost savings at 20 hybrid airships. We chose this quantity under the assumption that fewer hybrid airships will be required to support the current and future mission with greater payload capacity. We further assumed that with over double the cargo capacity, the hybrid airship will burn 45% of fuel compared to the KC-130J, rather than 30% when it carries only 12 tons. For this analysis, we will procure hybrid airships within the first four years since the previous cost model demonstrated this procurement schedule offers the most significant cost savings.



$3,921,108,253 Certainty: 90.000 % $4,197,986,890

	FY21$ Millions
Total procurement cost of hybrid airship fleet	$1,311.10
Mean O&S Cost Savings	$4,033.68
Net Benefit	**$2,722.58**

Figure 35. Payload Comparison

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IX. CONCLUSION

A. RESULTS

The cost related findings of our research were based on very conservative estimates. This was due to several factors. The most important was to protect the IP shared through the CRADA, and the trust that was established between ourselves and the HAV leadership. Next, a restriction on time pushed us to compare the airships against only C-130's and no other surface or air platforms. Finally, the conservativism was influenced by the dearth of data related to actual tonnage moved on individual sorties flown by KC-130J's. While USTRANSCOM does capture this information for its own purposes on select platforms, it does not appear to be widely and readily available for the USMC and USN fleets at large.

1. Procurement Related Findings

Our analysis suggests that over a ten-year period, O&S costs savings will offset much of the procurement costs, especially if the airships are purchased early. Using the 12 ton payload estimate for our models, the procurement schedule with the greatest net savings offset the procurement costs by 79%. Using the 50 ton payload model, there is the possibility of saving over $4 billion dollars in O&S costs over 10 years, for an estimated benefit of $2.72 billion dollars net of procurement cost. Beyond the financial savings captured in the cost estimate, the use of airships reduces the quantity of fuel consumed and pounds of CO_2 released.

Although the hydrostatic science behind hybrid airships is proven, the market for these platforms is still in its infancy. This presents a unique opportunity for the DOD, as potential early adopters of hybrid airships, to stimulate the market and the development of these platforms. Doing so can potentially drive down procurement costs, especially if the market evolves and becomes very large. Our research suggests that any effort on the part of the DOD to procure these platforms early will positively affect future production and future procurement costs. This may lower the DOD's future procurement costs, in the event the decision is made to acquire a larger number of the platforms.

2. Commercial Engagement Findings

Through our engagement with the commercial sector, we found that there is a wide range of opportunities to collaborate with technology partners, from systems engineering to supply chain management. Among the more important areas that the DOD can engage with the commercial sector is related to the learning curve rate. The fact that hybrid airships are not currently in production presents the DOD with another unique opportunity to closely monitor how the learning curve rate will change over time for each manufacturer. Our results reinforced how important the learning curve rate is for procurement decisions.

Although we did not quantify this effect, the CRADA resulted in our technology partners receiving timely and relevant feedback on their platform's capabilities, along with exposure to other complementary technologies for utilization. With the CRADA in place to protect information exchange, we were able to receive detailed briefings on the extent of HAV's production and manufacturing processes. By asking questions of these plans, HAV identified several areas that required immediate action. As a result of early military engagement, protected through the CRADA, HAV will be able to present a more applied and resilient version of their platform for the DOD's mobility challenges in the coming decades. Regarding our second research question, we determined that NPS technology progress and learning curve rates do not accelerate the development of airships. More research is needed to identify, capture, and quantify the ways in which MS&A can accelerate hybrid airship development.

Lastly, our market analysis of a dual-use platform resulted in a much better understanding of the market influences that will affect the potential adoption of this platform. Hybrid airships are likely going to be adopted in the short-haul, regional transport market first, which addresses our first research question. Traditionally, we consider all platforms from a military perspective and do not regard the commercial market implications. The market analysis revealed that primary markets to be regional transportation, which will affect the first designs and capabilities inherent in the baseline aircraft. Militarization of hybrid airships must progress in parallel to the commercial markets they are entering. It is essential that the DOD conduct its own market analyses and have a competent, working knowledge of the markets in which these aircraft will evolve, which addresses our fourth research question.

B. FUTURE RESEARCH OPPORTUNITIES REGARDING HYBRID AIRSHIPS

As noted in Section IIIB-C, the DOD already has a long history with hybrid airships. However, the technology is continuing to mature and bears further research and support as hybrid airships are further developed by the commercial sector.

1. Climate Considerations

Airship manufacturers are focusing efforts toward a zero-carbon aircraft. For instance, the Airlander platform with four combustion engines already reduces CO2 emitted into the environment by 75% over comparable aircraft. They have set the goal for hybrid-electric platforms reducing CO2 by 90% by 2027 and a fully electric version with zero emissions by 2028 (Gee et al., 2020). Using hydrogen as a fuel source for propulsion systems is another area where hybrid airships could serve as the test bed leading to widespread adoption. We recommend further cooperative research with commercial manufacturers to explore how hydrogen as a fuel can be implemented in the earliest versions of hybrid airships. This would include analysis of the propulsion systems and components, as well as the infrastructure necessary to support such capabilities. The race is already underway to make air travel more sustainable, but it is not certain how this will be accomplished and who the major players will be (Verhovek, 2021). If the DOD takes advantage of the situation now, it can find itself in a position to lead sustainability efforts for the global community.

Multiple airship manufacturers see hydrogen-as-a-fuel as the true goal for future propulsion and energy sourcing. Whether hydrogen fuel cell integration, or hydrogen combustion propulsion systems, hybrid airships will be some of the first platforms where zero carbon flight is the standard, not the adaptation. How the DOD can capitalize on these technology progressions is a research topic in itself, enabled by our atlas.

2. Downstream Effects

Modeling the downstream effects that the DOD can have on the hybrid airship's commercial market growth is similar to the idea of a demand-side strategy to spur innovation in critical areas for the DOD. Dew's (2012) research on the strategic acquisitions of unmanned systems for the Navy presents an argument for enabling demand-side factors that may help defense transportation sustainability. If it pursues significant procurement, the DOD can find itself in the role of venturesome user, meaning they become a lead user of the technology (Dew, 2012). If the DOD becomes that lead user, it can contribute to the market demand. The DOD is generally viewed as a source of stability through long-term commitments and could do the same for hybrid airship production. The by-product of the DOD being a lead user is the potential to attract a critical mass of other users. The result could be improvements in the learning curve rate and reduction in cost. Because hybrid airships are a dual-use platform, more research and analysis is needed to understand what role the DOD will play as the platform and markets continue to evolve.

3. Fleet Recapitalization

A Congressional Research Service report (2014) highlighted the 2013 decision to recapitalize the C-130 fleet with the KC-130J. Decisions like this are determined based on multiple factors, as the report states:

> As Congress decides the future of the tactical airlift fleet, a significant decision is whether or not to continue recapitalizing the fleet with new aircraft. This issue is fueled by several factors, including aircraft life cycles, cost, basing strategy, strategic guidance, the industrial base, and the desired capabilities mix. With these factors in mind, the services have committed to recapitalize a large portion of the C-130 fleet. However, at current production rates, there will still be aircraft in the fleet much older than the crews that fly them well into the future (CRS, 2014, p. 2).

To augment these studies, we recommend that a simultaneous analysis of potential alternative platforms be conducted. For future reports, the combination of emerging platform procurement costs and recapitalization costs could be paired together and assessed for maximization of capability and cost.

4. Fleet Augmentation

The “Pivot to the Pacific” and a focus on Artic operations mentioned in Section IIB-C require further analysis on the implications for the current air mobility fleet. Many small island chains in the Pacific Ocean have neither airfields nor deep water ports. Hybrid airships may be able to fill this void and allow conventional aircraft to provide front line support for time-sensitive operations. In addition to analyzing fleet recapitalization impacts, further research is recommended into the effect that hybrid airships would have on the operational fleet if used for the lower end, less-demanding mission sets currently serviced by the air mobility fleet. By releasing these high-end platforms from low-end missions, there are quantifiable impacts on the O&S planning for these fleets. If used as an augment to the existing fleet, as opposed to a replacement, the use of hybrid airships for certain missions might improve the life cycle and maintenance requirements of platforms like the KC-130J and C-17 Globemaster III.

C. THE ATLAS AS A LIVING DOCUMENT

We developed this atlas to encourage innovators not currently in a perceived position of influence to explore the art of the possible while maneuvering within the bureaucracy that is the U.S. military. In the last days of preparing this research journey, we received a great deal of constructive and informative feedback on the conceptual design of the atlas. Originally intended as a roadmap, the idea of it instead being an atlas evolved out of conversations with thought leaders at NPS. We intended for the atlas to be a living document and that is already how it is being received. The version of the atlas in these pages is essentially the minimum viable product, meaning the most basic product that could be produced to demonstrate the concept and viability. Many of these initial elements will change within the next six to twelve months. The milestones that we expected to identify were done at a basic level in the atlas, which addresses our third research question. It is incumbent upon the researcher or user of the atlas to determine whether those milestones fit within the particular scope and breadth of their own research efforts.

In the future, our hope is for the atlas to be adopted by a larger organization, like the Strategic Capabilities Office or DIU. The aim is to further enable and empower thought leaders and innovators of all ranks, services, and communities to conduct maneuver warfare successfully within the bureaucracy. No matter the research topic, the researcher, or the stakeholders, innovation in the DOD should never cease harnessing the power of its own personnel, for they are the most important weapon system that we will ever procure.

APPENDIX A. INNOVATION ORGANIZATIONS

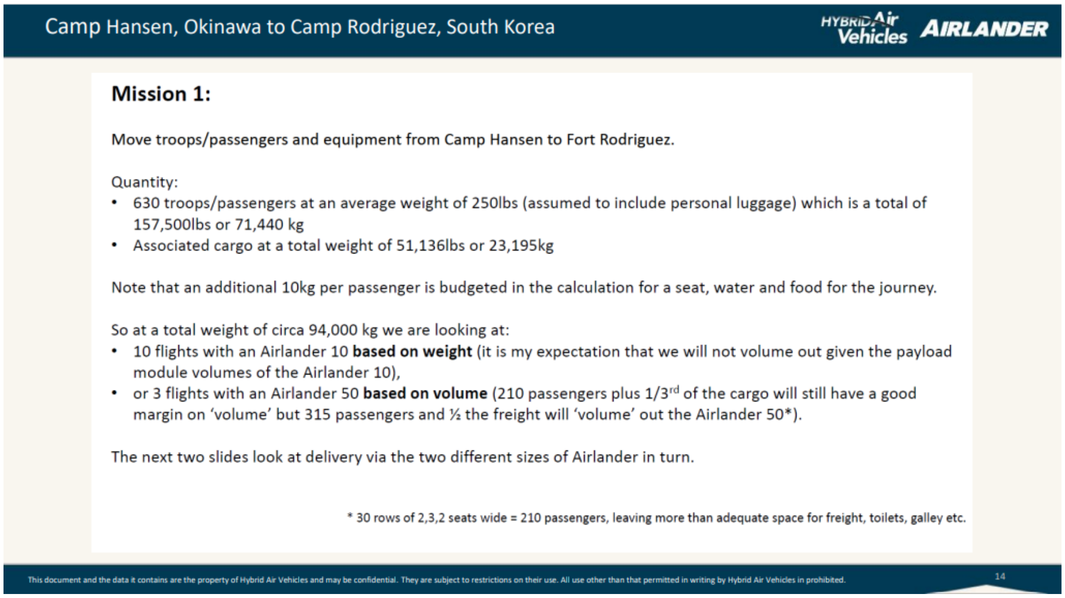
This list was taken primarily from the AiDA website (https://aida.mitre.org/dod-innovation-ecosystem/) which is updated by MITRE. From this website, there are links to each of these organizations.

- AF Techstars Accelerator
- AFWERX
- Air Force Research Lab
- Allied Space Accelerator
- Army Applications Lab
- Army Research Lab
- Catalyst Accelerator
- Challenge.gov
- DARPA
- Defense Innovation Fund
- Defense Innovation Marketplace
- Defense Innovation Unit - https://www.diu.mil/
- DEFENSEWERX
- DOD Labs
- Doolittle Institute
- ERDCWERX
- Hyperspace Challenge

- In-Q-Tel
- Marine Innovation Unit
- MGMWERX
- National Security Innovation Network
- Naval Postgraduate School
- Naval Research Lab
- NavalX
- NavalX TechBridges
- Navy SBIR/STTR
- Rapid Innovation Fund
- Rapid Reaction Technology Office
- SOFWERX
- Starburst Accelerator
- Strategic Capabilities Office
- STRIKEWERX
- T3 Accelerator

APPENDIX B. AIRLANDER SCENARIOS

A. CAMP HANSEN, OKINAWA TO RODRIGUEZ LIVE FIRE COMPLEX, SOUTH KOREA



Camp Hansen, Okinawa to Camp Rodriguez, South Korea

Mission 1:

Move troops/passengers and equipment from Camp Hansen to Fort Rodriguez.

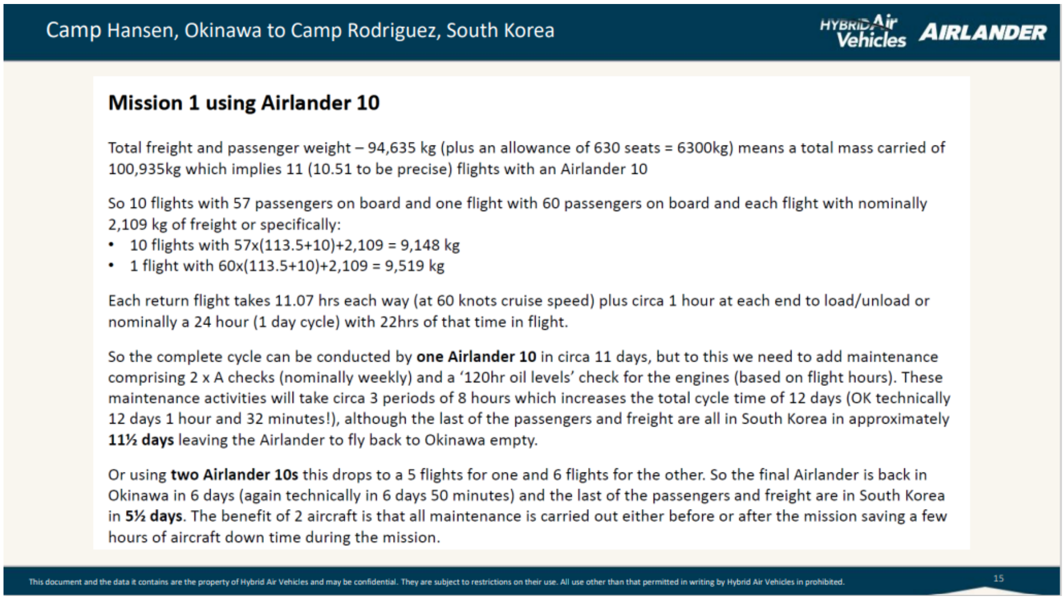
Quantity:
- 630 troops/passengers at an average weight of 250lbs (assumed to include personal luggage) which is a total of 157,500lbs or 71,440 kg
- Associated cargo at a total weight of 51,136lbs or 23,195kg

Note that an additional 10kg per passenger is budgeted in the calculation for a seat, water and food for the journey.

So at a total weight of circa 94,000 kg we are looking at:
- 10 flights with an Airlander 10 **based on weight** (it is my expectation that we will not volume out given the payload module volumes of the Airlander 10),
- or 3 flights with an Airlander 50 **based on volume** (210 passengers plus 1/3rd of the cargo will still have a good margin on 'volume' but 315 passengers and ½ the freight will 'volume' out the Airlander 50*).

The next two slides look at delivery via the two different sizes of Airlander in turn.

* 30 rows of 2,3,2 seats wide = 210 passengers, leaving more than adequate space for freight, toilets, galley etc.



Camp Hansen, Okinawa to Camp Rodriguez, South Korea

Mission 1 using Airlander 10

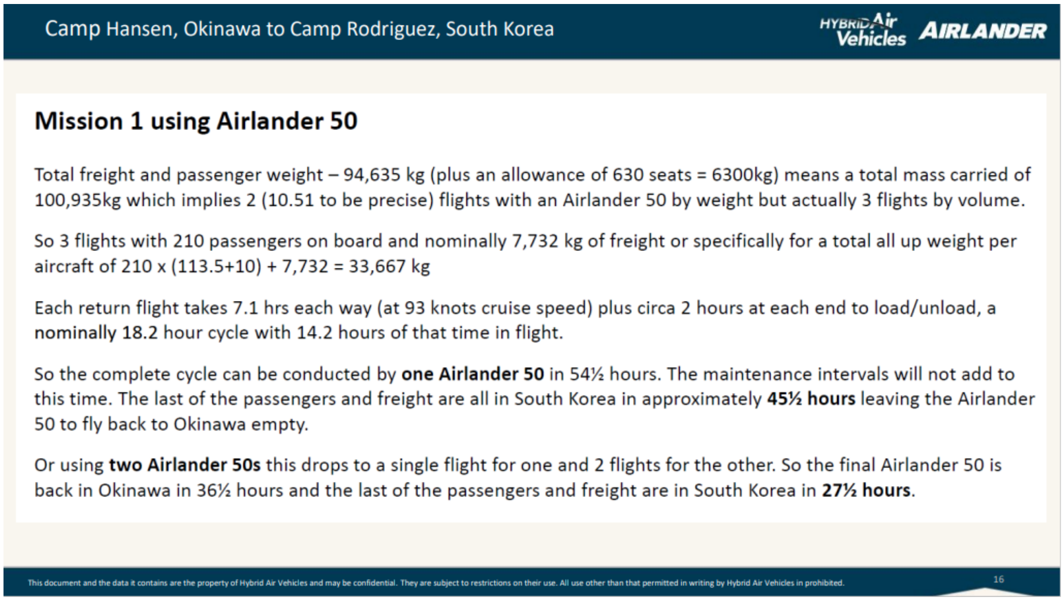
Total freight and passenger weight – 94,635 kg (plus an allowance of 630 seats = 6300kg) means a total mass carried of 100,935kg which implies 11 (10.51 to be precise) flights with an Airlander 10

So 10 flights with 57 passengers on board and one flight with 60 passengers on board and each flight with nominally 2,109 kg of freight or specifically:
- 10 flights with 57x(113.5+10)+2,109 = 9,148 kg
- 1 flight with 60x(113.5+10)+2,109 = 9,519 kg

Each return flight takes 11.07 hrs each way (at 60 knots cruise speed) plus circa 1 hour at each end to load/unload or nominally a 24 hour (1 day cycle) with 22hrs of that time in flight.

So the complete cycle can be conducted by **one Airlander 10** in circa 11 days, but to this we need to add maintenance comprising 2 x A checks (nominally weekly) and a '120hr oil levels' check for the engines (based on flight hours). These maintenance activities will take circa 3 periods of 8 hours which increases the total cycle time of 12 days (OK technically 12 days 1 hour and 32 minutes!), although the last of the passengers and freight are all in South Korea in approximately **11½ days** leaving the Airlander to fly back to Okinawa empty.

Or using **two Airlander 10s** this drops to a 5 flights for one and 6 flights for the other. So the final Airlander is back in Okinawa in 6 days (again technically in 6 days 50 minutes) and the last of the passengers and freight are in South Korea in **5½ days**. The benefit of 2 aircraft is that all maintenance is carried out either before or after the mission saving a few hours of aircraft down time during the mission.



Camp Hansen, Okinawa to Camp Rodriguez, South Korea

HYBRID Air Vehicles AIRLANDER

Mission 1 using Airlander 50

Total freight and passenger weight – 94,635 kg (plus an allowance of 630 seats = 6300kg) means a total mass carried of 100,935kg which implies 2 (10.51 to be precise) flights with an Airlander 50 by weight but actually 3 flights by volume.

So 3 flights with 210 passengers on board and nominally 7,732 kg of freight or specifically for a total all up weight per aircraft of 210 x (113.5+10) + 7,732 = 33,667 kg

Each return flight takes 7.1 hrs each way (at 93 knots cruise speed) plus circa 2 hours at each end to load/unload, a **nominally** 18.2 hour cycle with 14.2 hours of that time in flight.

So the complete cycle can be conducted by **one Airlander 50** in 54½ hours. The maintenance intervals will not add to this time. The last of the passengers and freight are all in South Korea in approximately **45½ hours** leaving the Airlander 50 to fly back to Okinawa empty.

Or using **two Airlander 50s** this drops to a single flight for one and 2 flights for the other. So the final Airlander 50 is back in Okinawa in 36½ hours and the last of the passengers and freight are in South Korea in **27½ hours**.

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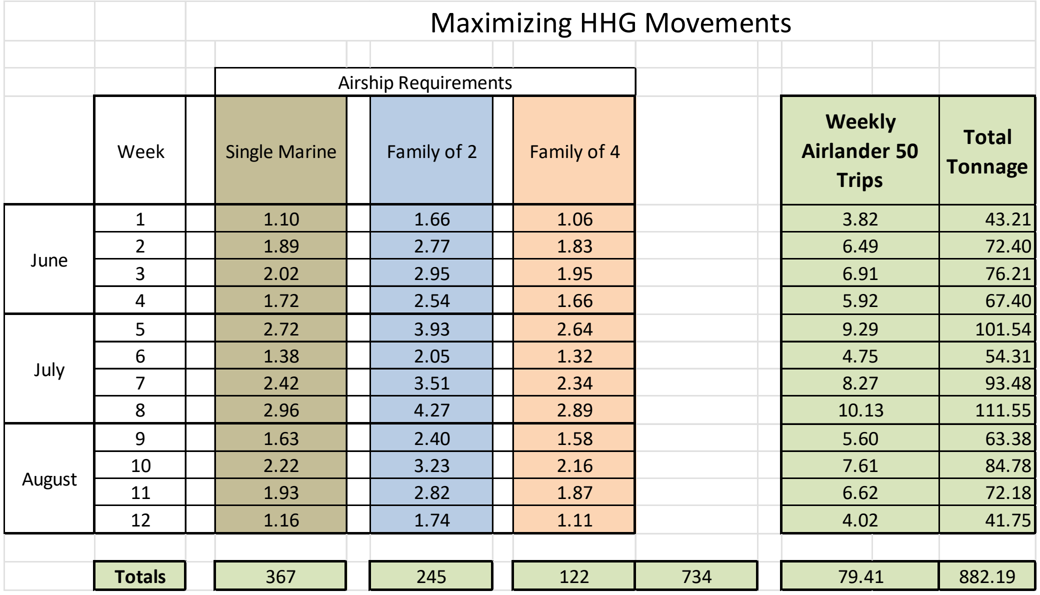
B. HOUSEHOLD GOODS MOVEMENT FROM MARINE CORPS AIRSTATION MIRAMAR TO KANEHOE BAY, HAWAII

1. Overall Results



Maximizing HHG Movements

		Airship Requirements					
	Week	Single Marine	Family of 2	Family of 4		Weekly Airlander 50 Trips	Total Tonnage
June	1	1.10	1.66	1.06		3.82	43.21
	2	1.89	2.77	1.83		6.49	72.40
	3	2.02	2.95	1.95		6.91	76.21
	4	1.72	2.54	1.66		5.92	67.40
July	5	2.72	3.93	2.64		9.29	101.54
	6	1.38	2.05	1.32		4.75	54.31
	7	2.42	3.51	2.34		8.27	93.48
	8	2.96	4.27	2.89		10.13	111.55
August	9	1.63	2.40	1.58		5.60	63.38
	10	2.22	3.23	2.16		7.61	84.78
	11	1.93	2.82	1.87		6.62	72.18
	12	1.16	1.74	1.11		4.02	41.75
	Totals	367	245	122	734	79.41	882.19

1. Airlander 50 capacity adjusted after feedback from HAV team.
2. PCS moves per group per week are simulated. Actual movment data from HQMC (MMEA/MMOA) or TRANSCOM could not be acquired in time
3. This model assumes that HHG shipments are put into "pods" or ISO Containers at home location
4. This model assumes that Airlander departs from MCAS Camp Pendleton and Arrives at MCAS Hawaii
5. This model assumes no more than 12 hours of load/unload time at each location
6. This model does not account for the vehicles of these families, but it can and should in the future.

Given the performance characteristics of the Airlander 50 with updated range and speeds from Mike Durham's team, it is feasible that x3 aircraft could be used to execute every PCS move from Pendleton to Hawaii (And presumably the opposite as well). Further stability could be added to the process if Marines' vehicles are modeled into this and Marines are able to "select" their movement week and flight. Availability of data in the future may support this work.

2. Single Marine/E-5

Distribution	Normal	**Average Weight (Lbs)**	5000	**Max Weight**	Acquired from Move.mil
Mean PCS Moves	30	**Average Weekly Weight (Lbs)**	159366	7000lbs	
Standard deviation	3				
Probability (More than two airships per week)		42%			

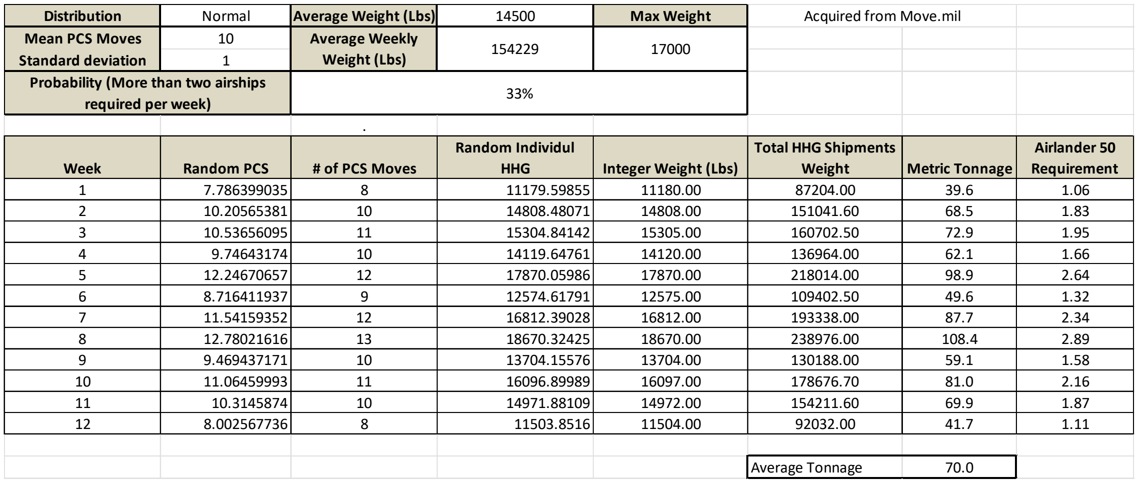
Week	Random PCS	# of PCS Moves	Random Individul HHG	Integer Weight (Lbs)	Total HHG Shipments Weight	Metric Tonnage	Airlander 50 Requirement
1	23.35919711	23	3893.199518	3893.00	91096.20	41.3	1.10
2	30.61696142	31	5102.826903	5103.00	156151.80	70.8	1.89
3	31.60968284	32	5268.280473	5268.00	166468.80	75.5	2.02
4	29.23929522	29	4873.21587	4873.00	142291.60	64.5	1.72
5	36.74011972	37	6123.353286	6123.00	224714.10	101.9	2.72
6	26.14923581	26	4358.205969	4358.00	113743.80	51.6	1.38
7	34.62478056	35	5770.79676	5771.00	199676.60	90.6	2.42
8	38.34064849	38	6390.108082	6390.00	244737.00	111.0	2.96
9	28.40831151	28	4734.718585	4735.00	134474.00	61.0	1.63
10	33.19379978	33	5532.299964	5532.00	183662.40	83.3	2.22
11	30.94376219	31	5157.293698	5157.00	159351.30	72.3	1.93
12	24.00770321	24	4001.283868	4001.00	96024.00	43.6	1.16
					Average Tonnage	72.3	

3. Family of Two/O-2

Distribution	Normal	**Average Weight (Lbs)**	11000	**Max Weight**	Acquired from Move.mil
Mean PCS Moves	20	**Average Weekly Weight (Lbs)**	233031	13500lbs	
Standard deviation	2				
Probability (More than two airships required per week)		83%			

Week	Random PCS	# of PCS Moves	Random Individul HHG	Integer Weight (Lbs)	Total HHG Shipments Weight	Metric Tonnage	Airlander 50 Requirement
1	15.57279807	16	8786.399035	8786.00	137061.60	62.2	1.66
2	20.41130761	20	11205.65381	11206.00	228602.40	103.7	2.77
3	21.07312189	21	11536.56095	11537.00	243430.70	110.4	2.95
4	19.49286348	20	10746.43174	10746.00	209547.00	95.0	2.54
5	24.49341314	25	13246.70657	13247.00	324551.50	147.2	3.93
6	17.43282387	17	9716.411937	9716.00	169058.40	76.7	2.05
7	23.08318704	23	12541.59352	12542.00	289720.20	131.4	3.51
8	25.56043233	26	13780.21616	13780.00	352768.00	160.0	4.27
9	18.93887434	19	10469.43717	10469.00	197864.10	89.7	2.40
10	22.12919986	22	12064.59993	12065.00	266636.50	120.9	3.23
11	20.62917479	21	11314.5874	11315.00	233089.00	105.7	2.82
12	16.00513547	16	9002.567736	9003.00	144048.00	65.3	1.74
					Average Tonnage	105.7	

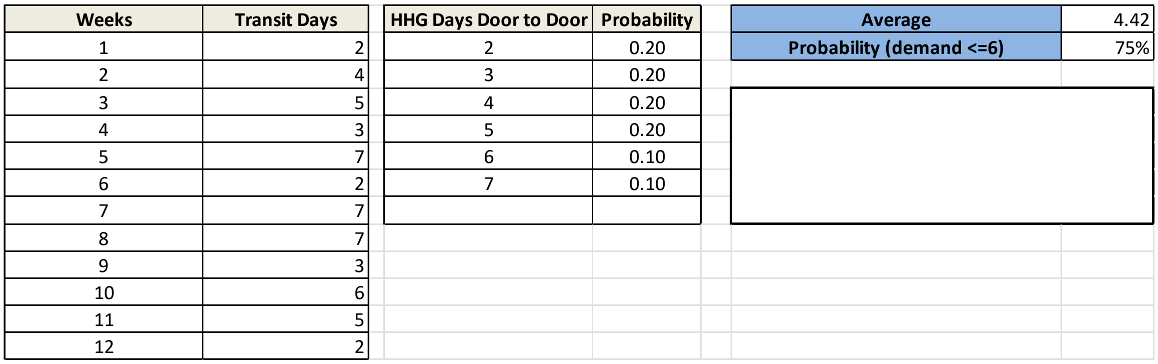
4. Family of Four/O-4



Distribution	Normal	**Average Weight (Lbs)**	14500	**Max Weight**	Acquired from Move.mil
Mean PCS Moves	10	**Average Weekly Weight (Lbs)**	154229	17000	
Standard deviation	1				
Probability (More than two airships required per week)		33%			

Week	**Random PCS**	**# of PCS Moves**	**Random Individul HHG**	**Integer Weight (Lbs)**	**Total HHG Shipments Weight**	**Metric Tonnage**	**Airlander 50 Requirement**
1	7.786399035	8	11179.59855	11180.00	87204.00	39.6	1.06
2	10.20565381	10	14808.48071	14808.00	151041.60	68.5	1.83
3	10.53656095	11	15304.84142	15305.00	160702.50	72.9	1.95
4	9.74643174	10	14119.64761	14120.00	136964.00	62.1	1.66
5	12.24670657	12	17870.05986	17870.00	218014.00	98.9	2.64
6	8.716411937	9	12574.61791	12575.00	109402.50	49.6	1.32
7	11.54159352	12	16812.39028	16812.00	193338.00	87.7	2.34
8	12.78021616	13	18670.32425	18670.00	238976.00	108.4	2.89
9	9.469437171	10	13704.15576	13704.00	130188.00	59.1	1.58
10	11.06459993	11	16096.89989	16097.00	178676.70	81.0	2.16
11	10.3145874	10	14971.88109	14972.00	154211.60	69.9	1.87
12	8.002567736	8	11503.8516	11504.00	92032.00	41.7	1.11
					Average Tonnage	70.0	

5. Airship movement probabilities

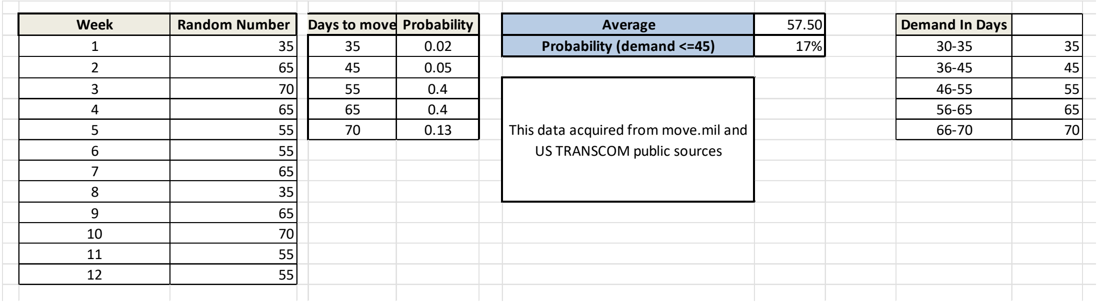


Weeks	**Transit Days**
1	2
2	4
3	5
4	3
5	7
6	2
7	7
8	7
9	3
10	6
11	5
12	2

HHG Days Door to Door	**Probability**
2	0.20
3	0.20
4	0.20
5	0.20
6	0.10
7	0.10

Average	4.42
Probability (demand <=6)	75%

6. Surface movement probabilities



Week	**Random Number**
1	35
2	65
3	70
4	65
5	55
6	55
7	65
8	35
9	65
10	70
11	55
12	55

Days to move	**Probability**
35	0.02
45	0.05
55	0.4
65	0.4
70	0.13

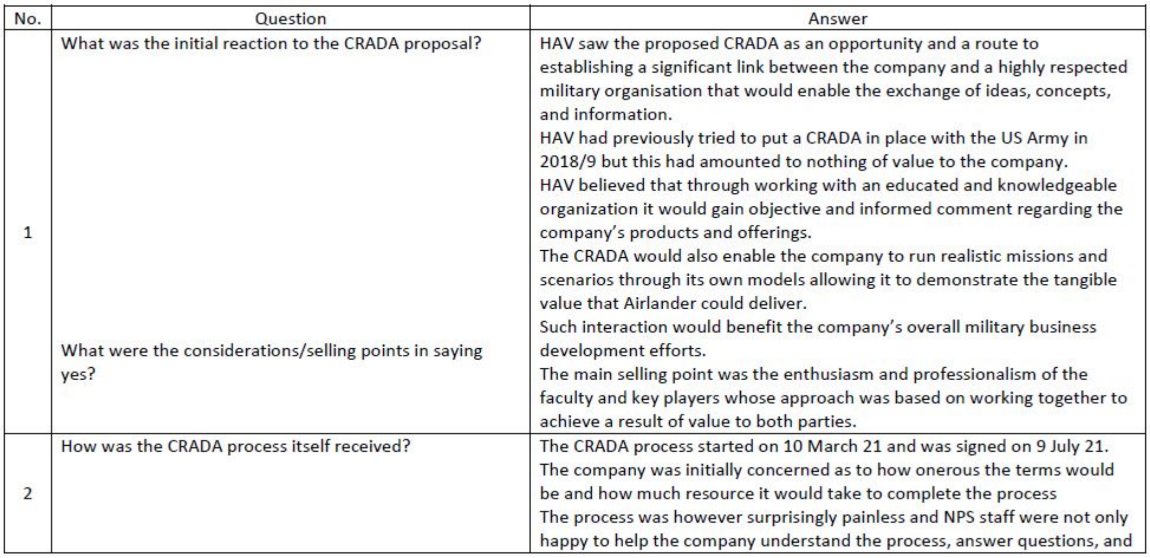
Average	57.50
Probability (demand <=45)	17%

This data acquired from move.mil and US TRANSCOM public sources

Demand In Days	
30-35	35
36-45	45
46-55	55
56-65	65
66-70	70

APPENDIX C. HAV LEADERSHIP OUTBRIEF

Invited Participants: Mike Durham, Neil Gee, Walt Kreitler, Gerry Geletzke, Robert Lehman, Bob Venner, and Tom Grundy



No.	Question	Answer
1	What was the initial reaction to the CRADA proposal? What were the considerations/selling points in saying yes?	HAV saw the proposed CRADA as an opportunity and a route to establishing a significant link between the company and a highly respected military organisation that would enable the exchange of ideas, concepts, and information. HAV had previously tried to put a CRADA in place with the US Army in 2018/9 but this had amounted to nothing of value to the company. HAV believed that through working with an educated and knowledgeable organization it would gain objective and informed comment regarding the company's products and offerings. The CRADA would also enable the company to run realistic missions and scenarios through its own models allowing it to demonstrate the tangible value that Airlander could deliver. Such interaction would benefit the company's overall military business development efforts. The main selling point was the enthusiasm and professionalism of the faculty and key players whose approach was based on working together to achieve a result of value to both parties.
2	How was the CRADA process itself received?	The CRADA process started on 10 March 21 and was signed on 9 July 21. The company was initially concerned as to how onerous the terms would be and how much resource it would take to complete the process The process was however surprisingly painless and NPS staff were not only happy to help the company understand the process, answer questions, and

	Was the timeframe reasonable? Did other concerns materialize in the CRADA development process?	negotiate, but they also responded promptly and with enthusiasm to get the job done properly (Agata Maslowska and team). The timeframe was reasonable. The main item of concern to HAV was the protection of the company's valuable intellectual property.
3	Was the visit to Bedford a good use of HAV's resources and personnel? Was there an impact on the working relationship as a result?	NPS's visit to the company's facilities in Bedford was pivotal in establishing the relationships and the trust on which the CRADA relied. Face-to-face, frank, open discussions combined with "show and tell" achieved a level of confidence in each other's abilities, pressure points and motivations. The visit enabled much more materiel to be covered than could have been achieved by other means and has had a lasting positive impact on the working relationship between HAV and NPS which could not have been achieved by alternative means such as videoconferencing.
4	What has yielded the most value to HAV (whether through the CRADA or not) in this relationship?	The CRADA has provided the company with realistic and relevant scenarios to model, particularly for Airlander 50. It has also made the company more aware of the military's thinking and rationale. NPS has also focused the company more and sooner on the benefits of digital engineering and how HAV might employ these technologies. Whilst HAV had already started to work with AMRC, the involvement of NPS hastened the company to think more about how digital engineering technology such as digital twin could be used to benefit design, production, and support. NPS/AMRC/HAV interaction prompted action much earlier than might have been the case which could prove crucial to delivering the benefits in a timely manner. Introducing NPS to AMRC has benefited both parties and the company in ways which were not originally foreseen. HAV has a better understanding of the possibilities and ongoing work such as that being pursued with Chris Fitzpatrick will benefit from this. The CRADA has helped the company learn how to work collaboratively with the NPS and USMC and has enabled the establishment of excellent working relationships that the company hopes will continue to grow long into the future.
5	Where would HAV like to see the CRADA go next? What research areas would be beneficial?	HAV believes that continued collaboration in modelling and simulation (even wargaming) using validated and realistic data would benefit the US military and HAV. Consequently, the company would like to see more scenarios developed to test the efficacy of the Airlander 10 and the Airlander 50. HAV would also like to see further collaboration in developing the Human-Machine Interface (HMI). Airlander is a unique concept and is in a stage of development where academics and thought leaders could influence the eventual design. Such collaboration would also influence the development of the military tactics, techniques, and procedures to be used on the aircraft. The company also sees the benefit of continued collaboration in digital engineering.
6	How has the HAV team's understanding of engaging with the US military changed over the past nine months?	HAV's confidence in the US military's desire to explore new ideas and technologies has increased significantly. Engaging with NPS has shown that some parts of the US military appreciate the challenges innovative companies offering disruptive technologies face when dealing with the DoD.
7	What is the understanding of what NPS is and does currently with HAV?	Prior to this engagement HAV was completely unaware of NPS, its role and the influence it has not only in the Navy and Marine Corps but in other national security organisations. The company has "had its eyes opened" to the variety of work undertaken by NPS and believes that so far it has only scratched the surface of what could be done together. HAV's understanding of NPS has been enabled through the professional relationships established and through being invited to join social media links such as LinkedIn.

APPENDIX D. CRADA TASKS

HAV will be responsible for the following tasks:

1. Develop and assess technical and operational solutions to meet mobility requirements of the three scenarios.

2. Provide all pertinent technical details and design specifications of the HAV family of aircraft (i.e. AL10 and AL50 variants) for MS&A.

3. Provide all pertinent aircraft performance data, whether simulated or real, for MS&A

4. Execute all three scenarios within the HAV performance simulation model

5. Providing all pertinent data and results collected from the execution of all performance simulations related to the three agreed upon scenarios.

6. Provide operational and maintenance cost data of all HAV aircraft used in the scenarios for comparison against current U.S. Military mobility assets.

NPS and HAV will be responsible for the following joint tasks:

1. Determine which Key Performance Indicators (KPI) will be appropriate for MS&A of all three scenarios.

2. Determine which Key Performance Parameters (KPP) will be appropriate for MS&A of all three scenarios.

3. Develop appropriate technical solutions in relation to the objectives of work.

4. Document best practices of data collection methodology testing results, and all relevant financial records for regular reporting to PI(s) and HAV leadership where appropriate.

5. Identify and plan a suitable field experimentation to demonstrate the capability (in the primary lines of effort -resilience, flexibility and rapid constitution of forces)

NPS will be responsible for the following tasks:

1. Design three scenarios to evaluate the impact that the HAV family of aircraft may have on mobility resilience and flexibility.

2. Develop Scenario One, based in the INDOPACOM Geographic region, that supports MS&A of the aircraft's impact as part of the Marine Corps Expeditionary Advanced Basing Operations (EABO) concept.

3. Develop Scenario Two, based in the Southwestern Continental United States (CONUS), that supports MS&A of the aircraft's impact on common exercise mobility requirements between six major training facilities and installations.

4. Develop Scenario Three, based within the Arctic Circle, that supports MS&A of the aircraft's impact on the deployment and redeployment of a U.S. Army Special Forces Operational Detachment Alpha (SFOD-A) and appropriate supporting equipment.

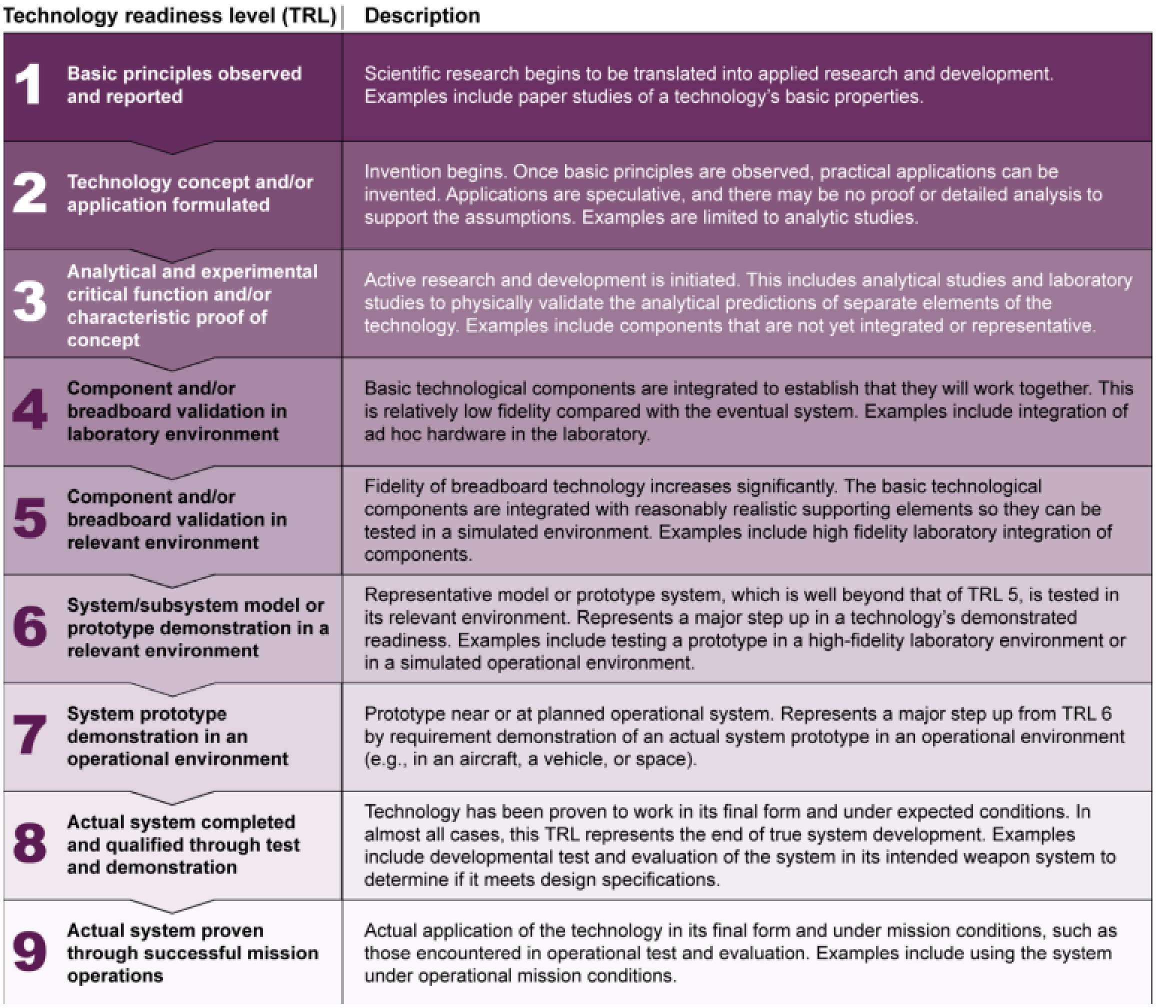
5. Provide pertinent, historical meteorological and oceanographic data that pertains to each of the three scenarios to HAV for processing in the flight simulator as part of the MS&A. This will be data that NPS has already collected and maintains within the appropriate departments.

6. Providing accurate operational and maintenance cost data related to all U.S. Military mobility assets to be used in the scenarios for comparison against the HAV family of aircraft

APPENDIX E. TECHNOLOGY READINESS LEVELS

The Technology Readiness Assessment Guide (2020b) is the source of this definition and figure:

> TRLs are the most common measure for systematically communicating the readiness of new technologies or new applications of existing technologies (sometimes referred to as heritage technologies) to be incorporated into a system or program. TRLs are a compendium of characteristics that describe increasing levels of technical maturity based on demonstrated (tested) capabilities. The performance of a technology is compared to levels of maturity (numbered 1–9) based on demonstrations of increasing fidelity and complexity. Other readiness level measures, for example manufacturing readiness levels (MRL), have been proposed with varying degrees of success and use throughout the life- cycle of a program. Some organizations have tailored the TRL definitions to suit their product development applications (p. 10).
>
> In general, TRLs are measured on a 1–9 scale, where level 1 generally represents paper studies of the basic concept, moving to laboratory demonstrations around level 4, and ending at level 9, where the technology is tested and proven, integrated into a product, and successfully operated in its intended environment. This appendix features the nine TRLs and descriptions that DOD, NASA, and other government organizations commonly use (p. 10).



Technology readiness level (TRL)		Description
1	Basic principles observed and reported	Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

APPENDIX F. COLLABORATIVE RESEARCH TOOLS

More information on each of these tools can be found by emailing research@nps.edu.

- Cooperative Research and Development Agreement (CRADA) - *https://acqnotes.com/acqnote/tasks/cooperative-research-and-development-agreement*
- Memorandum of Understanding (MOU) - *https://www.usaid.gov/sites/default/files/documents/1880/Section%206%20MOU%20Overview.public.updated022013.pdf*
- Memorandum of Agreement (MOA) - *https://acqnotes.com/acqnote/careerfields/memorandum-of-agreement-moa*
- Educational Partnership Agreement (EPA) - *https://www.navsea.navy.mil/Home/Warfare-Centers/Partnerships/Business-Partnerships/Educational-Partnership-Agreements/*
- Small Business Innovation Research (SBIR) - *https://www.sbir.gov/about*
- Small Business Technology Transfer (STTR) - *https://www.sbir.gov/about*
- Intergovernmental Agency Agreement - *https://cdola.colorado.gov/intergovernmental-agreements-igas*

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APPENDIX G. TECHNOLOGY PROGRESS MODEL

Year	Simulated fuel costs per gallon by year	Hybrid airship cost per ton-km	C-130J cost per ton-km	Hybrid airship fuel gallons burned per ton-km	C-130J fuel gallons burned per ton-km	Hybrid airships fuel cost per-km	C-130J fuel cost per-km	Hybrid airship fuel cost per ton-km	C-130J fuel cost per ton-km
0	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
1	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
2	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
3	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
4	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
5	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
6	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
7	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
8	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
9	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42
10	$3.38	$0.43	$1.64	0.45	1.50	$1.52	$5.07	$0.13	$0.42

Hybrid Airships Technology Progression Model

Year	Hybrid airships delivered to DOD	Hybrid airships delivered to Non-DOD organization	Total hybrid airships delivered by year	Cumulative number of hybrid airships delivered	DoD fleet size (# of hybrid airships) at end of year	Non-DOD total fleet size (# of hybrid airships) at end of year	Average unit production cost without DOD procurement (FY21$)	Average unit production cost with DOD procurement (FY21$)	DOD total annual cost of hybrid airships (FY21$)	Hybrid airship annual fleet operating hours	Hybrid airship annual fleet distance traveled (km)	Hybrid Airship vs C-130J cost reduction (FY21$)
0	0	1	1	1	0	1	$160,000,000.00	$160,000,000.00	$0	0	0	$0
1	2	4	6	7	2	5	$102,532,507.86	$94,754,453.91	$189,508,908	8400	1260000	$17,194,079
2	4	6	10	17	6	11	$79,645,780.06	$71,917,677.15	$287,670,709	25200	3780000	$48,204,501
3	4	8	12	29	10	19	$65,485,702.65	$59,304,583.70	$237,218,335	42000	6300000	$75,088,417
4	4	8	12	41	14	27	$56,361,498.27	$51,102,932.39	$204,411,730	58800	8820000	$98,246,888
5	4	8	12	53	18	35	$49,565,467.51	$44,970,398.23	$179,881,593	75600	11340000	$118,055,217
6	4	10	14	67	22	45	$43,668,563.37	$39,777,611.72	$159,110,447	92400	13860000	$134,839,038
7	4	10	14	81	26	55	$38,935,366.67	$35,557,025.60	$142,228,102	109200	16380000	$148,927,659
8	4	11	15	96	30	66	$34,867,686.86	$31,935,170.55	$127,740,682	126000	18900000	$160,608,080
9	5	12	17	113	35	78	$31,333,477.75	$28,725,227.93	$143,626,140	147000	22050000	$175,109,720
10	5	12	17	130	40	90	$28,316,405.75	$25,977,289.13	$129,886,446	168000	25200000	$187,026,545
Total	**40**	**90**	**130**						**$1,801,283,090**			**$1,163,300,144**
Average							**$48,274,316.86**	**$44,429,951.83**				

Hybrid Airship

Unit Procurement Cost Hybrid Airship (1st Unit)	$160,000,000	
Payload capacity	50	tons
Controlled Payload Capacity (tons)	12	tons
Airship Annual flight hours	4200	hours
Hybrid Airship speed	150	k/hr
O&S cost ton/km without fuel	$0.30	

Rate of Decay	ln(w)/ln(2)	**-0.234465254**
Learning Curve	w	**0.85**

OMB Circular A-94 Factors for Discount Rate of 7 percent

Year since Initiation, Renewal or Expansion	Year-end Discount Factors (7%)
0	1.0000
1	0.9346
2	0.8734
3	0.8163
4	0.7629
5	0.7130
6	0.6663
7	0.6227
8	0.5820
9	0.5439
10	0.5083

C-130J

Number of aircraft in fleet	100	planes
Estimated total distance flown for fleet	25000000	km
C-130J Cruise Speed	500	k/hr
C-130J Maximum Allowable Payload	23.5	tons
C-130J Maximum Normal Payload	12	tons
C-130J Average Annual Flight Hours per Aircraft	500	hours
Unit Cost (FY21$)	$85.90	million
Barrels of fuel burned per hour	17.86	barrels
gallons burned per hour	750.00	gallons
gallons burned per km using cruise rate	1.50	gallons
O&S cost ton/km without fuel	$1.22	

Airship fuel burn compared to KC-130J
30%

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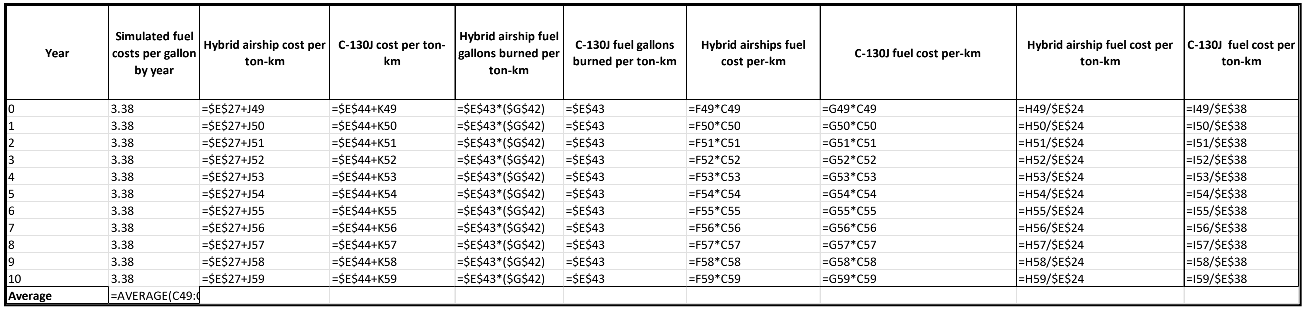
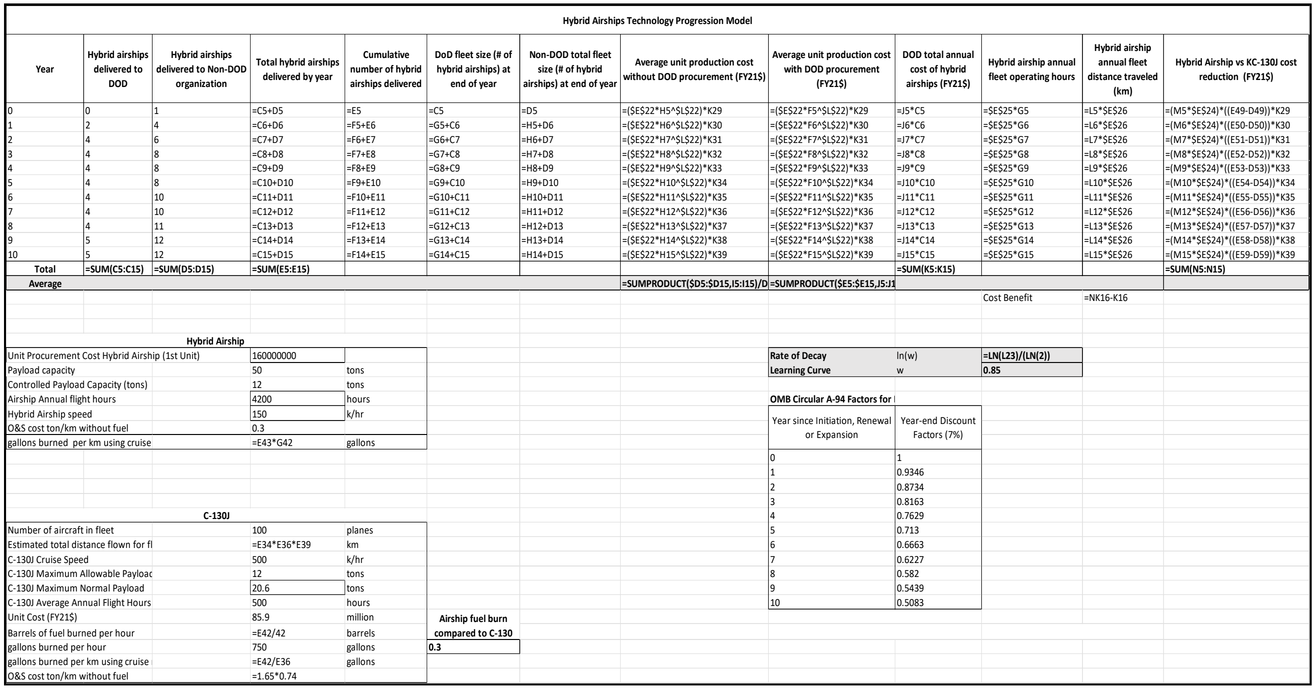
APPENDIX H. TECHNOLOGY PROGRESS MODEL FORMULAS



Year	Simulated fuel costs per gallon by year	Hybrid airship cost per ton-km	C-130J cost per ton-km	Hybrid airship fuel gallons burned per ton-km	C-130J fuel gallons burned per ton-km	Hybrid airships fuel cost per-km	C-130J fuel cost per-km	Hybrid airship fuel cost per ton-km	C-130J fuel cost per ton-km
0	3.38	=$E$27+J49	=$E$44+K49	=$E$43*($G$42)	=$E$43	=F49*C49	=G49*C49	=H49/$E$24	=I49/$E$38
1	3.38	=$E$27+J50	=$E$44+K50	=$E$43*($G$42)	=$E$43	=F50*C50	=G50*C50	=H50/$E$24	=I50/$E$38
2	3.38	=$E$27+J51	=$E$44+K51	=$E$43*($G$42)	=$E$43	=F51*C51	=G51*C51	=H51/$E$24	=I51/$E$38
3	3.38	=$E$27+J52	=$E$44+K52	=$E$43*($G$42)	=$E$43	=F52*C52	=G52*C52	=H52/$E$24	=I52/$E$38
4	3.38	=$E$27+J53	=$E$44+K53	=$E$43*($G$42)	=$E$43	=F53*C53	=G53*C53	=H53/$E$24	=I53/$E$38
5	3.38	=$E$27+J54	=$E$44+K54	=$E$43*($G$42)	=$E$43	=F54*C54	=G54*C54	=H54/$E$24	=I54/$E$38
6	3.38	=$E$27+J55	=$E$44+K55	=$E$43*($G$42)	=$E$43	=F55*C55	=G55*C55	=H55/$E$24	=I55/$E$38
7	3.38	=$E$27+J56	=$E$44+K56	=$E$43*($G$42)	=$E$43	=F56*C56	=G56*C56	=H56/$E$24	=I56/$E$38
8	3.38	=$E$27+J57	=$E$44+K57	=$E$43*($G$42)	=$E$43	=F57*C57	=G57*C57	=H57/$E$24	=I57/$E$38
9	3.38	=$E$27+J58	=$E$44+K58	=$E$43*($G$42)	=$E$43	=F58*C58	=G58*C58	=H58/$E$24	=I58/$E$38
10	3.38	=$E$27+J59	=$E$44+K59	=$E$43*($G$42)	=$E$43	=F59*C59	=G59*C59	=H59/$E$24	=I59/$E$38
Average	=AVERAGE(C49:(								



Hybrid Airships Technology Progression Model

Year	Hybrid airships delivered to DOD	Hybrid airships delivered to Non-DOD organization	Total hybrid airships delivered by year	Cumulative number of hybrid airships delivered	DoD fleet size (# of hybrid airships) at end of year	Non-DOD total fleet size (# of hybrid airships) at end of year
0	0	1	=C5+D5	=E5	=C5	=D5
1	2	4	=C6+D6	=F5+E6	=G5+C6	=H5+D6
2	4	6	=C7+D7	=F6+E7	=G6+C7	=H6+D7
3	4	8	=C8+D8	=F7+E8	=G7+C8	=H7+D8
4	4	8	=C9+D9	=F8+E9	=G8+C9	=H8+D9
5	4	8	=C10+D10	=F9+E10	=G9+C10	=H9+D10
6	4	10	=C11+D11	=F10+E11	=G10+C11	=H10+D11
7	4	10	=C12+D12	=F11+E12	=G11+C12	=H11+D12
8	4	11	=C13+D13	=F12+E13	=G12+C13	=H12+D13
9	5	12	=C14+D14	=F13+E14	=G13+C14	=H13+D14
10	5	12	=C15+D15	=F14+E15	=G14+C15	=H14+D15
Total	**=SUM(C5:C15)**	**=SUM(D5:D15)**	**=SUM(E5:E15)**			
Average						

Year	Average unit production cost without DOD procurement (FY21$)	Average unit production cost with DOD procurement (FY21$)	DOD total annual cost of hybrid airships (FY21$)	Hybrid airship annual fleet operating hours	Hybrid airship annual fleet distance traveled (km)	Hybrid Airship vs KC-130J cost reduction (FY21$)
0	=($E$22*H5^$L$22)*K29	=($E$22*F5^$L$22)*K29	=J5*C5	=$E$25*G5	=L5*$E$26	=(M5*$E$24)*((E49-D49))*K29
1	=($E$22*H6^$L$22)*K30	=($E$22*F6^$L$22)*K30	=J6*C6	=$E$25*G6	=L6*$E$26	=(M6*$E$24)*((E50-D50))*K30
2	=($E$22*H7^$L$22)*K31	=($E$22*F7^$L$22)*K31	=J7*C7	=$E$25*G7	=L7*$E$26	=(M7*$E$24)*((E51-D51))*K31
3	=($E$22*H8^$L$22)*K32	=($E$22*F8^$L$22)*K32	=J8*C8	=$E$25*G8	=L8*$E$26	=(M8*$E$24)*((E52-D52))*K32
4	=($E$22*H9^$L$22)*K33	=($E$22*F9^$L$22)*K33	=J9*C9	=$E$25*G9	=L9*$E$26	=(M9*$E$24)*((E53-D53))*K33
5	=($E$22*H10^$L$22)*K34	=($E$22*F10^$L$22)*K34	=J10*C10	=$E$25*G10	=L10*$E$26	=(M10*$E$24)*((E54-D54))*K34
6	=($E$22*H11^$L$22)*K35	=($E$22*F11^$L$22)*K35	=J11*C11	=$E$25*G11	=L11*$E$26	=(M11*$E$24)*((E55-D55))*K35
7	=($E$22*H12^$L$22)*K36	=($E$22*F12^$L$22)*K36	=J12*C12	=$E$25*G12	=L12*$E$26	=(M12*$E$24)*((E56-D56))*K36
8	=($E$22*H13^$L$22)*K37	=($E$22*F13^$L$22)*K37	=J13*C13	=$E$25*G13	=L13*$E$26	=(M13*$E$24)*((E57-D57))*K37
9	=($E$22*H14^$L$22)*K38	=($E$22*F14^$L$22)*K38	=J14*C14	=$E$25*G14	=L14*$E$26	=(M14*$E$24)*((E58-D58))*K38
10	=($E$22*H15^$L$22)*K39	=($E$22*F15^$L$22)*K39	=J15*C15	=$E$25*G15	=L15*$E$26	=(M15*$E$24)*((E59-D59))*K39
Total			**=SUM(K5:K15)**			**=SUM(N5:N15)**
Average	**=SUMPRODUCT($D5:$D15,I5:I15)/D**	**=SUMPRODUCT($E5:$E15,J5:J1**				
				Cost Benefit	=NK16-K16	

Hybrid Airship

Unit Procurement Cost Hybrid Airship (1st Unit)	160000000	
Payload capacity	50	tons
Controlled Payload Capacity (tons)	12	tons
Airship Annual flight hours	4200	hours
Hybrid Airship speed	150	k/hr
O&S cost ton/km without fuel	0.3	
gallons burned per km using cruise	=E43*G42	gallons

C-130J

Number of aircraft in fleet	100	planes
Estimated total distance flown for fl	=E34*E36*E39	km
C-130J Cruise Speed	500	k/hr
C-130J Maximum Allowable Payloac	12	tons
C-130J Maximum Normal Payload	20.6	tons
C-130J Average Annual Flight Hours	500	hours
Unit Cost (FY21$)	85.9	million
Barrels of fuel burned per hour	=E42/42	barrels
gallons burned per hour	750	gallons
gallons burned per km using cruise	=E42/E36	gallons
O&S cost ton/km without fuel	=1.65*0.74	

Airship fuel burn compared to C-130
0.3

Rate of Decay	ln(w)	**=LN(L23)/(LN(2))**
Learning Curve	w	**0.85**

OMB Circular A-94 Factors for

Year since Initiation, Renewal or Expansion	Year-end Discount Factors (7%)
0	1
1	0.9346
2	0.8734
3	0.8163
4	0.7629
5	0.713
6	0.6663
7	0.6227
8	0.582
9	0.5439
10	0.5083

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