AIR & SPACE POWER JOURNAL - FEATURE

Infrastructure Truths for Air, Space, and Cyberspace

Col Joel A. Sloan, USAF, PhD, PE
Lt Col M. Scott Stanford, USAF, PhD, PE
Dr. Thomas J. Phelan, PE, BCEE
Lt Col James B. Pocock, USAF, Retired, PhD, RA

Introduction

The importance of the air base and the physical infrastructure that it contains to the success of air operations is not a new concept. There is a general acknowledgment in the Air Force today that the air base itself is a "weapons system." As former Secretary of the Air Force Dr. Heather Wilson stated with the release of the Infrastructure Investment Strategy (I2S), "in the Air Force, we fight from our bases. . . the places we call home are also the platforms from which we project combat power."[1] The Air Force major command (MAJCOM) commanders further stated that "the foundation of Air Force readiness and lethality is an integrated network of resilient installations that enable advanced-generation, multidomain operations while also providing safe communities for our Airmen and families."[2] Nevertheless, budgets are tight, and it is often difficult to quantify the value provided to the mission through the investment in physical infrastructure or the risk to mission associated with neglecting infrastructure. To that end, this article describes a succinct set of "infrastructure truths," clear statements of the foundational principles of infrastructure management. Airmen and Guardians can use these principles to guide advocacy and funding decisions at all levels of leadership. To set the stage for these truths, this article includes a brief history of the important role that air base infrastructure has played in airpower employment with logical extensions to space and cyberspace and a brief review of current doctrine pertaining to infrastructure. Although infrastructure has a broader definition in some contexts, including industries and institutions, the focus of this work is on the physical infrastructure—the facilities, airfield pavement, and utilities that are integral components of mission success.

Infrastructure and Airpower—Historical Linkages

Although air bases looked much different in the early days of aviation than they do today, aviation pioneers recognized the importance of air base infrastructure to successful air operations. Airpower's reliance on physical infrastructure preceded the first powered flight. Photographs of the Wright brothers' first powered flights in December 1903 depict the Wright Flyer taking off from the first runway, a wooden monorail track, rather than asphalt or concrete-like modern runways. Given the modern reliance on concrete and asphalt runways, it is appropriate that this first flight launched from something other than an unimproved field or the bare sand at Kitty Hawk. The brothers' early photos also show two wooden buildings—the first aircraft maintenance shop and support building.

Likewise, in the first operational deployment of airpower, Maj Benjamin Foulois led the 1st Aero Squadron to support Brig Gen John J. Pershing's mission to locate and apprehend Pancho Villa in 1915. Operating from Columbus, New Mexico, the squadron conducted 548 flights.[3] Through the course of the mission, Major Foulois learned the seemingly obvious fact that air operations are inherently dependent on fixed bases when he remarked that "one or more aero squadrons operating in the field should have a base, conveniently located, from which all supplies, material, and personnel should be drawn."[4]

For many years, these first bases used grass fields or semiprepared strips since the combination of aircraft weight, tire pressure, and soil conditions required nothing more in the form of a runway. As aircraft became more technologically sophisticated and increased in weight, and the military leaders employing them demanded all-weather operations, the requirements for preparing runways and support facilities increased. The "airdrome" environment gradually evolved to a full-fledged air base with the standard training airfield design in World War I, consisting of 50 buildings to support 100 aircraft, 150 student pilots, and their instructors.[5]

Gen Henry H. "Hap" Arnold recognized the growing importance of the installation when he stated in 1941 that "air bases are a determining factor in the success of air operations. The two-legged stool of men and planes would topple over without this equally important third leg."[6] Campaigns in both Europe and the Pacific during World War II illustrated the importance of basing infrastructure. At the time, the Army Air Corps included more than 120,000 aviation engineers who built, improved, maintained, and operated airfield infrastructure. Aviation engineers from the IX Engineer Command constructed and opened the first landing strip on Utah Beach approximately 15 hours after the beginning of the D-Day invasion. What followed was best summarized by an aviation officer as he briefed the 834th Engineer Battalion: "you engineers have the vital job of paving the way for the air cover to back us up all the way to Berlin. Each base you build will be a steppingstone toward victory because the faster you move and work, the faster 'the air' moves and gets at the enemy—up close where it counts."[7] By V-E Day on 8 May 1945, the IX Engineer Command built or refurbished 241 airfields in France, Belgium, Holland, Luxembourg, and Germany with a peak production of opening a new airfield every 36 hours. In total, engineers built, improved, or maintained 1,435 airfields for the Army Air Forces in 67 countries during World War II.[8]

The end of World War II saw a significant reduction in the number of installations and infrastructure. The reduction in conventional capabilities was short-lived as the Cold War required the development of the nation's nuclear capability, along with infrastructure investment and expansion to support those new capabilities. The inventory of Air Force facilities grew from $3.1 billion in 1950 to $8.9 billion in 1958—an increase of approximately $51 billion in 2020 dollars in just eight years.[9] Despite this investment, Gen Curtis LeMay testified to Congress in 1956 that "the building of bases has lagged behind the production of airplanes to form wings; this has resulted in a shortage of bases and a crowding up of units and aircraft on bases."[10] LeMay and then Chief of Staff of the Air Force (CSAF) Gen Nathan Twining feared that overcrowding at installations provided the Soviet Union with easy targets and sought to disperse aircraft at new installations.

The Vietnam conflict required contingency buildups and bed-downs as the Department of Defense (DOD) executed what some have called the "largest military construction project in history" that entailed the construction of six new airfields in Vietnam, adding six more in Thailand, enlarging two French-constructed airfields, and constructing 100 smaller airfields and landing sites for helicopters and smaller aircraft, along with new ports and roads, around South Vietnam.[11] The DOD created Prime Base Engineer Emergency Force and Rapid Engineer Deployable Heavy Operational Repair Squadron Engineers units to construct, operate, and maintain air installations with as many as 55,000 military engineers from all services present in Vietnam.[12]

The 1990 buildup to the Gulf War saw aircraft deployment to numerous locations in the Persian Gulf region. Perhaps the most important contribution pertaining to infrastructure and warfare came from the perspective of targeting the enemy's infrastructure as CNN and other news outlets played clips of precision munitions destroying Iraqi infrastructure with pinpoint accuracy. Although adversaries targeted infrastructure in conflicts dating back hundreds, if not thousands, of years, precision-guided munitions and the targeting strategy in Col John Warden's concentric ring theory made this historical period significant. In Warden's theory, physical infrastructure is a key component of the enemy's system as the third most critical ring, along with leadership, organic essentials, the population, and the fielded military.[13] Warden demonstrated that, in addition to understanding how protection of our critical infrastructure is a key component to sustain our mission, it is equally important to understand how disrupting the enemy's infrastructure can affect their ability to govern and wage war.

The end of the Cold War and drawdown after the 1991 Gulf War brought a reduction in budgets, force structure, and personnel. The inextricable linkage between infrastructure and force structure became readily apparent through the Base Realignment and Closure rounds in 1988, 1991, 1993, 1995, and 2005 as basing and infrastructure were reduced in accordance with the reductions in both personnel and weapons systems.[14] Since the end of the Gulf War, the Air Force had 60 percent fewer fighter squadrons and 40 percent fewer Airmen but surprisingly only 15 percent fewer CONUS installations with a current estimate of 24 percent excess infrastructure capacity.[15] Considering the Government Accountability Office has rated DOD support infrastructure management as "high-risk" since 1997, this complicates leaders' decision-making process when determining how to allocate precious resources among research and development of new capabilities, current operational capability, quality-of-life improvements, and infrastructure investment.[16]

Infrastructure and Current Doctrine

This brief historical review demonstrates the reliance of United States Air Force (USAF) combat power on the air base and the physical infrastructure it contains. Further, it underscores a fundamental tenant of Air Force doctrine that "[a]irpower results from the effective integration of capabilities, people, weapons, *bases, logistics, and all supporting infrastructure*."[17] Without the public and private infrastructure on both sides of the air base fence-line, the traditional weapons systems (e.g., aircraft, intercontinental ballistic missiles, satellites, etc.) are ineffective—airplanes need a runway and satellite control requires reliable power. Cyber and remotely piloted aircraft (RPA) operations require facilities with resilient and reliable building systems (e.g., air conditioning to keep servers from overheating and reliable backup power). Airmen and space professionals operating across all domains require the services that physical infrastructure provides, such as clean drinking water, adequate sanitation, and suitable housing, whether at home station or deployed. All these infrastructure components are integrally linked to successful mission execution.

Air Force Basic Doctrine Volume 1 further states that "supporting bases with their people, systems, and facilities are essential to the launch, recovery, and sustainment of Air Force forces. . . the availability and operability of suitable bases can be the dominant factor in employment planning and execution."[18] Former CSAF Gen David Goldfein summarized this point succinctly when he stated, "we don't project power without the network of bases and infrastructure needed to execute multidomain operations."[19]

The 2018 *National Defense Strategy* (*NDS*) summary also makes it clear that air superiority is not an inherent right that US forces will always enjoy and that there are no sanctuaries from enemy attack. The future employment of airpower will require sufficient air base defense capabilities to protect the aircraft, people, and infrastructure therein, and may require "smaller, dispersed, resilient, adaptive basing that include active and passive defenses."[20] Recent publications have noted that air base defense can easily "fall between the cracks" between the Air Force, Army, and host nation support, leading to potential vulnerabilities to the mission, and that the base itself may be an "Achilles heel,"[21] as current doctrine fails to give requisite attention to the importance of the air base in airpower employment. Operations planning doctrine reinforces that developed basing infrastructure is a concern, particularly during contingency operations. Recently released doctrine on Joint All-Domain Operations states that operational units may not be able to rely on the level of infrastructure support that they enjoyed in recent history while directing units to question assumptions about the availability of logistics and infrastructure support.[22]

A careful reading of the *National Security Strategy* (*NSS*) and *NDS* summary reveals several important themes pertaining to physical infrastructure:

- The protection, resilience, and security of US critical infrastructure
- The use of infrastructure for malicious purposes by transnational criminal organizations
- Quality infrastructure as a mechanism to stimulate the US economic power
- Modernizing key defense infrastructure, particularly nuclear infrastructure
- Infrastructure investment by China and Russia across the globe to expand influence over other governments and gain access to natural resources

As shown in figure 1, the word *infrastructure* appears in these documents as often, if not more, than other terms commonly recognized as vital to the USAF and USSF missions—for example, nuclear, cyber, and space, as well as emerging technologies such as artificial intelligence and hypersonics. Further, energy is a fundamental component of infrastructure and a key theme in these documents.

Based on the foundation in the *NSS* and *NDS*, the Infrastructure Investment Strategy describes a strategic commitment to manage USAF infrastructure better and to fund it appropriately at an annual minimum of 2 percent of the plant replacement value, the capital cost in present dollars to replace the USAF's physical infrastructure.[23]

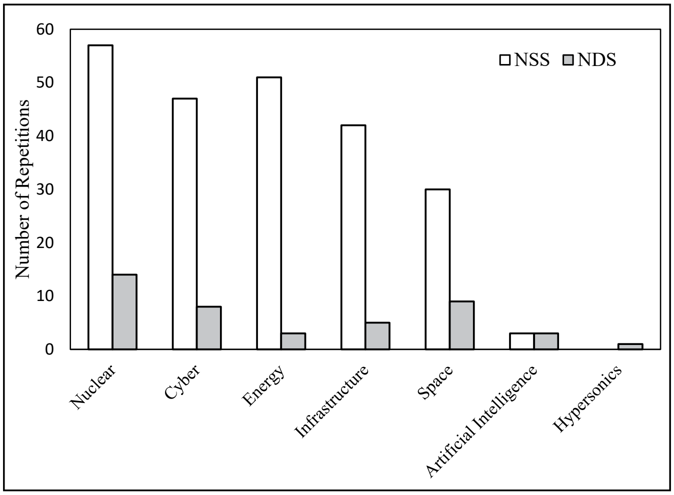

Figure 1. Repetitions of keywords in the 2017 *National Security Strategy* and 2018 *National Defense Strategy* Summary

Sources: *NDS* and *NSS*

Infrastructure Truths

Physical infrastructure will continue to play an ever more important role due to the increasingly complex requirements of current and future weapons systems and the reliance of these weapons systems on an infrastructure backbone of support. As such, it is helpful to have a common understanding of the role that infrastructure plays in executing air, space, and cyberspace operations. The special operations community defines five special operations force (SOF) truths to help military and civilian leaders understand the differences in employing SOF compared to conventional forces. As an analog, the following five "infrastructure truths" are proposed to develop a common understanding of infrastructure as a critical component of the mission and communicate the role that infrastructure plays in the Air and Space Forces' multidomain mission. Figure 2 shows the five infrastructure truths, along with a brief description of each. The subsections that follow define each truth in further detail.

INFRASTRUCTURE TRUTHS

1. **Infrastructure is an integral component of air, space, and cyber operations.**
   Based on the lessons of history and the guidance of current doctrine, physical infrastructure inside and outside the air base fence-line is an integral component of success in air, space, and cyberspace.

2. **Quality infrastructure requires investment.**
   Quality infrastructure that enables the mission requires time and money to build, maintain, and protect.

3. **Critical infrastructure systems must be sustainable and resilient.**
   Infrastructure is a network of systems that must be sustainable and resilient, as problems at one node of the system can cause cascading effects elsewhere.

4. **Neglecting infrastructure puts the mission at risk.**
   If the infrastructure fails, the mission fails…and costs to repair and maintain physical infrastructure only compound with time.

5. **Infrastructure is for all leaders.**
   All leaders must be aware of the status and capabilities of infrastructure systems within their span of control, from military family housing to runways, maintenance facilities, and operations centers.

Figure 2. Infrastructure truths

1. Infrastructure Is an Integral Component of Air, Space, and Cyber Operations.

This statement naturally follows from the historical review of infrastructure and airpower, and the current doctrine outlined previously. The Air Force Infrastructure Investment Strategy begins: "Installations—both enduring and expeditionary—are foundational platforms from which the Air Force successfully executes its five core missions–air and space superiority; intelligence, surveillance, and reconnaissance (ISR); rapid global mobility; global strike; and command and control."[24] Put simply: without reliable infrastructure, our squadrons and wings cannot deliver the readiness or combat power that our nation requires.

Further, airpower is inherently different than combat operations on the ground or at sea due to the shorter duration that aircraft can be self-sustaining compared to Army mechanized or infantry units and Navy ships. Even with the benefit of aerial refueling, the time aircraft remain aloft is measured in minutes and hours compared to the weeks or months a nuclear-powered ship can remain at sea. Most weapons systems require air base infrastructure within close proximity to the mission objective and "up close where it counts," in the words of the World War II briefing officer. In the case of manned and unmanned ISR platforms, the closer the better since finite fuel capacity makes the time-on-target inversely proportional to the transit time between the installation and the objective.

Although this historical review focuses primarily on airpower, reliable infrastructure is equally vital, if not more so, to space and cyber operations. Control of satellites and execution of offensive and defensive cyber operations require a network of military, public, and private systems. These systems must have highly reliable power and cooling systems, uninterrupted satellite and fiber-optic relays, and many other physical infrastructure components. The vast majority of these systems require redundancy for backup because a downtime of even a few seconds or minutes can be detrimental to mission success, which is one reason for executing "black-start" exercises emphasizing continuity of operations during outages.[25]

2. Quality Infrastructure Requires Investment.

Physical infrastructure that provides the robustness, redundancy, and reliability to execute the mission demands significant time, money, and effort to create and maintain. In short, managing infrastructure is resource-intensive and requires continued investment over time. Physical infrastructure systems consist of large-scale components made of steel, concrete, wood, copper, and custom-designed materials that require significant effort to design, install, and maintain. Technological advances that reduce the size of aerospace applications or computing power do not necessarily transfer to the built environment. In fact, advancements in air, space, and cyber platforms often drive the need for greater physical infrastructure, not less, as evidenced by the growing air base infrastructure support requirements described in the historical review.

Furthermore, physical infrastructure systems, such as runways or command centers, are typically designed for a 50-year lifespan to minimize life cycle and recapitalization costs. In most cases, providing these systems for this life span, at the level of service that the mission demands, is costly. The construction industry has long recognized the "iron triangle" of time, quality, and cost for physical infrastructure systems.[26] A benefit in one component comes at the expense of the others. For example, hastily constructed infrastructure may come with a less-expensive price tag, but quality is typically sacrificed in the process. The same is true for long-term infrastructure maintenance, as providing quality infrastructure requires adequate investment over a system's entire life cycle.

Another reason physical infrastructure is resource-intensive is due to the design-once, build-once nature of construction. Unlike the manufacturing industry that produces aircraft parts—for example, where a single product can be designed once, tested, refined, and produced thousands or millions of times—each construction project is unique; it is designed once and then built once. Even with Air Force initiatives on standardized facility designs or standardized equipment, these "off-the-shelf" solutions still require engineered site adaptation and locally or regionally sourced construction crews each time they are built.[27]

Physical infrastructure is also highly regulated and involves compliance with numerous laws such as the National Environmental Policy Act, the Federal Acquisition Regulation, minor construction limits established in the National Defense Authorization Act, host nation requirements for overseas locations, and State Historic Preservation Office regulations at US installations. In a perfect scenario, leaders can incorporate these requirements into infrastructure project planning. Still these regulatory components often end up on the critical path of project completion, particularly when a project requirement arises on short notice, as in a contingency environment or an unforeseen surge requirement at the home station.

3. Critical Infrastructure Systems Must Be Sustainable and Resilient.

The term *critical infrastructure* was first defined in 1996 with Executive Order 13010,[28] and the term came into vogue after 9/11 with the recognition that our nation's critical infrastructure was vulnerable to attack from terrorist organizations. Such attacks could have a debilitating effect on our national defense and economic well-being. The United States established the critical infrastructure program through several additional legislative acts and Presidential directives (e.g., the Critical Infrastructures Protection Act of 2001 and Homeland Security Presidential Directive 7).[29] DOD Directive 3020.40 defines *infrastructure* as "the framework of interdependent physical and cyber-based systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services essential to the defense and economic security of the United States, to the smooth function of government at all levels, and to society as a whole."[30]

The focus on infrastructure protection eventually broadened into the need for sustainability and resilience of physical infrastructure. Sustainable development entails meeting today's needs without compromising future needs.[31] Specifically for the USAF and USSF, this entails managing physical infrastructure in a way that meets the current mission without risking the mission in the future. Examples of this might include efficient use of water at Cannon AFB, New Mexico) to preserve the Ogallala Aquifer as a viable water source for the installation or the use of renewable energy sources to minimize the risk of a blackout.

Resilient infrastructure refers to infrastructure that can withstand a disturbance and still maintain its function and capacity. An example of this might be backup generators in combination with an uninterruptible power supply at an RPA operations center. The concept of resilience entails risk management and acknowledges the technical and financial inability to protect all critical infrastructure against all threats.

Critical infrastructure resilience includes defending against enemy attacks in a national defense context, whether kinetic or nonkinetic cyber attacks. As stated earlier, this includes homeland installations. Although homeland air bases have largely been safe from aerial attack since Pearl Harbor, many of our expeditionary air bases in Iraq and Afghanistan have consistently been subject to indirect fire and more coordinated attacks such as the January 2020 Iranian missile attack on US personnel at Iraqi air bases. In addition to targeting personnel or aircraft, these attacks often affect air base infrastructure with lasting adverse effects to the mission, consistent with Warden's view of the enemy as a system and physical infrastructure being a critical component of that system.

"Attacks" via accidents and natural disasters can also limit the capability of infrastructure and, therefore, of mission accomplishment. Consider Hurricane Michael in 2018, which damaged F-22s housed in World War II-era hangars at Tyndall AFB, Florida, or the Joint Base Elmendorf-Richardson, Alaska earthquake in 2018, or Offutt AFB, Nebraska flooding in 2019, each of which resulted in degradation to the installations' respective missions. History shows that these are not anomalous events. A 1952 windstorm at Carswell AFB, Texas, damaged more than 70 B-36 Peacemakers and prompted Strategic Air Command Commander Gen Curtis LeMay to disperse aircraft to other sites. Homestead AFB, Florida, took direct hits from massive hurricanes in 1945 and 1992, causing years-long mission disruption in both cases and resulting in the redesignation of the base as an air reserve station.[32]

Furthermore, providing sustainable and resilient infrastructure systems is not simply about the ability to withstand large, one-time attacks or sudden shocks. It also includes "slow-onset impacts."[33] These could include the impact of routine weather or climate events, such as the impact of freeze and thaw cycles on building foundations, erosion caused by wind and rain, or corrosion caused by saltwater. It likewise extends to preparing our bases for the long-term effects of climate change, such as wildfires or flooding due to sea-level rise.[34] These slow-onset events are perhaps easier to ignore but can result in equally devastating mission impacts over the long-term.

Finally, providing reliable critical infrastructure requires partnership with other public and private entities. Many of our installations' utility services, such as electricity, natural gas, telecommunications, water, and wastewater services, are supplied from off-installation sources. As such, the mission infrastructure system is vulnerable to threats largely outside of the direct control of installation personnel. Consider an anecdote from one of the authors, whose base lost mission-critical communications because a lawnmower cut a fiber-optic line located off the installation. Dealing with such vulnerabilities requires installation leaders to develop and maintain partnerships with the local community and consideration for on-base redundancy or backup capabilities when off-base sources fail.

4. Neglecting Infrastructure Puts the Mission at Risk.

Given its tie to the mission, its resource-intensive nature, and the requirement for resilience (truths 1–3), leaders cannot afford to neglect infrastructure investment. The Department of the Air Force (DAF) currently has a $33 billion backlog of infrastructure maintenance across its portfolio as the Air Force has taken a significant risk in deferred facility maintenance for the past several decades.[35] Annually, senior DAF leaders make difficult tradeoffs between new weapons systems, personnel costs, modernization, and other priorities. Each of these decisions carries its own risk, so communicating and understanding the infrastructure underinvestment risk to the mission is vital.

The principal of the time value of money dictates that a dollar wisely invested today yields better outcomes than the same dollar invested in the future. Delayed costs result in increased costs. Additionally, during that period of delay or neglect, infrastructure continues to degrade. Both effects, a dollar doing less in the future and infrastructure degrading with time, doubly compound the cost of repairs over time. Figure 3 provides a notional example of the additional costs incurred by delaying investment (e.g., delaying crack/joint sealing in a runway may result in a requirement for full-depth replacement of the pavement given its continued and accelerated deterioration over time). Degradation curves like the one in figure 3 were initially developed for pavement management, but the concept applies to other infrastructure systems as well. Note that failing to invest earlier in the life cycle of the system leads not only to more degradation but to more *rapid* degradation.[36]

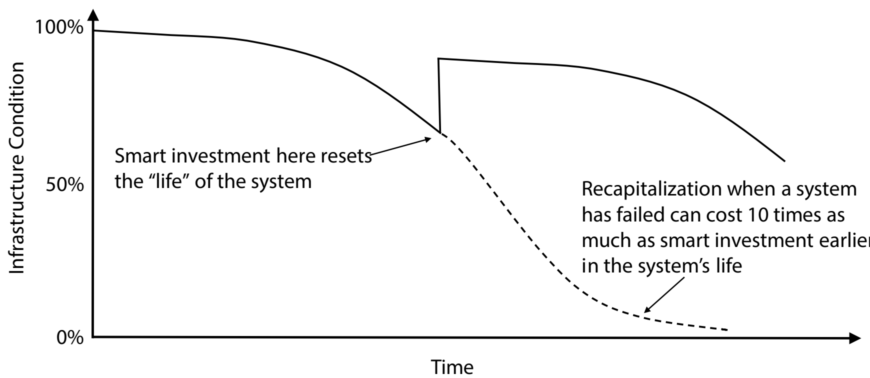

Figure 3. Infrastructure degradation with time showing the positive impact of timely maintenance and repair, along with the negative impacts of no investment

Historically, one of the challenges of infrastructure funding has been quantifying the risk of delaying infrastructure investment. Major weapon system program offices have done the research and maintained the documentation to determine when aircraft parts will fail.[37] This documentation enables an investment strategy and detailed life cycle maintenance plan to ensure the weapon system can continue to perform, in many cases beyond its originally intended life cycle. The data required to build failure-prediction algorithms are more easily obtained for mass-produced parts whose installation follows a well-documented technical order. In contrast, building systems are typically designed once and built once, as explained earlier, and are generally comprised of a nearly infinite number of components from a variety of manufacturers. Until recently, the Air Force had no such failure-prediction algorithms for built infrastructure. Without the historical asset management data that enables the ability to predict when a roof will leak, disable a critical server, a heating, ventilation, and air-conditioning system will malfunction, or runway concrete will spall, it becomes difficult to capture the risk of failure accurately.

Fortunately, in the last decade, Air Force civil engineers have improved their ability to quantify mission risk based on infrastructure requirements. The new approach implements asset management principles, including developing accurate inventories of infrastructure components at each installation down to the subfacility level (e.g., roofs, electrical systems, fire suppression, runway pavement, etc.); assessing the condition of each of these systems and components, and; forecasting, based on documentation and manufacturer recommendations when each system requires maintenance or replacement.[38] A second major development was implementing a risk assessment based on a facility's condition and its importance to the mission.[39] This assessment provides tools for leaders to plan maintenance, prioritize requirements, communicate risk, and advocate for investment. Figure 4 provides an example of these tools, showing current facility conditions and future conditions based on three different investment levels over a 30-year period. Facilities are shown by USAF MAJCOM and the USSF, with each pixel representing a facility. Green indicates a good "condition index" on a 0–100 scale, with yellow and red facilities having increasingly worse condition indices. Facilities with a higher mission dependency index (MDI)—a rating of the importance of the facility to mission execution—are on the left, with the lower MDI facilities on the right. Continuing to fund infrastructure investment at historical levels (figure 4b) is untenable, which is why the Infrastructure Investment Strategy commits to funding at a minimum of 2 percent of PRV. Even a modest increase of 0.3 percent PRV or an additional $350 million annually (figure 4d compared to 4c), results in a significant improvement in facility condition over the 30-year period. Based on the same database, the Air Force Installation and Mission Support Center

(AFIMSC) can also produce charts for the facilities at each installation or for the condition of a particular subfacility component (e.g., the condition of all runway pavement or roofs in the USAF and USSF).

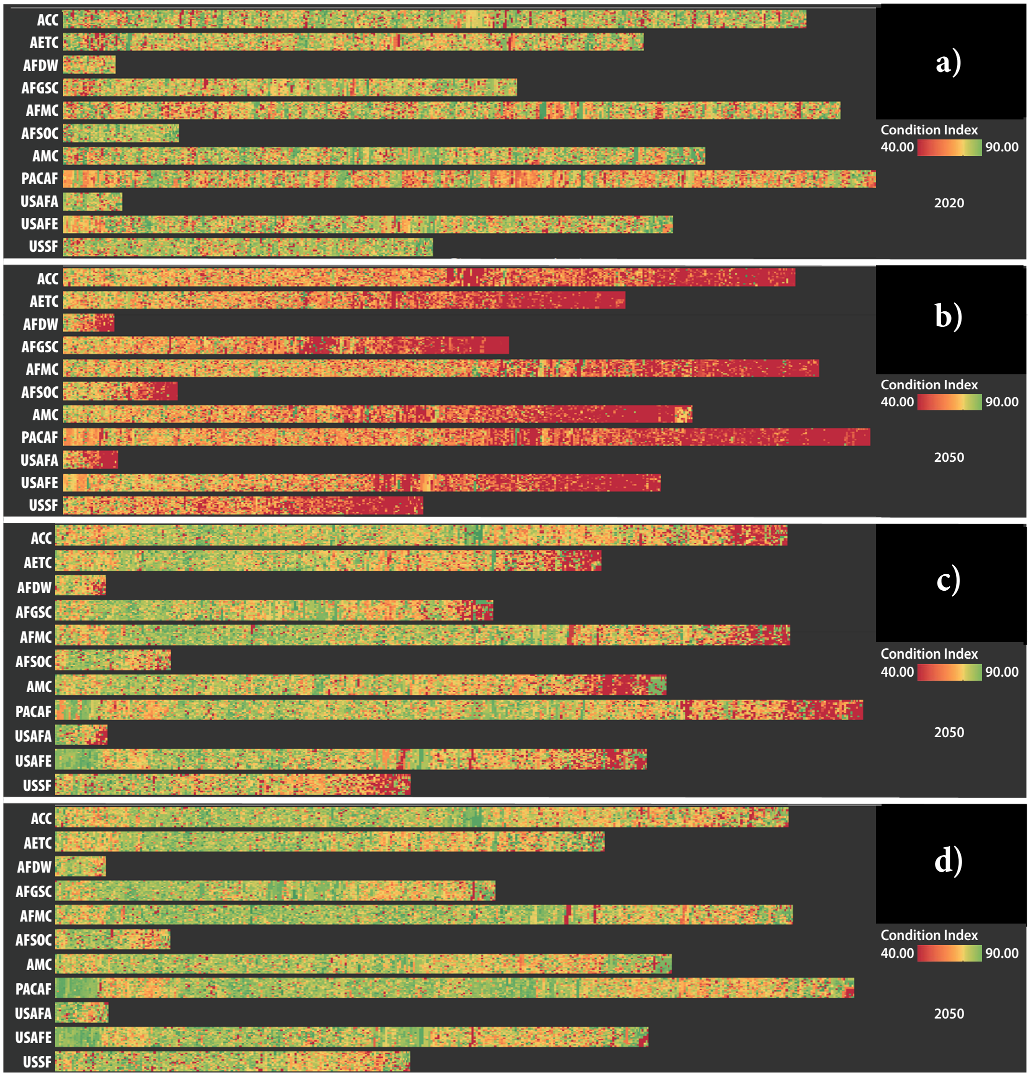

Figure 4. (a) The current condition of facilities by USAF MAJCOM and USSF, (b) condition of facilities in 2050 with pre-I2S funding, (c) condition of facilities in 2050 with an investment of 2.0 percent of PRV per year, and (d) condition of facilities in 2050 with an investment of 2.3 percent of PRV per year

Source: Figure courtesy of AFIMSC Expeditionary Support Directorate

Note: Since readers of the print edition will view figure 4 in black and white, and the authors refer to green, yellow, and red in the text, the lighter color (green in the online edition) indicates a good condition index on a 1-100 scale; darker colors (yellow and red online) refer to having increasingly worse condition indices.

5. Infrastructure Is for All Leaders.

Because of its essential role in executing the mission, infrastructure is a concern for every Air Force and Space Force leader.[40] The Air Force aircraft inventory has a replacement cost of $600 billion in 2018 dollars, and the plant replacement value of its facilities and utilities is $359 billion, which does not include the cost of its 8.5 million acres and the natural and cultural resources.[41] Thus, the value of the USAF's physical infrastructure is on the same order of magnitude as its aircraft—clearly, both natural and built infrastructure are valuable resources and important to executing the mission.

Because of the tendency to create functional stovepipes (e.g., the consolidation of infrastructure funding at AFIMSC), it could be tempting for MAJCOM staff officers, for example, to think that they can leave the infrastructure for AFIMSC or Air Force Civil Engineer Center to manage. Yet delivering and maintaining quality infrastructure requires support from a range of leaders at the wing, MAJCOM, and functional command levels. The installation commander makes most major infrastructure decisions at the installation level with informed support from various subordinates, only some of whom are technical experts. Commanders certainly have a diverse set of responsibilities, but a basic working knowledge of the requirements of infrastructure and investment can pay dividends in securing the future of the base's systems and in executing the mission within each commanders' span of control. A simple example might be educating the airfield owner (usually in an operations support squadron) of the need to shut down the airfield on occasion to perform needed repairs. On a larger scale, it may require cross-MAJCOM coordination to utilize resources when a critical facility is down for an extended period for repair or replacement. It may also include coordinating with civilian entities, such as the recent Offutt AFB runway replacement project, where installation leaders had to coordinate the transfer of operations to the municipal airport for up to a year. When an infrastructure issue arises, it is incumbent on leaders across functional areas to find a solution, up to and including our most senior leaders, as highlighted in the Service Secretaries and Chiefs' testimony to the Senate Armed Services Committee on military family housing problems.[42]

As noted earlier, infrastructure reductions have not paralleled the cuts in personnel and aircraft. The global coronavirus pandemic that started in 2019 may also provide an opportunity to reduce physical infrastructure needs. Although a reduction in operations and maintenance, command and control, or mission facilities is unlikely, there may be opportunities to reduce administrative spaces due to the anticipated increase in teleworking moving forward. Some have appropriately called for leaders to think differently about air bases to make them more efficient and support multiple missions,[43] but the reality is that political ramifications are likely to limit the extent of future closures and consolidation if they happen. In the absence of future reductions, it is ever more likely that leaders will be forced to deal with difficult resource allocation decisions as the funding available is unlikely to maintain the portfolio of infrastructure at the quality that the mission requires. Such a condition requires all leaders to advocate for infrastructure funding and be cognizant of mission impacts due to infrastructure failures.

Conclusion

Given the lessons of history and current doctrine guidance, resilient air base infrastructure is an integral and inseparable component of air and space power. As the future of warfare evolves and new technologies emerge, infrastructure will only increase in importance as high-tech weapons systems require even more sophisticated and reliable physical infrastructure systems. Physical infrastructure requires significant investment in time and money to achieve the resiliency required for today's missions. The mission dependency and current state of infrastructure necessitate that all leaders be aware of the risk to mission associated with infrastructure failure. Leaders must also be prepared to advocate, along with functional experts, for the investment required to maintain the infrastructure within their span of control adequately. The infrastructure truths provide a succinct summary of the value of infrastructure to the mission and a framework of important considerations for decision-making. ✪

Col Joel A. Sloan, USAF, PhD, PE

Colonel Sloan (BS, United States Air Force Academy [USAFA]; MS, University of Colorado; PhD, Virginia Tech) is the head of the USAFA Department of Civil and Environmental Engineering.

Lt Col M. Scott Stanford, USAF, PhD, PE

Lieutenant Colonel Stanford (BS, MS, Clemson University; PhD, University of Colorado) teaches Civil Engineering at the USAFA.

Dr. Thomas J. Phelan, PE, BCEE

Dr. Phelan (BS, Manhattan College; MS and PhD, University of Michigan) teaches Environmental Engineering at the USAFA.

Lt Col James B. Pocock, USAF, Retired, PhD, RA

Lieutenant Colonel Pocock (BS, University of Michigan; MS, Pennsylvania State University; PhD, University of Illinois at Urbana-Champaign) teaches Civil Engineering at the USAFA.

Notes

1. Heather A. Wilson, "USAF Infrastructure Investment Strategy," 21 March 2019, video, Emily Mueller, Headquarters Air Force, Office of the Director of Civil Engineers, https://www.dvidshub.net/.
2. Gen Tod D. Wolters, commander, US Air Forces in Europe, et al., memorandum for record, *US Air Force Infrastructure Investment Strategy*, 29 January 2019, https://www.af.mil/.
3. Roger G. Miller, *A Preliminary to War: The 1st Aero Squadron and the Mexican Punitive Expedition of 1916* (Washington, DC: Air Force History and Museums Program, 2003), 47.
4. Miller, *A Preliminary to War*, 47.
5. Ronald B. Hartzer et al., *Leading the Way: The History of Air Force Civil Engineers 1907–2012* (Tallahassee, FL: R. Christopher Goodwin and Associate, 2012), 8–9.
6. Gen Henry "Hap" Arnold, quoted in Maj Gen Timothy Byers, "USAF: Building to Last, Leading the Change," *The Military Engineer* 105, no. 683, 67–69, https://www.jstor.org/.
7. Hartzer, *Leading the Way*, 43.
8. Hartzer, *Leading the Way*, 27–76.
9. Hartzer, *Leading the Way*, 139.
10. Daniel L. Haulman, "Air Force Bases, 1947–1960," in *Locating Air Force Base Sites: History's Legacy*, ed. Frederick J. Shaw (Washington, DC: Air Force History and Museums Program, 2004), 61, https://www.afhra.af.mil/.
11. Mel Schenck, "The Largest Military Construction Project in History," *New York Times*, 16 January 2018, https://www.nytimes.com/.
12. Schenck, "The Largest Military Construction Project in History"; and Hartzer, *Leading the Way*, 260–75.
13. Col John A. Warden III, "The Enemy as a System," *Airpower Journal* 9, no. 1 (Spring 1995): 40–55. https://www.airuniversity.af.edu/.
14. Jeffrey P. Sahaida, "Reorganization after the Cold War, 1988–2003," in *Locating Air Force Base Sites: History's Legacy*, ed. Frederick J. Shaw (Washington, DC: Air Force History and Museums Program, 2004), 151–202, https://www.afhra.af.mil/.
15. SAF/IEIP, "Air Force Base Realignment and Closure (BRAC)," graphic dated 15 February 2017.
16. US Government Accountability Office, "High Risk List: DOD Support Infrastructure Management," 17 November 2020, https://www.gao.gov/.
17. Curtis E. LeMay Center for Doctrine Development and Education, *Air Force Basic Doctrine Vol 1*, 35.
18. Curtis E. Lemay Center, *Air Force Basic Doctrine Vol 1*.
19. Gen David Goldfein quoted in Joseph Trevithick, "USAF Wants Units to Rapidly Build and Fly from New Bases in the Middle of a Future War," 19 September 2018, https://www.thedrive.com/.
20. DoD, *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge* (Washington DC: Office of the Secretary of Defense, January 2018), 10, https://dod.defense.gov/.
21. Joseph T. Buontempo and Joseph E. Ringer, "Airbase Defense Falls Between the Cracks," *Joint Forces Quarterly* 97 (2nd Quarter, April 2020), https://ndupress.ndu.edu/; and Lt Col Price T. Bingham, "The Air Base: The Air Force's Achilles' Heel," *Air Force magazine*, 1 October 2020, https://www.airforcemag.com/.

22. Air Force Doctrine Annex 3-0, *Operations and Planning*, 34; and Annex 3-99, *Department of the Air Force Role in Joint All-Domain Operations*, 23.

23. Wolters, *US Air Force Infrastructure Investment Strategy*.

24. Wolters, *US Air Force Infrastructure Investment Strategy*.

25. Rachel S. Cohen, "DoD's 'Black-Start' Exercises Explore What Happens When Utilities Go Dark," *Air Force Magazine*, 17 October 2019, https://www.airforcemag.com/.

26. Julien Pollack, Jane Helm, and Daniel Adler, "What Is the Iron Triangle, and How Has It Changed?" *International Journal of Managing Projects in Business* 11, no. 2 (2018), 527–47.

27. Mark A. Correll, Deputy Assistant Secretary of the Air Force for Environment, Safety and Infrastructure, memorandum, "Policy on Use of Air Force Corporate Facilities Standards and Standard Designs," Department of the Air Force, 9 May 2016, https://www.wbdg.org/; and Defense Pricing and Contracting, "Category Management and Strategic Sourcing Defined," site discontinued, accessed 23 June 2020.

28. President William J. Clinton, "Executive Order 13010—Critical Infrastructure Protection," White House, 15 July 1996, https://fas.org/.

29. 107th US Congress, "Critical Infrastructures Protection Act of 2001." Sen Pete V. Domenici, sponsor, https://www.congress.gov/; Cybersecurity and Infrastructure Security Agency; and "Homeland Security Presidential Directive 7: Critical Infrastructure Identification, Prioritization, and Protection," 17 December 2003, https://www.cisa.gov/.

30. DOD Directive 3020.40, "Mission Assurance (MA)," 11 September 2018, Office of the undersecretary of Defense for Policy, https://fas.org/.

31. Gro Harlem Brundtland, "Report of the World Commission on Environment and Development: Our Common Future," 20 March 1987, http://www.un-documents.net/.

32. Haulman, "Air Force Bases, 1947–1960," 58–59; and *History of Homestead Air Reserve Base*, 4 April 2018, https://www.homestead.afrc.af.mil/.

33. C. Gallego-Lopez and J. Essex, "Designing for Infrastructure Resilience," *Evidence on Demand*, July 2016, 22, https://assets.publishing.service.gov/.

34. DOD Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, "Department of Defense Climate-Related Risk to DoD Infrastructure Initial Vulnerability Assessment Survey (SLVAS) Report," January 2018, https://www.acq.osd.mil/.

35. Heather Wilson and David L. Goldfein, "U.S. Air Force Infrastructure Investment Strategy (I2S)," 29 January 2019, https://www.af.mil/.

36. Mo Y. Shahin, *Pavement Management for Airports, Roads, and Parking Lots*, 2nd ed. (New York: Springer, 4 May 2006).

37. Tim Kurtz, "Soothsayers: Software Group Utilizing Tools to Predict Parts Failure," Warner Robins Air Logistics Complex Operations Management Office, 9 April 2019, https://www.af.mil/.

38. Leah Suttle, "CE Users Get a Handle on AFCEC's Comprehensive Asset Management Plan Process," *AFCEC Public Affairs*, 30 January 2014, https://www.afcec.af.mil/.

39. Rachel Zaney, "Air Force Launches Strategic Approach to Asset Management," *AFCEC Public Affairs*, 7 August 2014, https://www.af.mil/.

40. Hon. John Henderson, Assistant Secretary of the Air Force for Energy, Installations and Environment, interview by the first author, US Air Force Academy, CO, 29 October 2019.

41. Congress of the United States, "The Cost of Replacing Today's Air Force Fleet," Congressional Budget Office, December 2018, https://www.cbo.gov/; and Air Force Physical Plant Profile

compiled from the 2019 DM&R 3rd quarter report, the J-book numbers from 2018, and the current real property database.

42. United States Senate Committee on Armed Services, testimony of Mark T. Esper et al., 4 March 2020, https://www.armed-services.senate.gov/.

43. Col Kevin L. Parker, "Thinking Differently about Air Bases," *Air & Space Power Journal* (Fall 2019): 52–67, https://www.airuniversity.af.edu/.