Hold the Drones

Fostering the Development of Big Data Paradigms through Regulatory Frameworks

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***Abstract*—We are at a critical phase in the proliferation of unmanned aircraft systems as a transformative technology, and the shape of regulatory policy for the broad civil use of these systems will be a determining factor in our ability to leverage pervasive remote sensing as a strategic national capability. In this paper, we explore the state of policy for civil unmanned aircraft systems and employ historical hindcasting of trends for comparably transformative technologies to gain insights into the role of public policy and regulation in the development of strategic capabilities. While the absence of a regulatory framework for unmanned aircraft operations has been a** blind spot **negatively impacting the growth of non-military unmanned aircraft capabilities to date, a prospective framework must strike a difficult balance between freedom and security. On the one hand, the American unmanned aircraft industry requires the freedom to experiment with innovative designs and applications. On the other hand, the American citizenry demands security against the potential threats posed by the misuse and malicious use of these systems. As we demonstrate with the example of space exploration, a clear vision of the goals to be achieved with a strategic capability is needed to drive the development and sustainment of that national capability, lest resources be wasted and control over it be ceded to competing nations. Similarly, the history of car making illustrates the danger of establishing policy that facilitates technological stagnation and systemic** brittleness **by absolving private industry of the imperative to innovate competitively and in the public interest. In light of these lessons, we find that a** resilient **regulatory framework must capitalize on the potential benefits of this promising technology while respecting the danger it poses.**

Keywords- Big Data, Blind Spots, Brittleness, Pervasive Remote Sensing, Resilience, Unmanned Aircraft System

I. INTRODUCTION

Pervasive remote sensing is a significant enabling capability for conducting critical infrastructure protection and other vital missions in a Big Data paradigm [1]. In turn, the rise of Unmanned Aircraft Systems (UAS) is the primary driver of the transition from satellite-based remote sensing to a **pervasive remote sensing** capability, and represents an area of rapidly evolving technology around the world [2]. While the United States has enjoyed a relative monopoly on such technology for military applications in the first decade of the 21st century, the slow development of a regulatory framework for their broader domestic use represents a **blind spot** that has hampered the nation's ability to maintain a qualitative edge over the use of UAS as a critical enabler for a variety of strategic capabilities. While the Federal Aviation Administration (FAA) and other U.S. Government (USG) entities have limited the use of UAS for public and commercial use for the time being, the development of a regulatory framework that fosters UAS growth and outlines a strategic vision for their broader role in national capabilities will generate wealth and serve the public good. While closely related and often complementary, national and commercial strategic capabilities are distinguishable primarily by their ultimate purpose; whereas commercial capabilities are developed to generate financial profit, national capabilities are developed in order to serve a public need, such as defense. Commercial capabilities can and frequently are marketed to governments in support of a national capability (i.e., the defense industrial base, commercial satellite imagery providers, contractors and private consultants for many Information and Communication Technology (ICT)-related functions, etc.).

Nations that embrace UAS through the development of robust regulatory frameworks will be postured to leverage the benefits of pervasive remote sensing and to mitigate the threats posed by the employment of UAS for malicious purposes. Such frameworks must incorporate a wide variety of social and technical considerations, from the potential for misuse of UAS platforms and the significance of individual air rights, to the latent **brittleness** of next-generation communications infrastructure that relies upon a particular frequency of the radio spectrum that is highly sensitive to atmospheric conditions (e.g., Ka Band). The current gap in U.S. policy with regard to UAS represents both a lost commercial economic opportunity and a potential erosion of national security.

In this paper, we aim to demonstrate how the development of policy and regulation regarding UAS impacts the U.S. at a national strategic level, in particular its ability to employ pervasive remote sensing within a Big Data paradigm. We begin in Section II by establishing a systemic context for understanding the impact of policy and regulation on the advancement of transformative technology through historical hindcasting of automobile manufacturing and space exploration. The history of car making illustrates the danger of establishing policy that facilitates technological stagnation and systemic brittleness by absolving private industry of the imperative to innovate competitively and in the public interest. Similarly, the example of space exploration demonstrates the need for long term strategic vision to drive the development and sustainment of national capabilities, lest resources be wasted and control over them be ceded to competing nations. We go on in Section III to survey past and present implementation of UAS, and in Section IV we conduct a comparative analysis of national and international legal precedents which may bear relevance for UAS regulation. We find that while UAS have a significant military deployment history, as applications have expanded for their public and commercial domestic use, a commensurate regulatory framework has taken longer to develop in the U.S. While the absence of a regulatory framework for unmanned aircraft operations has been a blind spot impacting growth of non-military unmanned aircraft capabilities to date, a prospective framework must strike a difficult balance between freedom and security. On the one hand, industry requires freedom to experiment with innovative designs and applications. On the other hand, citizens demand security against threats posed by misuse and malicious use of these systems. We explore the consequences of this trend, and propose ways to improve leverage over UAS as a key enabling technology. We conclude in Section V that while current UAS policy is negatively impacting the economy and security of the U.S., such a trend is reversible. We also begin turning towards additional areas of strategic import in which a Big Data paradigm could be beneficially applied.

II. FROM CARS TO SPACESHIPS: SYSTEMIC CONTEXT FOR TRANSFORMATIVE TECHNOLOGY AND CAPABILITY DEVELOPMENT

In order to better appreciate the influence of policy on the development of pervasive remote sensing as a strategic national capability; it is illuminating to hindcast similar historical parallels. In doing so, we consider the rise of comparably transformative technologies; outlining the role they have played in national security and economic welfare. In particular, we take automobile manufacturing and space exploration as two areas which exemplify the importance of sustained innovation and forward-looking policy development. In both of these cases, we see that large investments fueled — initially — significant U.S. accomplishments, followed by a decrease in progressive momentum perpetuated by a mutually interactive combination of lax regulatory policy and industry malaise. The resulting lack of sustained innovation in both space capability and automobile manufacturing offered footholds for international competitors to capitalize on adaptations or expansions of early American achievement. In turn, the rise of international competition in both space endeavors and car making has born significant economic and national security consequences for the U.S. that help to illustrate the importance of fostering hospitable conditions to expand UAS capabilities in a Big Data Paradigm.

A. Automobile Manufacturing: the engine of innovation

The 20th century was a breakout era for mankind's advance in technological invention and critical problem-solving, which reached a crescendo with our arrival on the moon. Yet before mankind could reach into space, the car had to take him down the road. The production of the automobile begins as a story of individual rivals locked in a heated yet solitary contest to innovate, and unfolds as a lesson in the strength of group decision engineering. As illustrated below in Figure 1, automobile manufacturing was dominated by U.S. firms going into the second half of the last century, and yet the North American auto industry's doom appeared all but certain a few short years ago. The events that transpired during the intervening period show that while incremental innovation by individuals can yield significant technological breakthrough, it takes a whole society integrated around the technology's processes to truly maximize its value.

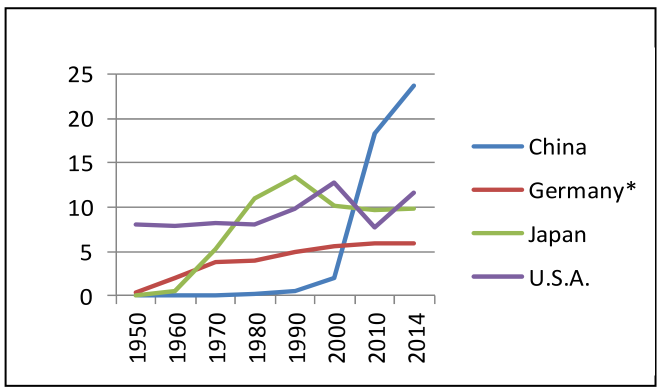

Figure 1. Annual Motor Vehicle Production (millions)
Sources: OICA; JAMA; U.S. Bureau of Transportation Statistics
West Germany prior to 1990

The first car was born out of competition to unify chemistry with physics and mathematics to achieve combustion-driven transportation. Whereas steam engines, wind power, and other power sources have remained common in transportation and other human processes, the first combustion engine fundamentally transformed individual human mobility. Two Germans, Carl Benz and Gottlieb Daimler each invented their own versions of an internal combustion engine mounted on wheeled vehicles within months of each other in 1896, working less than 100 miles apart [3]. However, it was roughly 4000 miles west and 20 years later that Henry Ford's vision of the Model T truly revolutionized transportation by socializing the construction of vehicles on a massive scale.

Ford's breakthrough was in making cars affordable and widely available by adapting mass production techniques from other industries in his design of a modular platform [4]. Early car making was a time consuming and expensive process that resulted in a product which only the wealthy few could afford. However, by the early 1920s, Ford was producing 2 million Model Ts per year at a price that average citizens could pay for. Yet, such a breakthrough would not have been possible without the advent of the electric utility industry, the socialization of production, and the development of global supply chains, which facilitated the transition from belt-shaft networks of water wheels and coal-powered steam engines to more efficient unit drive assembly lines powered by large teams of skilled workers and electric motors [5]. Ford's role as an innovator is particularly notable not for his technological inventions, but for his integration of existing technologies and human skills that allowed him to achieve unprecedented production levels at a low cost. Similarly, Edward Budd's development of metal stamping improved assembly line efficiency, and Alfred Sloan's development of a comprehensive business model for the auto industry established the blueprint for how car makers could best market their products and maximize profits by employing ever larger groups in the auto ecosystem [6]. A single individual invented the first car on Earth, but now the global auto industry system comprises 50 million members of networked teams that bring 165 thousand new cars to market each day.

For the first half of the 20th century, American car manufacturers led the global auto industry by adhering to the model established by early leaders like Ford and Sloan, but their inability to sustain innovation compromised their position as a world leader. After World War II, the Japanese government instituted policies to protect the growth of Japanese auto makers by limiting the import of foreign cars to 1% of the domestic market, while manufacturers continually improved production efficiency through the adoption of just-in-time production techniques and decreasing worker specialization in favor of flexibility [7]. By the mid 1960s, Japanese productivity levels matched and surpassed that of its U.S. competitors. A critical factor for maximizing Japanese productivity was the horizontal integration of a highly organized network of component suppliers and assemblers, or keiretsu [8]. By engendering trust through exclusive transactions, close coordination, and information sharing, these keiretsu facilitated high levels of cooperative specialization between sectors of Japan's auto industry [8]. The keiretsu also enhanced the resilience of Japan's auto industry, as evidenced in 1997 by the Toyota group's ability to coordinate the actions of over 200 individual firms and quickly redirect production of a crucial brake system component after a fire destroyed the plant that had been the component's sole producer [9]. Meanwhile, U.S. production, characterized by vertically integrated and comparatively disorganized supplier-assembler networks remained largely constant into the 1980s, at which time Japanese production efficiency levels were vastly superior. U.S. manufacturers were path dependent, falsely assuming that their production efficiency either could not or did not need to be improved.

By the time of the worldwide economic crisis of 2007, the decline of the U.S. auto industry was drawn into sharp relief in contrast to skyrocketing Chinese production, begging the question of government's role in private industry. The bankruptcy of America's Big Three car makers (General Motors, Chrysler, and Ford) threatened to inflict the loss of one million jobs on the national economy, and the USG was forced to intercede with the Automotive Industry Financing Program, an $80 billion conditional industry bailout in 2009 [10]. Following in the tradition of technology-forcing legislation, such as the Clean Air Amendment Act of 1970 that mandated a reduction in carbon emissions [11], the conditional nature of the bailout enabled the USG to further induce U.S. automakers to embrace areas of innovation, particularly hybrid and electric vehicles, in order to increase their global competiveness. Nonetheless, the potential for a government bailout was itself a component of the American car industry's **brittleness**, in that the Big Three knew they could safely rely upon the precedent of bailouts established by the 1980 Chrysler Loan Guarantee Act, the post 9/11 airline industry bailout, and many other instances of the USG rescuing private companies from financial collapse [12]. Having established a universally known precedent for bailouts, the USG — in effect — dis-incentivized car makers from adapting their production to meet an evolving market.

The American experience in automobile manufacturing illustrates the imperative for continuous innovation, and the consequences for failing to heed that imperative. The early success of American auto makers led the U.S. to become a car-dependent society, but the ability of foreign auto makers to produce better cars at a cheaper price ultimately undermined the U.S. economy. Events like the 2009 bailout demonstrate that while industries cannot be forced to act strategically, government action and public policy play an important role in the development of technology. The history of car making also demonstrates the value of complementary technology, in that just as electricity facilitated mass production, UAS can facilitate pervasive remote sensing in a Big Data paradigm.

B. Outer Space: the sky is not the limit

The space race of the mid 20th century pushed the U.S. to achieve one of humanity's greatest accomplishments in

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successfully journeying onto the moon and back, via the Apollo Program. Yet, little more than half a century later, the cession of American supremacy in space appears to be a near-term inevitability. What happened?

Driven by the Cold War urgency of winning the battle in space against the Soviet Union, the Apollo Program was a massive research and development effort with a single focus; getting to the moon first. However, the U.S. lacked a strategic vision of what to do with its hard-won space capability after achieving that feat, and was therefore challenged to follow up its huge investment with coherent progression. Although successive U.S. space programs have benefited from a more deliberate approach, they have also generally continued on Apollo's trajectory of increasingly complex and aggregated projects, which are expensive and subject to long development timelines [13].

Meanwhile, with the help of U.S. policies, other countries have developed notable space capabilities of their own. During the 1960s, the U.S. led the development of a regulated commercial space industry, with universal standards promoted by organizations like the International Telecommunications Satellite Organization (Intelsat). However, beginning in the early 1970s with the launch of the Open Skies initiative, the progressive deregulation of the satellite industry fueled the growth of global competition in space and gave rise to an increase in the number of small private firms in favor of large conglomerates like Intelsat [14]. At the same time that U.S.-led deregulation helped to increase the number of countries venturing into space, stringent export control laws severely limited the ability of American companies to capitalize on the expanding global market [15]. In addition, the refusal to carry foreign satellites into orbit aboard U.S. launch vehicles forced other countries to develop their own launch capability. A prime example of this dynamic is France's Arianespace, which was the first and remains among the world's largest commercial space launch providers [16].

While the development or acquisition of a space capability still requires significant national resources, including robust scientific and technological human capital, over 50 countries now have satellites in space and 12 have demonstrated a space launch capability [17]. To determine America's standing in this celestial mix, a review of two basic indicators is informative: where spacecraft are built and where they are launched from. Of the spacecraft launched in 2013, only 27% were manufactured in the U.S., compared with 41% in 2009 [18]. In the period 2000-2011, 80% of commercial low-earth orbit satellites and 90% of commercial geosynchronous earth orbit satellites were launched outside the U.S. [19]. These trends produce interesting outcomes, such as when the Department of Defense (DoD) is forced to rely on Chinese satellites to meet the communications requirements of U.S. Geographic Combatant Commands [20]. Yet, as commercial space operations have expanded and the nature of space capabilities have transformed, the U.S. has demonstrated its ability to continue making important breakthroughs in space. In contrast to other U.S. strategic space capabilities that rely on a small amount of large and hard to defend assets, the Global Positioning System (GPS) developed by the DoD leverages a distributed architecture consisting of a variety of assets that lend to the system's resilience by avoiding single points of failure [21]. Yet after 20 years in development, and despite becoming the world's primary navigation utility, GPS has not generated revenue to help offset U.S. investments in space and the system is vulnerable to a variety of threats including spectrum encroachment, jamming, spoofing, and space weather [22]. In addition, competing systems like Europe's Galileo, Russia's Global Navigation Satellite System (GLONASS) [23], and China's BeiDou Satellite Constellation [24] are all competing technologies with the potential to overtake the now aging GPS in the areas of accuracy and reliability.

Today, space assets are more vital to national security than ever before for their role in collecting and distributing information, but the U.S. ability to safeguard these assets is also more challenged than ever before [25]. While products of the Cold War space rivalry have been combined to achieve a monumental feat of global scientific and technological cooperation in the form of the International Space Station [26], emerging rivalries threaten to upset the extraterrestrial balance of power. In particular, China's rapidly expanding space program represents a potentially significant destabilizing force for U.S. space operations [27]. Since terminating its manned space shuttle program in 2011 in exchange for commercial crew and cargo programs, the U.S. has adopted a space strategy that relies on the cooperation and capabilities of private industry and other nations [28]. This policy shift has introduced a potential **blind spot** for the USG, in that it has divested itself of an engineering capability which took several generations to attain, and would ostensibly take several generations to reclaim. Meanwhile, China's national space program continues to progress along a deliberate and independent trajectory, gaining in sophistication with each mission [29]. Although the consequences of these divergent approaches to space have yet to fully materialize, it is clear that space is an area of increasing vulnerability for U.S. national security.

As unmanned aircraft technology advances, several key lessons from the ongoing American saga in space remain salient. First, a strategic vision of the broader capability to be achieved is a prerequisite for guiding the incremental development of scalable technology that will ultimately lead to that capability. Second, establishing a robust regulatory framework that accounts for both national security and revenue generation will ensure that a critical defense

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capability does not have to sacrificed, because it is too expensive. This includes the ability to reconcile export control restrictions and allow industries to compete globally by marketing their technology overseas. Humanity's arrival in outer space is arguably among the most historically significant events in Earth's history, and the ecosystem of teams that can harness the potential of unmanned aircraft will propel the trajectory of exploration and capability into even as-yet unknown moments of innovation [30].

III. A Brief History of Unmanned Aircraft systems

Having seen how automobiles transformed ground transportation, we now move on to explore how the rise of unmanned aircraft and related systems is transforming aviation. Similar to the development of space capabilities, we will see how UAS grew from a national security tool into a ubiquitous technology. We will first trace the roots of early UAS application in war fighting and proceed to enumerate the diverse variety of devices and applications that have since evolved. Unmanned flight is not a recent development, but the increasing omnipresence of unmanned systems and their continually expanding functionality is novel. UAS, which include Unmanned Aerial Vehicles (UAVs) or drones, Remotely Piloted Aircraft (RPA), and other related technology refer to an aircraft and its associated elements that can operate without a human pilot onboard [31].

The history of unmanned flight is closely tied to international conflict and the evolving requirements of military operations. Indeed, the genesis of Unmanned Aircraft (UA) dates back nearly a century, to when American, British, and German inventors worked to develop aircraft like the Curtiss Speed-Scout and Kettering Bug for use in World War I [32]. During World War II, the British Queen Bees, American Denny Drones and German V-1 Buzzbombs were employed as pilot training aids in target practice and explosive ordinance delivery systems [33]. As the conclusion of the Second World War segued to a more protracted Cold War, Intelligence, Surveillance, and Reconnaissance (ISR) became a vital national capability. With the downing of U2 spy planes and capture or death of their pilots in 1959 over the Soviet Union and Cuba in 1962, the U.S. was forced to recognize the value of unmanned reconnaissance aircraft, and the Air Force and Central Intelligence Agency coordinated through the National Reconnaissance Office (NRO) to develop multiple variants of the Ryan Firebee, which were flown extensively during the Vietnam War in order to conduct surveillance and battle damage assessments [34]. While the intelligence community was a significant contributor to the development of unmanned capability, via the NRO, through the 1970s and into the 1980s, the U.S. reduced its focus on UAS in favor of satellite reconnaissance, and by 1991, the U.S. looked to Israel's Pioneer unmanned platform for ISR support over Iraq [35]. While satellites are a vital component of national intelligence capability, they are constrained in their ability to adapt to mobile objects of interest. The re-commissioning of SR-71 Blackbirds into military service in the mid 1990s demonstrates the unchanging need for a responsive and flexible reconnaissance capability, which satellites simply cannot fulfill in light of their fixed orbits [36].

As a result of Pioneer's significant contributions during the Persian Gulf War, the DoD increased its own research and development efforts for unmanned systems, and fielded the Predator in operations over the Balkan Peninsula in the mid 1990s. Imagery generated by the Predator and other remote sensing assets was so useful during negotiations of the 1995 Dayton Peace Accords that the National Imagery and Mapping Agency (NIMA) was created the following year, combining personnel from eight agencies to lead the integration of cartographic imagery and intelligence analysis [37]. The USG continued to increase its investment in UAS into the new millennium, and NIMA's transformation into the National Geospatial-Intelligence Agency (NGA) in 2003 represents the vital role that remote sensing has come to play in national security.

While NGA is the USG's lead integrator of remote sensing imagery, including that collected with unmanned aircraft, each of the military services now employ a large and diverse fleet of UAS for a variety of long-endurance and high-risk missions. These include ISR, force protection, resupply, signals collection, and direct strikes [38]. In fact, the DoD's inventory of UA is fast approaching that of manned aircraft, at roughly 7,500 and 10,700, respectively [39]. And these unmanned assets are generating vast amounts of data; at the height of U.S. campaigns in both Iraq and Afghanistan, UAS generated 24 years' worth of surveillance in a single year [40]. The operation of just one Global Hawk UAS generates 500 megabits of data per second, which is about five times the satellite-relayed data flow or bandwidth used by the entire U.S. military during the Persian Gulf War [41]. The explosion in data throughput requirements brought on by UAS capability has introduced its own set of challenges, as the expansion of fiber optic cable networks have stunted the growth of satellite bandwidth. During early deployments at the onset of Operation Enduring Freedom in Afghanistan, operators of the Global Hawk frequently had to lower its video resolution and cope with fuzzier images in order to avoid overwhelming the capacity of communication systems. Indeed, the availability of satellite bandwidth will continue to be an important consideration for both military and civil UAS operations going forward.

While the technical achievements of UAS in war are significant, it is important to note that their use for kinetic operations or direct strike missions is not without

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controversy [42]. The United Kingdom's Ministry of Defence has acknowledged that unmanned direct strikes may actually undermine military campaigns by giving adversaries a "potent propaganda weapon" [43]. The precedent which the U.S. and its coalition partners have established by using UAS overseas for targeted killings raises important questions about international regulation in light of recent developments in Pakistan and elsewhere [44]. We will explore this issue further in the following section.

While the military service record of UAS for carrying out dull, dirty, and dangerous missions is well-established, their employment for non-military use represents an area of potentially enormous expansion. As demonstrated below in Figure 2, military applications continue to dominate UAS sales, and the civil UAS market is controlled by a small number of manufacturers. Within non-military UAS applications, the FAA delineates three broad civil categories: public (i.e. governmental), commercial, and private. UAS use is growing rapidly in each of these areas, as we will further explore below.

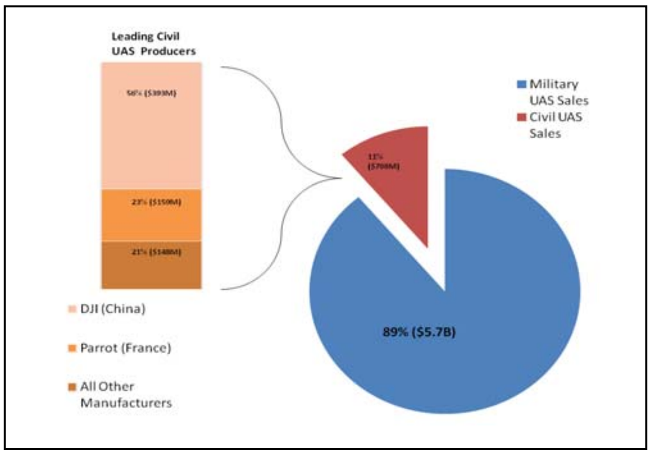

Figure 2. Estimated 2014 UAS Market Characteristics, Sources: Bloomberg News; Teal Group Corporation

Employing UAS as remote sensors holds promise for many public services; because it enables civilian government agencies to collect information that otherwise would be prohibitively expensive to gather using manned aircraft or satellite surveillance. Such a capability can be particularly valuable in safeguarding critical infrastructure and responding to natural disasters. For example, the early detection and continuous tracking of forest fires is a perennial challenge due to the inaccessible and mountainous terrain in which many fires occur. However, by using UAS to detect the outbreak and monitor the path of forest fires, state and federal responders are able to safely and more effectively stop their spread [45]. Similarly, law enforcement officers are beginning to use drones to detect illegal activities and track perpetrators, a capability that was historically limited by the cost of manned helicopters [46]. The Department of Homeland Security has been using UAS since 2004 to help close the gap in its ability to monitor isolated portions of the southern U.S. land and littoral borders, and today operates a fleet of 10 UAS platforms, with plans to expand the program in the future [47]. UAS can also play a pivotal role in environmental monitoring and enhancing our ability to understand and predict extreme weather phenomena by enabling scientists to collect more precise and complete climatic data, with the National Aeronautic and Space Administration's Helios project being one notable example [48]. Similarly, natural resource management efforts, including analysis of the effects of livestock grazing on the health of rangeland ecology are benefitting from UAS capabilities [49]. Remote sensing via UAS is also enabling federal and state Departments of Transportation to conduct traffic surveillance, assess road conditions, analyze travel patterns, and detect emergencies [50]. These examples are only a glimpse of the many potential benefits to be gained by the public use of UAS.

Commercial applications for UAS are equally varied, with only a small portion of potential uses having been realized thus far. In addition to the potential for UAS to enhance critical infrastructure protection, which combines aspects of public safety and commercial benefit, there are many opportunities for improved business efficiency. In Japan, 90% of all precision pesticide-spraying is done with a fleet of over 2500 unmanned helicopters [51]. Other examples include real estate mapping, aerial news and sporting event coverage, movie and television production, and cargo transportation. As UAS technology becomes more affordable, it is reasonable to expect that pervasive remote sensing itself will be marketed as a commodity in much the same way that smart phones have given rise to novel data-driven services [52].

Private UAS use carries on a well-established tradition of model aircraft piloting for recreational purposes, but also represents a significant threat if used for malicious purposes. As we have demonstrated in earlier research, UAS represent an important component in Improvisational Malignant Devices (coined as IMDs), which are characterized by low levels of sophistication and required resources, yet can yield significant destabilizing impact on complex systems such as critical infrastructure. While the U.S. has demonstrated some success in averting plans to employ UAS in malicious acts [53], events like the recent White House fly over and crash landing underscore the challenges associated with quickly detecting and responding to such acts as they occur [54].

IV. COMPARING U.S. AND INTERNATIONAL LEGAL PRECEDENT TO INFORM UAS REGULATION

Having established the comparatively long history of UA operations, and the wide variety of applications into which their employment has expanded, we now turn to the policies and regulations which govern their use. While Congress has mandated that regulations be developed to govern the operation of UAS in the National Airspace System (NAS) before the end of this year, the policy of the FAA for the last ten years has been to broadly prohibit the operation of UAS for public or commercial purposes, instead regulating their exceptional limited use by issuing special air worthiness certificates and certificates of waiver or authorization [55].

This tact contrasts sharply with the U.S. Commercial Remote Sensing Policy, which asserts that maintaining the nation's leadership in remote sensing activities and enhancing the industry will protect national security and foster economic growth [56]. A more deliberate policy linkage between remote sensing and UAS could go a long way to reconciling this divergence, and promoting the advance of national capabilities in pervasive remote sensing. The FAA's recent release of a notice of proposed rulemaking for operation and certification of small UAS is a promising first step towards opening a sliver of the NAS to commercial unmanned activities [57]. The proposal reflects a balanced incremental approach, as it would place narrow limits on UAS operations and institute safe guards such as security threat assessments for prospective operators and mandatory device registration.

With regard to private operations, FAA's guidance for model aircraft from 1981 has been applied to UAS, advising that aircraft be operated away from populated areas at no higher than 400 ft above the ground, at least three miles from airports [58]. However, as with the proposed small UAS rule, such an advisory relies largely on the ability of local law enforcement to detect the misuse of UAS, and does not establish a systematic mechanism for addressing misuse or malicious use. As Figure 3 illustrates, there are a variety of complex dynamics at play in UAS regulation.

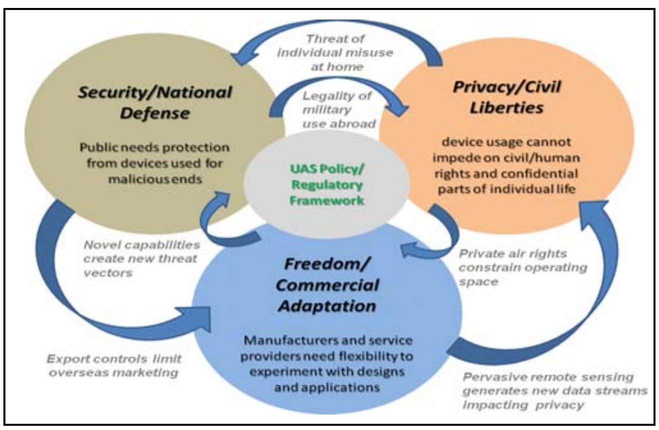

Figure 3. Sample of competing systemic factors impacting the development of comprehensive UAS policy

Indeed, any robust regulatory framework for unmanned aircraft operations must address the **blind spot** of maliciously-employed UAS as an emerging threat vector.

To be sure, the development of policy for the broad civilian use and commercialization of domestic unmanned flight is no simple task. The difficulty of this task is compounded by the need to ensure harmony with a variety of contending issues as depicted in Figure 3, not to mention the technical complexity of UAS themselves.

While the FAA has rightly focused on the practical mechanics of safe operation, such as sense and avoid protocols, airworthiness standards, and pilot certification [59], a host of broader existential challenges also loom. For example, the case law for air rights establishes that the owner of a property also owns and is entitled to exclusive use of as much of the uncontrolled airspace above that property as they are reasonably capable of using [60].With the advent of UAS, property owners are now capable of using much more of their airspace. Therefore, a careful balance must be struck to ensure that public and commercial UAS are able to operate effectively without infringing on citizens' rights to their own airspace. Meanwhile, defining what constitutes acceptable use of one's airspace is also a central concern. As the State Department has encountered resistance from host nations regarding the U.S. authority to collect and disseminate data from the airspace above its embassies [61], it is clear that enhanced data collection capability will require more sophisticated forms of regulation.

In addition to reconciling potential conflict with existing law, UAS regulations must also complement the FAA's larger Next Generation Air Transportation System (NextGen) transformation effort [62]. NextGen aims to leverage satellite communication to supersede the currently overburdened radar systems in order to increase air traffic volume, safety, and efficiency. But, how to achieve these goals while integrating UAS is an open question, albeit one that appears to lend itself well to a Big Data paradigm based on effective management of increased data availability. In the NextGen system, more networked communication between air traffic controllers, aircraft pilots, and aircraft themselves will result in much larger amounts of data being generated, which raises important socio-techno concerns. Broadly speaking, we must determine how the roles of man and machine in air traffic control operations should evolve. More specifically, we must determine whether trends such as the Federal Communications Commission's support of an industry-wide shift from the Ku to Ka frequency bands for satellite links with UAS and other earth stations is introducing **brittleness** into the national communications infrastructure in light of Ka band's demonstrated vulnerability to signal attenuation in moist atmospheric conditions [63].

Although the tenets of international UAS regulation are perhaps even more ambiguous than those of U.S. policy, a review of legal precedent is instructive. The basic freedoms of the air established in the Chicago Convention and promoted by the United Nations (UN) International Civil Aviation Organization (ICAO) address issues of passenger aircraft, providing that states may grant each other the privileges of flying across, landing in, taking on, and putting down traffic between states [64]. The ICAO has identified preliminary steps to bring UAS under the Chicago Convention rubric, but the transformative nature of the technology may warrant an even more fundamental restructuring of the framework governing air operations.

In this regard, the principles guiding maritime affairs potentially offer insight. In particular, Admiralty Law governing maritime navigation and shipping establishes that a ship's flag determines the source of law, such that vessels traveling outside their own national waters remain subject to the laws of their home nation. Assuming the U.S. and other nations develop regulations for the use of UAS in their own borders, applying the Admiralty principle to unmanned operation in international airspace appears logical. In addition, the UN Convention on the Law of the Sea (LOS) [65] establishes territorial seas in which the sovereignty of a state is extended 12 miles beyond its shore, including airspace above the water. Foreign vessels are permitted innocent or transitory passage through another nation's territorial waters, but solely for the purpose of traversal. Notably, conducting any survey activities during the passage of another nation's territorial waters is construed as prejudicial to the peace of that nation, and therefore illegal. The Convention also establishes Exclusive Economic Zones (EEZs) extending 200 nautical miles from a sovereign nation's shore in which that nation enjoys exclusive commercial and exploratory rights. Any area outside the territorial seas and EEZs are designated as the high seas, and are open to all states for peaceful purposes.

Extrapolating from the LOS, international airspace correlates neatly to the high seas and controlled national airspace correlates to territorial seas, but what about exclusive economic zones? As remote sensing capabilities expand with UAS, public and commercial applications requiring global circumnavigation will undoubtedly emerge. U.S. national airspace above 60,000 feet is currently designated Class E, the least regulated of any of the six airspace classes. Looking above the atmosphere, the Outer Space Treaty establishes that all nations and non-governmental organizations have the right to freely explore outer space without any discrimination [66]. From this context, an upper limit of nationally controlled airspace above which nations could freely navigate UAS is conceivable.

The employment of UAS across international borders for military operations is governed by established laws of armed conflict such as the 1949 Geneva Convention, yet new precedent is unquestionably being established by the U.S. amidst its global pursuit of Al-Qa'ida and affiliated entities [67]. Whether the protracted deployment of UAS for worldwide low intensity applications of force is indeed conducive to a stable international system is somewhat doubtful. In contrast, the Antarctic Treaty System (ATS) offers a more viable alternative. It establishes that as the only continent with no recognized or disputed claims of sovereignty, Antarctica will be used solely for peaceful purposes, namely scientific investigation and cooperation between its 50 signatories. While conflicts regarding the ATS do arise, such as the dispute between militant conservationists and whale "research" vessels [68], the cooperative spirit of the ATS lends credibility to a similarly open arrangement for globally operating UAS. Enabling the use of UAS for pervasive remote sensing increases our data collection capacity, this in turn increases our understanding of complex phenomena and contributes to enhanced **resilience**. However, addressing the privacy and security ramifications of a global pervasive remote sensing capability will be of chief importance to future international UAS regulations.

Although the exact form of UAS regulation has yet to crystallize, several facts are clear. First, the de-facto ban on public and commercial operations in the U.S. has confined the development of non-military UAS production. It is estimated that growth of the civil UAS industry will generate 70 thousand jobs in the first three years of integration and $80 billion over the next ten years, with each day of non-integration representing nearly a $28 million loss [69]. Indeed, the world's top two producers of commercial UAS are outside the U.S., and in an ironic turn of events, the platform being touted as the "Model T of unmanned aircraft" – The DJI Phantom – is being produced in the Silicon Valley of the East; Shenzhen, China [70]. Second, as UAS become more widely available, their potential to destabilize **brittle** systems through accidental misuse or deliberate malicious action will increase. Although they are areas for future research, geo-fencing and mandatory device registration are two possible components of a technical solution to UAS malicious use. More generally, developing policies and regulations that foster innovation and harness UAS as pervasive remote sensors can both mitigate the potential threat of **blind spots** posed by such technology while leveraging it to enhance **resilience**. Most importantly, creating a strategic vision that builds on the military and intelligence value of UAS by incorporating the technology into each of the remaining elements of national power can strengthen the nation's economy and expand its diplomatic reach.

V. CONCLUSION

From the assertion that Big Data is essential to building critical infrastructural **resilience**, we have come to the question centering upon how that capability is actually developed at a national strategic level through public policy and regulation. We are at a critical phase in the proliferation of unmanned aircraft systems as a transformative technology, and the shape of regulatory policy for the broad civil use of these systems will be a determining factor in the fate of pervasive remote sensing as a strategic national capability. UAS offer a potential doorway to pervasive remote sensing in a Big Data Paradigm. But, in order to unlock the door, public policy must catch up with

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technology. Our historical hindcasting of trends in international space capability and automobile manufacturing underscore the influence that policy and regulation exert on the development of transformative technology. Through these cases, the potential for **blind spots** in public policy to introduce **brittleness** into critically important national capabilities is clear. A resilient civil UAS regulatory framework can and must capitalize on the potential benefits of this promising technology while respecting the danger it poses. Unmanned aircraft systems have shown significant success as a tool for generating Big Data to inform overseas military and intelligence operations, yet as applications are quickly expanding worldwide for their civil use, a commensurate regulatory framework for the systematic integration into the national airspace system has taken longer to develop. This constitutes a significant **blind spot** that is resulting in a loss of economic opportunities and degradation of national security.

While unmanned aircraft pose a unique set of policy challenges, the development of a robust regulatory framework for their civil operation is not an insurmountable task. In order to be effective, such a framework must outline a strategic vision for employing UAS as a national capability while directly addressing the security threats posed by such technology. In particular, sound UAS policy will include mechanisms that incentivize industry to develop technology that is both commercially competitive in the global marketplace, and complementary to national strategic priorities. In turn, the technological advantages presented by unmanned aircraft systems have the potential to yield vast increases in the amount of data available to engineer more sound decisions, including decisions regarding the prevention and mitigation of UAS malicious use.

This increase in available data and enhanced decision engineering is at the core of a Big Data Paradigm for pervasive remote sensing, and can improve our approach to a variety of missions, including critical infrastructure protection, homeland defense, law enforcement, resource management, environmental stewardship, and disaster response. Pervasive remote sensing will drive the advance of analytics in a host of commercial and research fields, as it makes more data available. However, this potential can only be realized if the proliferation of UAS is managed proactively and wisely. In light of a Big Data paradigm’s value for these issues, we look forward to future work exploring what other areas of strategic interest might similarly benefit from such a paradigm.

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