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Incentive Contracts—Motivating Performance and Allocating Risk

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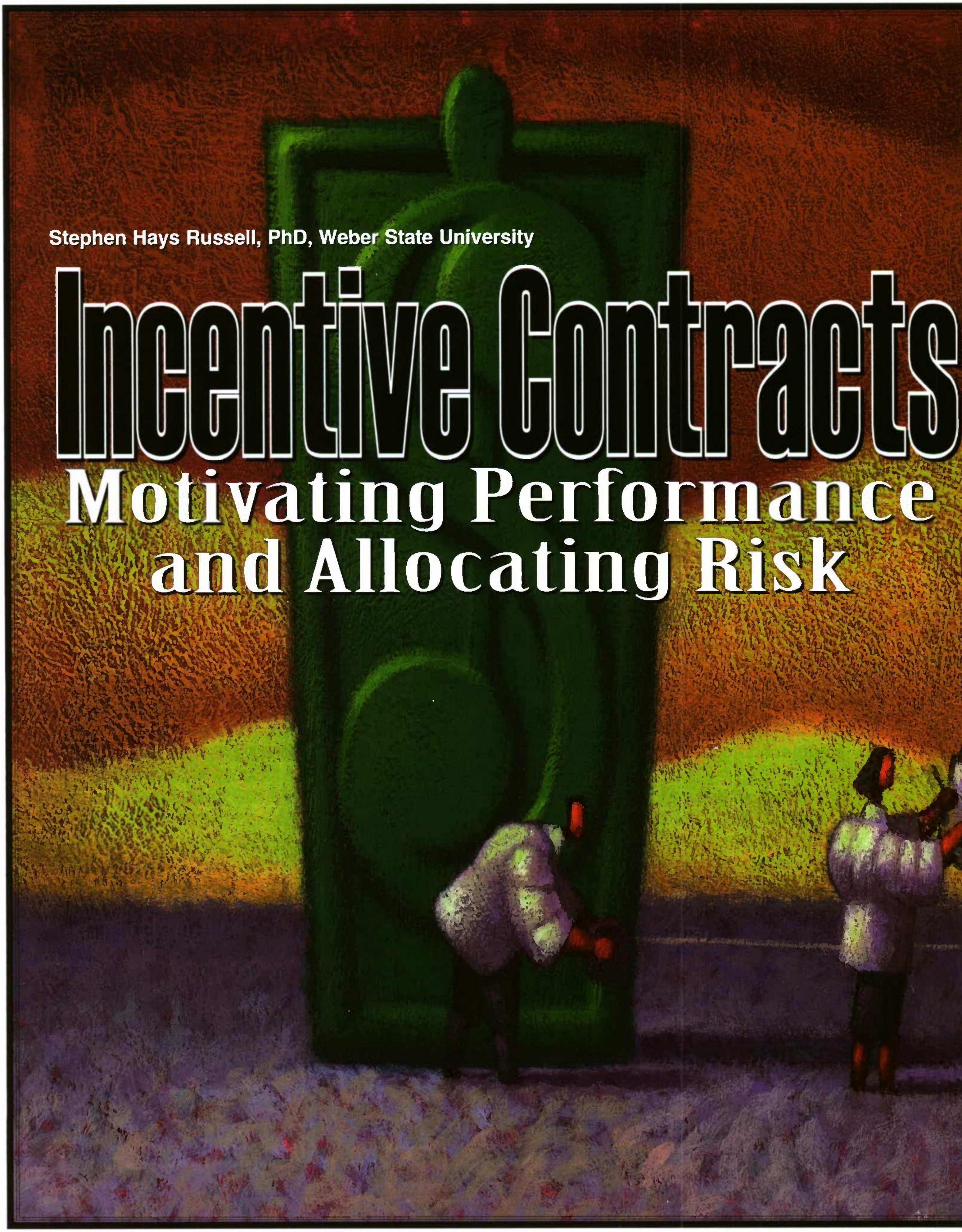
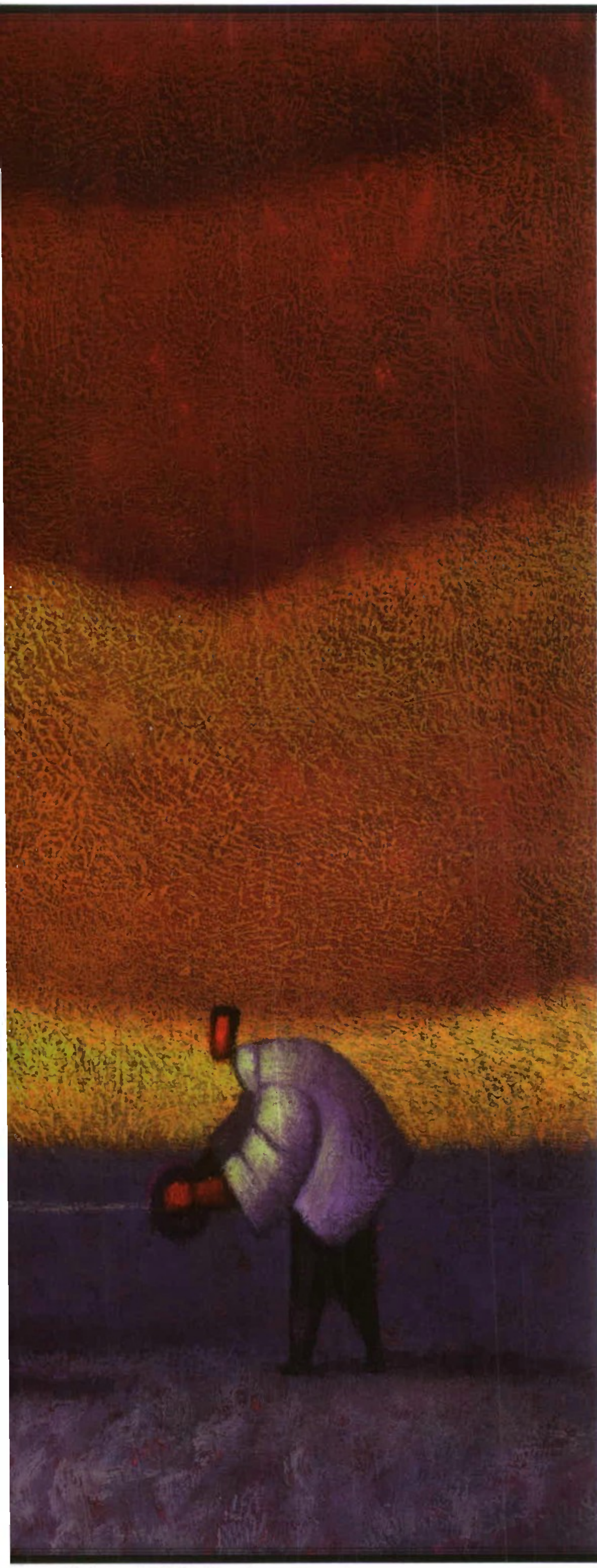
Incentive Contracts

Motivating Performance and Allocating Risk





Introduction

Contracting—an integral part of the logistics process and a formal subdiscipline within the logistics umbrella—is undergoing substantial philosophical and procedural changes. Table 1 on page 4 summarizes the continuing movement from what might be called *classical contracting* to *New-Age Contracting*.[1]

Special Feature

In classical contracting, the buying organization seeks the minimum contract price from a wide field of contractors based upon the competitive bid process. Contracts are typically fixed-price and the parties pereeive each other as having competing objectives. In New-Age Contracting, world-elass eontractors with leading-edge technologies are important partners to the buying organization. New-Age Contractors assist in defining requirements—collaboration is essential, and long-term relationships are important. Contract terms are negotiated and incentives to motivate performance and allocate risk are typically incorporated.[2]

This article considers various types of incentives that can be introduced into contracts, presents both a mathematical and graphic presentation of various types of incentive contracts, and demonstrates how incentive contracts not only guide contractor performance to the advantage of the buying organization but also allocates risk between the parties.

Key Decisions in Procurement

The critical decisions in procurement are as follows.

- The nature of the specifications
- Contractor selection
- Price
- Contract type
- How to manage contractor performance

Classical contracting focuses primarily on the first three critical decisions. New-Age Contracting, on the other hand, adds emphasis to improving performance with collaborative buyer-contractor relationships and to contract type. Judicious attention to contract type will appropriately allocate risk between the buying organization and the contractor and will motivate performance.

The Issue of Risk in Contracts

Contract risk is of four types.

- Failure to perform
- Cost
- Technical
- Schedule

Failure to perform means the chosen contractor is not capable of meeting his contractual obligation. Cost risk is defined as uncertainty in final costs to the contractor and uncertainty in final

Article Highlights

In classical contracting, the buying organization seeks the minimum contract price from a wide field of contractors based upon the competitive bid process. In New-Age Contracting, world-class contractors with leading-edge technologies are important partners to the buying organization. New-Age Contractors assist in defining requirements.

In "Incentive Contracts—Motivating Performance and Allocating Risk," Dr Stephen Hays Russell of Weber State University examines the various types of incentives that can be introduced into contracts, presents both a mathematical and graphic presentation of various types of incentive contracts, and demonstrates how incentive contracts not only guide contractor performance

financial obligation of the buying organization. Technical risk relates to quality issues and compliance with the technical specifications of the contract. Schedule risk is whether the deliverables of the contract will meet the required contract time schedule.

Failure to perform is not a significant risk issue when financially stable contractors with solid performance histories are selected. The formidable risk challenges in contracting relate to cost, technical, and schedule issues.

Contract Type and Cost-Risk Allocation

A fixed-price contract allocates all cost risk to the contractor. Regardless of what his actual costs turn out to be, the contractor is obligated to perform the requirements of the contract and will be paid only the fixed contract price. Obviously, the contractor has an incentive to control costs because of the dollar-for-dollar inverse relationship between cost and profit to him.

At the other extreme, a straight cost-reimbursable contract allocates all cost risk to the buying organization. The contractor has no incentive to control costs because he or she gets reimbursed dollar for dollar by his or her customer.

Incorporating Incentives into Contracts

Incentives in contracts will not only motivate performance and award achievement, but incentives also allocate risk between the parties. The important role incentive contracts play in New-Age Contracting was highlighted in a 2007 Office of Management and Budget memorandum, wherein chief acquisition officers throughout the federal government were admonished to give increased attention to the judicious employment of incentive contracts.[3]

Most incentive contracts focus on cost inasmuch as cost is often the biggest element of risk in contracting. Contractors by nature are risk averse. If a contractual effort involves substantial uncertainty in costs to be incurred (because of technology challenges or uncertain material prices, for example), contractors will not agree to a fixed-price contract (with all cost risk on them). As explained in the section that follows, an incentive contract on cost will allocate the risk between the parties and at the same time motivate the contractor to control costs. The literature defines the two general categories of cost-incentive contracts as linear and piecewise linear contracts.[4, 5]

	Classical Contracting	New-Age Contracting
Contract objective	Compliance at minimum price	Value with emphasis on performance and service
Supplier base	Huge	Circumscribed to world-class contractors
Relationships	Arms length; adversarial	Integrative
Trust	Tentative, personal	Trusted partners
Buyer's view of contractor	Source	Resource
Specifications	Imposed	Jointly developed with contractor input
Loyalty to contractor	Price chasing; frequent contractor switching	Earned loyalty; long-term contracts
Legal approach	Highly legalistic	Adaptive to mutual satisfaction
Pricing and award mechanism	Emphasis on competitive bidding	Emphasis on proposal and negotiation
Service contracts	Detailed statements-of-work	Performance-based specifications
Conflict resolution	Heavy-handed blame assignment; punitive remedies	Contractor-buyer collaborative resolution; emphasis on the continuing relationship
Contract type	Extensive employment of fixed-price contracts	Growing use of incentive contracts

Table 1. Characteristics of New-Age Contracting Compared to Classical Contracting

Linear Risk-Sharing Contracts on Cost

Linear risk-sharing contracts on cost set forth a target cost, a target profit, and a contractor cost-share rate. The share rate, between zero and one, sets the fraction of the difference between target cost and actual cost incurred by the contractor which is absorbed by the contractor (via decreases or increases in profit), with the balance being absorbed by the buying organization.

Consider Figure 1 on page 6. Cost is plotted on the horizontal axis. Price (the sum of cost plus profit) is plotted on the vertical axis. If actual cost turns out to be the target cost (C_T), then actual price will be the target price (denoted by $\pi_T + C_T$, where π_T is target profit and C_T is target cost). The slope of the diagonal line reflects cost sharing between the contractor and the buying organization when actual cost deviates from target cost. Assume, for example, that the contractor share rate (symbolized by b) is .25 (meaning that for each dollar of cost overrun the contractor absorbs $0.25 by way of reduced profit and the buying organization picks up $0.75 in the form of a higher final price). Then the slope of the diagonal line in Figure 1 is 1 - b, or .75.

A numeric example will illustrate both the allocation of risk and the incentive to control costs in this type of contract. Assume target cost (C_T) is $1,000, target price ($\pi_T + C_T$) is $1,100 (the sum of target cost of $1,000 and target profit of $100). If actual cost turns out to be right on target ($1,000), the buyer-firm pays the contractor the target price ($1,000 for cost and $100 for profit, or $1,100). Instead, if actual cost is $1,200 (reflecting a $200 overrun and depicted as point C_1 in Figure 1, the buyer-firm pays the contractor the target price ($1,100) plus just .75 of the $200 overrun for an actual price of $1,250. The $50 of the cost overrun not paid by the buyer-firm (representing 25 percent of the overrun) becomes a profit penalty to the contractor because his actual profit on this contract is $100 - $50 or $50.) These results are portrayed graphically in Figure 1 with points C_1 and P_1.

Mathematically, a linear risk-sharing contract is shown as follows.

$$P_A = \pi_T + C_A + b(C_T - C_A)$$

where

P_A = actual price (final contract price; what the buying organization pays in total)

C_A = actual contractor cost for the contract effort

π_T = target profit (a negotiated value)

b = contractor cost-share rate, a negotiated value ($0 \leq b \leq 1$)

C_T = target cost (a negotiated value)

Equation 1

In words, Equation 1 states that the actual final price of the contract is the target profit plus the actual cost, but adjusted by the contractor's share of the overrun or underrun. Note in the equation 1 and in Figure 1 that if C_A equals C_T (that is, if the contractor performs right on target cost), actual price equals target price at point $\pi_T + C_T$.

Equation 1 can be rearranged:

$$P_A = \pi_T + bC_T + (1 - b)C_A$$

Equation 2

Article Highlights

to the advantage of the buying organization but also allocate risk between the parties. He concludes with the following five points.

- Incentive contracts both motivate performance and allocate risk.
- Incentives can be applied to the three substantial risk areas in contracting: cost, technical, and schedule performance.
- Incentive contracts on cost are either linear or piece-wise linear. The predominant contracts of this category in the Department of Defense are Cost-Plus-Incentive-Fee contracts and Fixed-Price-Incentive Contracts. Risk is allocated by setting a contractor share ratio for cost overruns and cost underruns. These contracts typically have upper limits in sharing provisions.
- Incentive contracts for technical or schedule performance are objective (formula-type) contracts. For these contracts, performance measurement is quantifiable. When achievement in a performance area is not amenable to specific quantitative measurement, subjective (award-fee) contracts are employed.
- Incentive contracts require a substantial investment of time in administering. However, these contracts are cost-effective promoters of improved cost, technical, and delivery outcomes in all situations where risk is substantial or where risk and cost-benefit analyses demonstrate a clear advantage to an incentive contract.

Article Acronyms

CPIF – Cost-Plus-Incentive-Fee
FPI – Fixed-Price-Incentive
PEB – Performance Evaluation Board

In this form, actual price is seen as a lump sum and a 1 - b share of actual cost. This relationship is depicted graphically in Figure 1 inasmuch as Equation 2 is the equation for the diagonal line. The slope of the actual price equation is 1 - b, which is the buying organization's cost-share rate.

Also note in Figure 1 that before a contractor begins incurring costs in a linear risk-sharing contract on cost, he theoretically has a $\pi_T + bC_T$ amount of profit (all price is profit when costs are zero). As effort on the contract is executed and costs are incurred (illustrated in Figure 1 by rightward movement along the diagonal line), price increases less than cost; hence, profits fall.

The incentive to control cost is obvious. In this example, for every dollar actual costs are below target cost, the contractor keeps $0.25 of the underrun as incentive profit in addition to the target profit. For every dollar actual costs are above target costs, the contractor loses $0.25 of the target profit.

The allocation of cost risk is accomplished by setting b. The higher the contractor share rate, the greater the risk on the contractor.

Piece-Wise Linear Risk-Sharing Contracts on Cost

Piece-wise linear contracts are precisely the linear risk-sharing contracts on cost discussed previously but with upper and lower boundaries on the risk-sharing. Piece-wise linear contracts are such because contract provisions include profit ceilings and floors, or price ceilings, which cause the diagonal sharing line in Figure 1 to kink.

Two piece-wise linear risk-sharing contracts heavily employed in the defense industry are reviewed below.

Cost-Plus-Incentive-Fee (CPIF) Contracts. If the risk-sharing contract specifies upper and lower limits on risk-sharing, a piece-wise linear contract is defined (see Figure 2). Between cost levels C_O and C_P we have a standard linear risk-sharing contract with a contractor cost share of b and a slope of 1 - b. Actual costs above C_T reduce contractor profit; actual costs below C_T reward the contractor with increased profit (as previously presented with Figure 1). But in Figure 2 this risk-sharing arrangement ends at the kinks on the line at cost levels C_O and C_P.[6]

To the left of C_O, the slope of the diagonal sharing line steepens to 1.0, meaning the contractor share rate (b) goes to zero. Every additional dollar of cost underrun to the left of C_O goes to the buying organization in the form of reduced price. This means that by contract provision contractor profit is maximized at C_O.

Similarly, the slope of the diagonal share line steepens to 1.0 at C_P as well. All cost risk beyond this point is on the buying organization (because b—the contractor's cost share—is now zero with slope at 1.0). The entire burden (risk) of more cost overrun beyond this point is on the buying organization because, beyond C_P, every dollar of cost increase is a dollar increase in price paid by the buying organization. Accordingly, the cost level C_P is the point where a minimum profit level is guaranteed to the contractor.

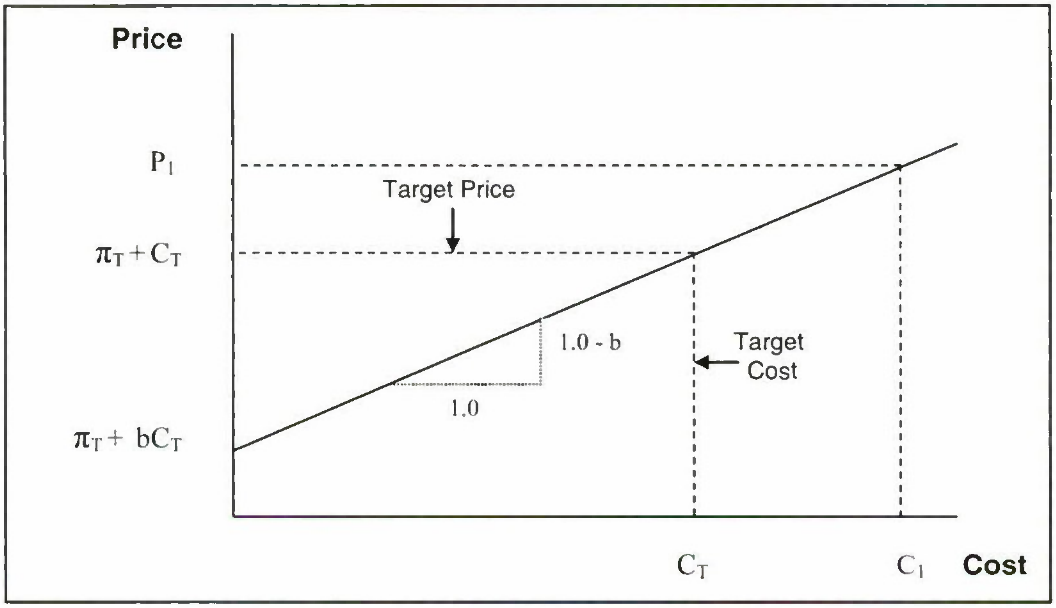


Figure 1. Linear Risk-Sharing Contract on Cost

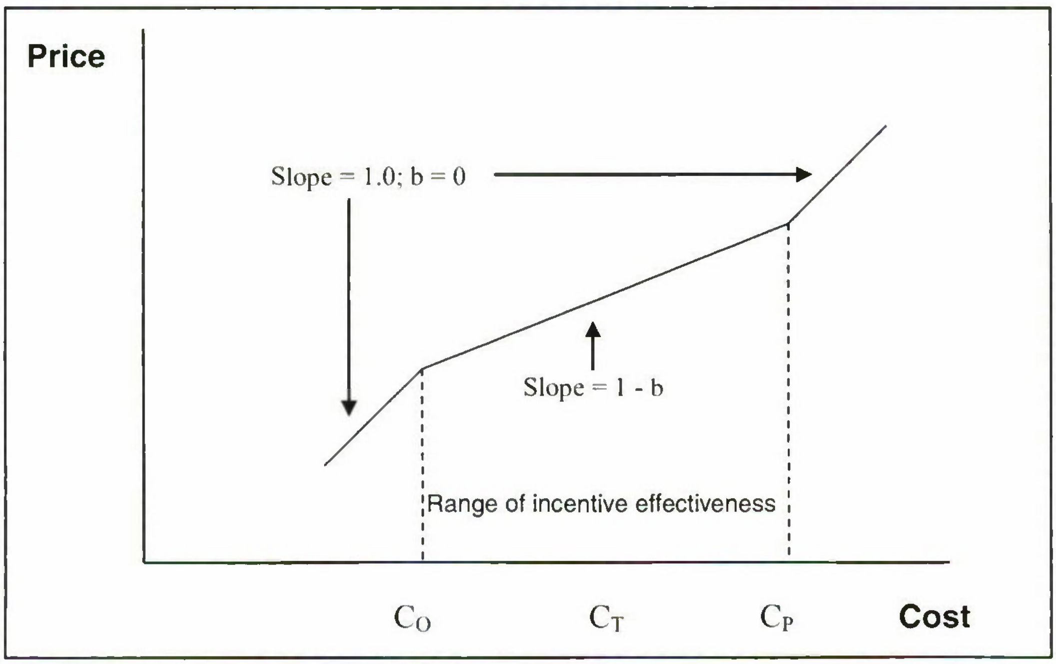


Figure 2. Cost-Plus-Incentive-Fee Contract

With these kinks in a CPIF contract, incentives apply and risk is shared between C_0 and C_p. All cost risk is born by the buying organization outside of this range.[7]

Fixed-Price-Incentive (FPI) Contracts. The imposition of minimum and maximum profit levels is not the only manner in which a linear risk-sharing contract on cost becomes piece-wise linear. If the buying organization places a ceiling on actual price in a risk-sharing arrangement, a kink is introduced.

This contract type is illustrated in Figure 3. In this diagram, P_C is the ceiling price, the contractual maximum compensation to be paid to the contractor, regardless of actual cost. Note that cost-sharing ceases where the diagonal share line becomes perfectly horizontal at the ceiling price. Mathematically, given the negotiated target cost, target price, contractor share ratio, and ceiling price, the level of actual cost that brings the contract to the ceiling price is given as follows.

$$C_C = [P_C - P_T]/(1 - b) + C_T$$

where,

C_C = the ceiling cost

P_T = target price $(\pi_T + C_T)$

Equation 3

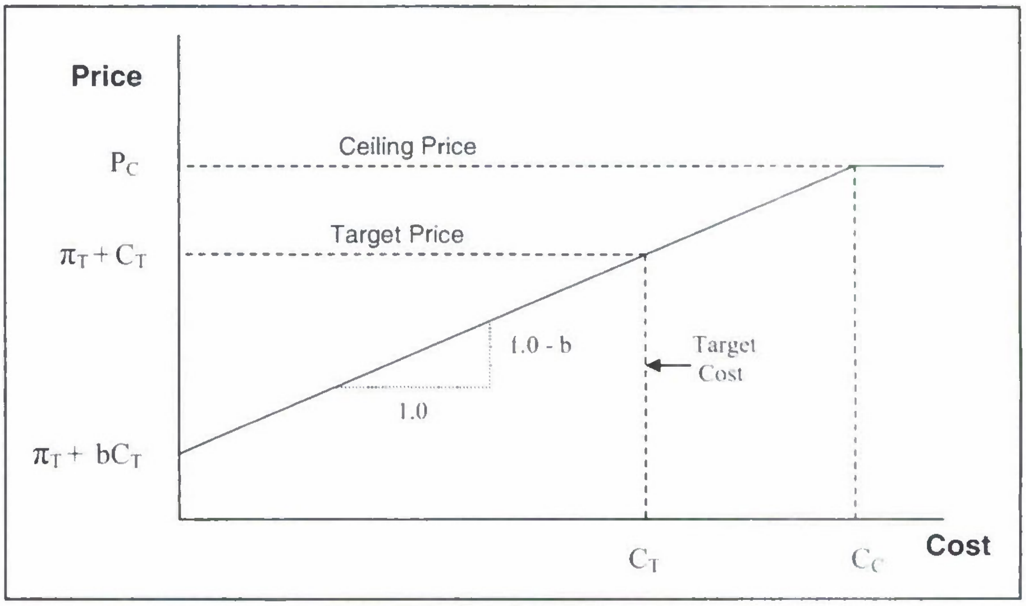


Figure 3. Fixed-Price-Incentive (FPI) Contract

At point C_c in Figure 3 risk-sharing ceases and all cost risk is now on the contractor (b is now 1.0). Regardless of costs incurred beyond C_c, the compensation to the contractor is maximized (becomes a fixed price) at P_c.

The ceiling cost is sometimes referred to as *the point of total assumption* because the contractor absorbs dollar for dollar all costs beyond C_c.[8]

Objective Risk-Sharing Contracts on Technical or Delivery Performance

Objective risk-sharing contracts on technical or delivery performance allocate risk by making at least a portion of contractor profit a function of contractor performance in such areas as logistics response time (the average time between generation of a requisition and receipt of the material by the customer), inventory accuracy, forecasting accuracy, completion date, defect rates, energy efficiency, or mean time between failure achievement. In this type of contract, a target price and a target achievement level for delivery or technical performance is set. Deviations from the target in actual achievement yield profit bonuses or penalties. Such a scheme motivates performance and allocates some risk to the contractor by putting his realized level of profit at risk.

Figure 4 illustrates this type of contract. Actual price is a negotiated target price adjusted by penalty or bonus as actual achievement deviates from the plan. In Figure 4, the slope of the line represents the penalty or bonus per unit of variance. For example, units of favorable variance along the horizontal axis to point V_1 would move the actual price from the target price to P_1, a price with bonus profit.

An example of this type of contract would be a highway construction contract with a target price of \$25M and a bonus (penalty) for early (delayed) completion of \$25K per day.

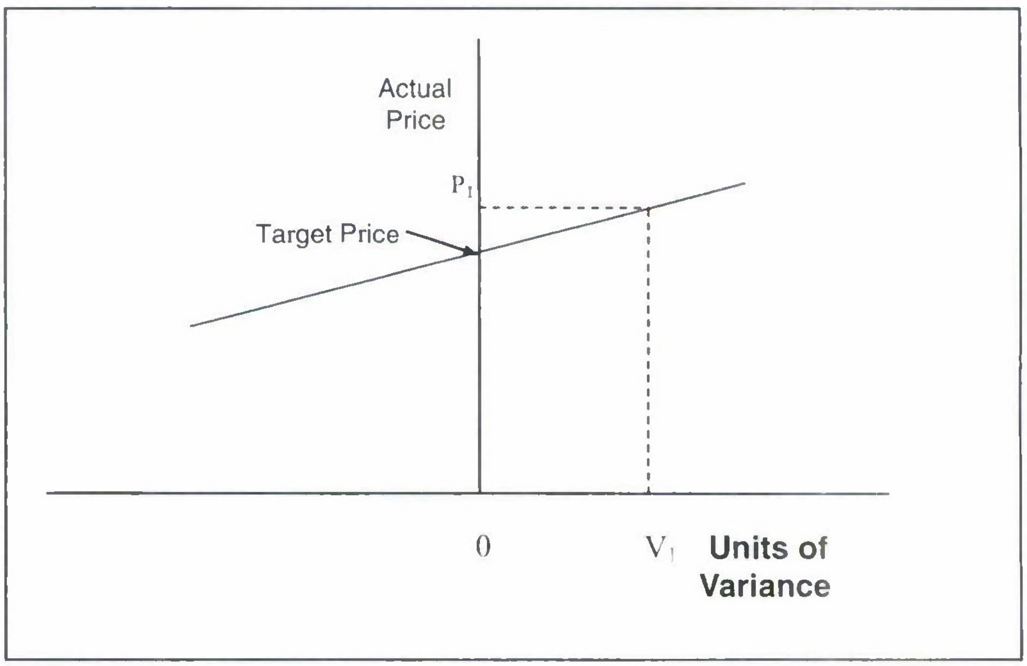


Figure 4. Objective Risk-Sharing Contract Where Actual Price Depends Upon Positive or Negative Units of Variance from Target Objective

Subjective Risk-Sharing Contracts

Subjective risk-sharing contracts are designed to reward contractors for exceptional levels of achievement in areas not amenable to quantifiable or specific measurement (such as value-added services, technical ingenuity, customer satisfaction with services, and problem identification and resolution skills). Evaluations in these areas are judgments by the buying organization, and the earned compensation is called *award fee*.[9]

These contracts (generally called *visible hand* or award fee contracts) are always hybrid contracts in that an award fee provision is always used in conjunction with either an underlying fixed-price or cost-reimbursable provision.[10]

A contract with an award fee provision incorporates an award fee pool, which is a dollar amount of award money that the contractor can potentially earn over the course of the contract. Typically the buying firm will convene a performance evaluation board (PEB) quarterly or semiannually to review contractor performance in the areas specified by the award fee plan of the contract. The PEB makes a subjective judgment as to what percentage of the award fee pool for this period should be awarded the contractor.

Subjective risk-sharing contracts allow the buying organization to change areas of emphasis for award fee in each evaluation period. This way the buying organization can more effectively manage contractor effort by allowing new areas of evaluation to evolve during the course of the contract.

The contractor shares in the risk of performance because the percentage of the fee pool awarded in each evaluation period is tied directly to the buying organization's evaluation of contractor performance. Shortfalls in performance become foregone award fee.

Conclusion

From performance-based contracting for a multitude of services, to award-fee provisions in system support contracts to cost-incentive provisions in materiel contracts, the logistics community is seeing increasing emphasis on incentive contracts. This trend is part of a new sophistication in contracting which can be described as New-Age Contracting.

This article demonstrates with mathematical exposition, graphs, and narrative how incentive contracts both motivate performance and allocate risk.

Incentives can be applied to the three substantial risk areas in contracting: cost, technical, and schedule performance.

Incentive contracts on cost are either linear or piece-wise linear. The predominant contracts of this category in the Department of Defense are CPIF contracts and FPI contracts. Risk is allocated by setting a contractor share ratio for cost overruns and cost underruns. These contracts typically have upper limits in sharing provisions.

Incentive contracts for technical or schedule performance are objective (formula-type) contracts. For these contracts, performance measurement is quantifiable. When achievement in a performance area is not amenable to specific quantitative measurement, subjective (award-fee) contracts are employed.

Incentive contracts require a substantial investment of time in administering. However, these contracts are cost-effective promoters of improved cost, technical, and delivery outcomes in all situations where risk is substantial or where risk and cost-benefit analyses demonstrate a clear advantage to an incentive contract.[11]

Notes

1. For an overview of the differences between classical contracting and New-Age Contracting in the automobile industry, see "Detroit's Demise Stems from Flawed Supplier Relations" by procurement guru David N. Burt, *The Warren Company Current Issues*, November 2008, [Online] Available: www.warrenco.com/html/detroit_s_demise.html, accessed 28 October 2010.
2. A clarification is important: When the buying organization has a need for standard, readily-available materials or services or otherwise has well-defined requirements with price rather than an enduring relationship as the legitimate contract objective, and at least three capable and willing contractors are available, a classical approach is acceptable, even in the era of New-Age Contracting.
3. Executive Office of the President, Office of Management and Budget, Memorandum for Chief Acquisition Officers, Subject: Appropriate Use of Incentive Contracts, 4 December 2007, [Online] Available: http://www.whitehouse.gov/sites/default/files/omb/procurement/memo/incentive_contracts_120407.pdf, accessed 30 October 2010.
4. R. K. Goel, "Choosing the Sharing Rate for Incentive Contracts," *The American Economist*, Volume 39, No 2, 68-72.
5. Joseph Y. Chen and Bruce L. Miller, "On the Relative Performance of Linear vs. Piecewise-Linear-Threshold Intertemporal Incentives," *Management Science*, Volume 55, No 10, October 2009, 1743-1752.
6. Kinks occur in a CPIF contract at end points in a cost range from "optimistic cost estimate" (C_O) to "pessimistic cost estimate" (C_P).
7. The range between C_O and C_P can be referred to as the *range of risk sharing* or the *range of incentive effectiveness*.
8. Note that a CPIF contract has no limit on the financial obligation of the buying organization, whereas the FPI contract caps financial obligation at the ceiling price. Clearly a CPIF contract allocates more risk to the buying organization than does an FPI contract, and is appropriate only when uncertainties in cost are so great that a contractor is unwilling to accept any type of a *fixed* price contract. See the parameters for employing a CPIF contract in the Federal Acquisition Regulation (FAR) Volume 1, Subpart 16.3, *Cost Reimbursement Contracts*, March 2005, [Online] Available: https://www.acquisition.gov/far/current/html/Subpart%2016_3.html#wp1077348, accessed 18 November 2010.
9. *National Aeronautics and Space Administration Award Fee Contracting Guide*, 27 June 2001, [Online] Available: http://www.hq.nasa.gov/office/procurement/regs/afguidee.html, accessed 22 September 2010.
10. Code of Federal Regulations–Title48, *Federal Acquisition Regulations System*, Chapter 1, Subchapter C, Part 16, "Types of Contracts," 16.405-2, "Cost-Plus-Award-Fee Contracts," undated, [Online] Available: http://cfr.vlex.com/vid/16-405-2-cost-plus-award-fee-contracts-19870012, accessed 13 November 2010.
11. FAR Volume 1, Subpart 16.4, *Incentive Contracts*, March 2005, [Online] Available: https://www.acquisition.gov/far/05-47-1/pdf/FAR.book.pdf, accessed 18 November 2010.

***Lieutenant Colonel Stephen Hays Russell**, PhD, USAF (Ret) is professor of supply chain management, John B. Goddard School of Business and Economics, Weber State University, Ogden, Utah. Dr Russell teaches courses in procurement, cost analysis, and statistics. His active duty assignments included senior cost analyst for the F-111 System Program Office and program control manager for the B-1 development program.*

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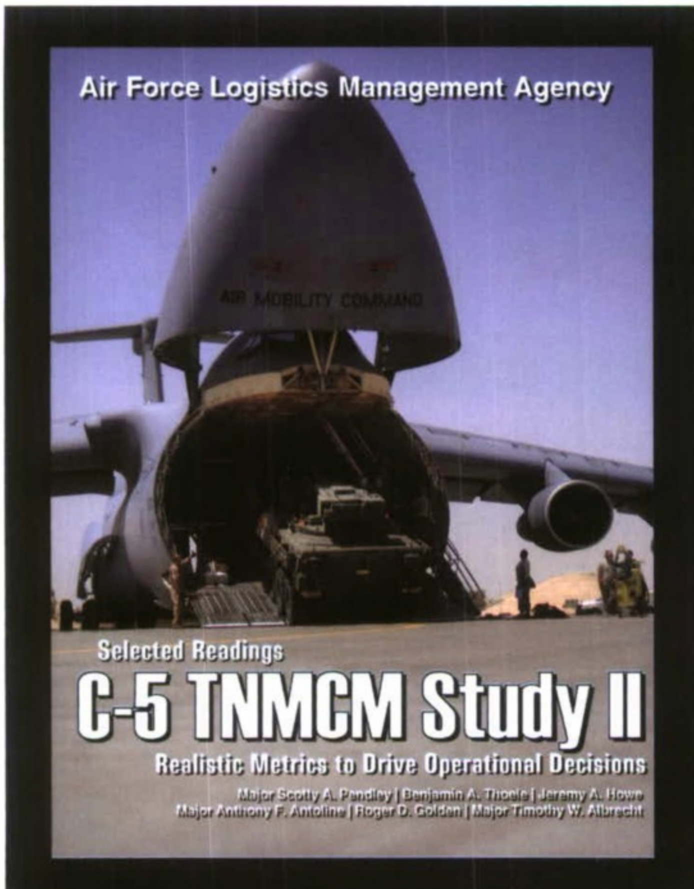


The *C-5 TNMCM Study II* proved to be a stem test of AFLMA's abilities and perseverance. Considering the numerous potential factors that impact TNMCM rates as well as the C-5's historical challenges in the areas of availability and achieving established performance standards, the study team was determined to apply new thinking to an old problem. The research addressed areas of concern including maintaining a historically challenged aircraft, fleet restructuring, shrinking resources, and the need for accurate and useful metrics to drive desired enterprise results. The team applied fresh perspectives, ideas and transformational thinking. As a result, the study team developed a new detailed methodology to attack similar research problems, formulated a new personnel capacity equation that goes beyond the traditional authorized versus assigned method, and analyzed the overall process of setting maintenance metric standards. AFLMA also formed a strategic partnership with the Office of Aerospace Studies at Kirtland AFB in order to accomplish an analysis of the return on investment of previous C-5 modifications and improvement initiatives. A series of articles was produced that describes various portions of the research and accompanying results. Those articles are consolidated in this book.

AFLMA

Generating Transformational Solutions Today; Focusing the Logistics Enterprise of the Future

Special Feature

Introduction

The United States (US) is at a critical juncture in space technology, and national security leaders should be cautious. While the US has maintained space supremacy, global competitors have begun to rapidly erode that leading edge. Global competitors include state and nonstate actors, and they have the capability to exploit the space domain's immense vulnerabilities. Russia and China have clearly demonstrated a direct kinetic kill anti-satellite (ASAT) capability. In addition, several other nations and nonstate actors are working on active, effective ASAT offensive warfare capabilities. Furthermore, the recent collision between a US and Russian satellite highlights the increasing vulnerabilities seen in space.

It is no secret that the US depends on the employment of land, sea, air, and cyber warfighting capabilities to defend the nation. We are equally dependent on the availability, reliability, and viability of US space assets. Therefore, space is vital to the national security of the US today, as it will continue to be for tomorrow. There are no viable alternatives to space systems, and threats from global competitors are real. The nation must overcome its greatest challenges in space and capitalize on disruptive and emerging technologies before it is too late.

The greatest challenges the US faces today in the acquisition and launch of additional advanced, hardened, and secure space assets are as follows.

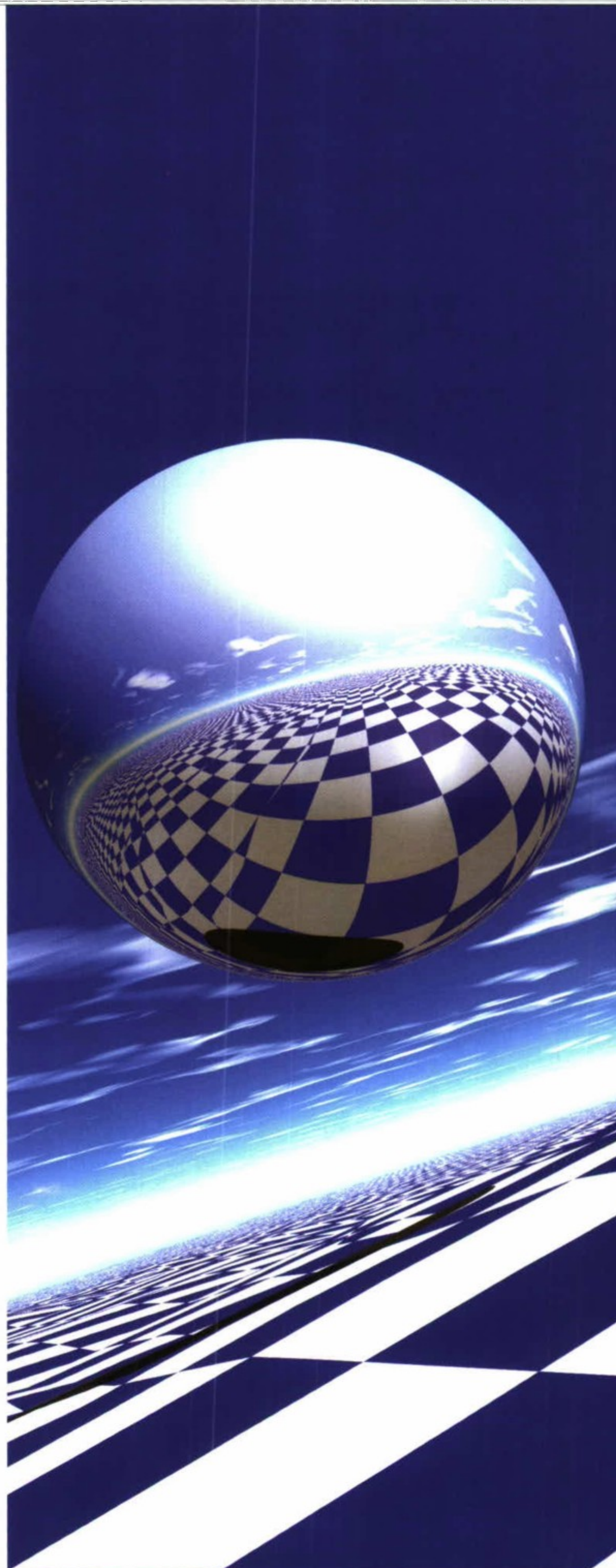
- Their massive cost coupled with their enormous weight
- The ability to provide lift
- Supply extended power
- Manage heat

Fortunately, the potential solutions are many and varied. The US can seek the following options.

- Reduce the cost of launch
- Improve spacecraft performance
- Decrease the cost of power consumption and increase longevity
- Expand spacecraft functionality
- Decrease the cost of communications while expanding life expectancies and currency
- Reduce spacecraft cost in dollars per kilogram for the function and performance it provides

Alternately, the US can exponentially improve the spacecraft function and performance so that the spacecraft capabilities far outweigh the cost. For this to occur, the US must renew its commitment to the advanced research and development of new technologies and restore its commitment to space.

This historic crossroads requires innovation, thinking out-of-the-box, and focusing on the vast array of exponential technological possibilities. Rapidly advancing technologies with the ability to transform and revolutionize virtually every



Eva S. Jenkins, Colonel, PhD, USAF

Nanotechnology

Enabling Future Space Viability

Article Highlights

With the application of nanotechnology-enabled space systems, the US will have the ability to retain its dominance in space and sustain the viability of employing space-enabled technology in national defense.

The United States (US) is at a critical juncture in space, and national security leaders should take heed. Global competitors have begun to rapidly erode the US's lead in space supremacy. The employment of US land, sea, air, and cyber warfighting capabilities in the nation's defense are critically dependent today on the availability, reliability, and viability of US space assets and always will be. Henceforth, space is vital to the nation's security now and in the future.

The biggest challenges the US faces in the acquisition and launch of additional secure, advanced, and hardened space assets are their massive cost coupled with their enormous weight, the ability to provide lift, to supply extended power, and to manage heat. This crossroad requires innovation, thinking out-of-the-box, and a focus on exponential technological possibilities. Nanotechnology, a disruptive technology ripe for exploitation, is an underlying technology that makes other things possible. It is the likely driving force of the next industrial revolution.

The properties of nanotechnology-enabled systems and materials are ideal for space. In the near term, these space systems will have significantly enhanced flexibility, robustness, and performance capabilities with reduced costs. The high payoffs include ultra small sensors, communication and navigation, power sources, and propulsion; dramatically reduced emission,

industry, to include space, are ripe for exploitation. Genetics, robotics, information technology, and nanotechnology are truly transformative technologies with the potential to impact national security both positively and negatively. The technological advances predicted in the coming years are expected to exponentially surpass the advances seen during the past century. But of the four technologies mentioned here, nanotechnology is the underlying technology that makes other things possible. It is the key to future space viability and dominance. Nanotechnology is research and technology development at the 1 to 100th nanometer (nm) scale; the creation and use of structures that have novel properties because of their small size; and last, the ability to control or manipulate at the atomic scale. Nanotechnology may very well be the driving force of the next industrial revolution.

The properties of nanotechnology-enabled materials are ideal for space. As such, nanotechnology holds the key to transforming the space domain, and is the major driving force in the expansion of space capabilities. Over 60 nations have established nanotechnology initiatives, and over 4,000 companies and research institutes are working on nanotechnology developments worldwide. In the near term, nanotechnology-enabled space systems will have significantly enhanced flexibility, robustness, performance capabilities, and eventual reductions in costs. The high payoffs include ultra small sensors, communication and navigation, power sources, and propulsion; dramatically reduced emissions, mass, volume, heat, and power and fuel consumption; easily reconfigurable, autonomous systems; and single-chip satellites with multiple capabilities. In the longer term, nanotechnology-enabled systems will likely provide space systems with 1,000 times the performance of today's systems; weapon systems at the warfighters' fingertips enabled by nanotechnology; and carbon nanotube space elevators, among others. There is no doubt that these revolutionary systems will be enabled by nanotechnology, and will be employed in space. Whether they will be routinely employed in space by the US or by someone else is yet to be seen. The US must take decisive action before the nation's security posture is irrevocably weakened. The development of the future frontier[1] has only just begun.

This article briefly explores the importance of space today to the US, and surveys its most obvious vulnerabilities. Second, it examines the landscape of advancing technologies, focuses in on the changer—nanotechnology—and its practical space applications, and explores who the leading competitors are in the realm of nanotechnology research and development. Third, this article envisions a future space enabled by nanotechnology by exploring real near-term possibilities, surveying long-term predictions, and addressing the impact of nanotechnology-enabled space on future US national security. Four alternate future scenarios are explored. At the conclusion, this article contends that aggressive development of nanotechnology-enabled space systems today has the potential to facilitate future space viability and dominance in 2035 and beyond.

Space Today

The space age began over a half-century ago. Since then the world witnessed the development of astounding technological advancements in the space domain, and the enormous growth in the global space industry. In 2007 the overall worth of the commercial, civilian, and military space industry reached nearly \$220B.[2] The global financial crisis, which began in October of 2008, remains today and will likely precipitate a short-term industry slowdown. However, because space has become an integral part of the lives of so many around the world, the recent economic downturn will likely have little effect on the long-term future of space development.

Importance

The contributions of space-enabled technologies touch billions of people every day in areas such as television broadcasting, telephone services, commercial aviation and shipping, train transportation, police and fire emergency services, personal vehicle navigation, finance and banking, product tracking, agriculture, and so much more.[3] While important to our daily lives, space is critical to the nation's security and defense. Key federal agencies, such as the Department of Homeland Security and the Department of Defense (DoD) depend on space assets as they protect the US, its citizens, and American interests around the world.

The value of space or its importance to the US economy, military, and overall security is lost on many Americans. Furthermore, not everyone agrees with the assertions that space power is critical to the US, that we are increasingly dependent on space assets, and that the nation will become even more vulnerable if we do not retain dominance in space. The article "Spacepower: A Strategic Assessment and Way Forward" warns that "...spacepower remains misunderstood, underdeveloped and underexploited...Spacepower offers the prospect of tremendous benefits to humanity...Failure to understand the nature of spacepower and how to wield it productively could lead to serious miscalculations and tragic consequences."[4] Fortunately, some of the nation's best scientists, engineers, researchers, and leaders in the public, private, and academic sectors are working on issues and developments that will contribute to the ability of the US to avoid future catastrophic consequences in space. But can more be done?

A May 2003 report of the Defense Science Board and Air Force Scientific Advisory Board Joint Task Force on Acquisition on National Security Space Programs conveyed in its findings that "US national security is critically dependent upon space capabilities and that dependence will continue to grow."[5] The report stated that our nation must continue to be able to monitor worldwide activities, transfer massive amounts of data, and provide global force projection. It added that the nation requires "robust space assets" to be able to meet these national requirements effectively and that there is "no viable alternative to the unique capabilities that space systems provide."[6] In 2005, General James E. Cartwright, commander of the US Strategic Command was the DoD's leader charged with overseeing US military global strategic planning, including nuclear deterrence and space operations. General Cartwright testified to the Strategic Forces Subcommittee of the Senate Armed Services Committee that US national security, the economy, and the quality of our way of life "are all linked to our freedom of action in space." General Cartwright added that it is vitally important to "protect our space assets and our ability to operate freely in—and from—space."[7]

The Defense Science Board, Air Force Science Advisory Board, and Department of Defense leaders are not the only advocates of space and its significance to the nation's security. This claim is echoed by academics as well. The assertion that "...space has been

Article Highlights

mass, volume, heat, and power and fuel consumption; easily reconfigurable, autonomous systems; and multifunctioning single chip satellites. In the longer term, they may include systems with 1,000 times the performance and weapon systems enabled by nanotechnology.

Space is the future frontier once again. The US must take decisive action before the nation's security posture is irrevocably weakened. This article contends that aggressive development of nanotechnology-enabled space systems by the US today has the potential to facilitate the nation's future space viability and dominance in 2035 and beyond.

Article Acronyms

AFM – Atomic Force Microscope
AFRL – Air Force Research Laboratory
ASAT – Antisatellite
CNSI – California NanoSystem Institute
CNT – Carbon Nanotube
CONUS – Continental United States
DARPA – Defense Advanced Research Projects Agency
DCI – Director Central Intelligence
DoD – Department of Defense
FEEP – Field Emission Electric Propulsion
GNR – Genetics, Nanotechnology, and Robotics
GPS – Global Positioning System
JSTARS – Joint Surveillance Target Attack Radar System
Kg – Kilogram
MEMS – Microelectromechanical Systems
MIT – Massachusetts Institute of Technology
mm – Millimeter
MNT – Micro and Nano Technologies
MST – Microsystem Technology
NASA – National Aeronautics and Space Administration
NHREVC – National High Reliability Electronics Virtual Center
nm – Nanometer
NNI – National Nanotechnology Initiative
UCLA – University of California Los Angeles
US – United States

and will continue to be important to our national security"[8] is supported by numerous authors and noted experts on space including Barry Watts in *The Military Use of Space: A Diagnostic Assessment*; Steven Lambakis in *On the Edge of Earth: The Future of American Space Power*; Everett C. Dolman in *Astropolitik: Classical Geopolitics in the Space Age*; Bob Preston and his team in their RAND book *Space Weapons, Earth Wars*; and M. V. Smith in his article *Ten Propositions Regarding Space Power*. Some of the preceding authors also address the ongoing debate on whether to weaponize space or not. While this debate relates to issues of national security, it is a highly controversial topic and though vitally important, it will not be addressed in this article. Ultimately, future wars will be fought in this newest domain and nations must be prepared to address the prospect.

While open warfare is currently not being fought in the highest frontier, it is being fought on land, in and on the sea, and in the air. Space systems such as the Global Positioning System (GPS), Satellite Communications, and Space-Based Infrared System High, among others, aid the national security apparatus to navigate, communicate, conduct intelligence, and accomplish command and control. Because the nation's defense is reliant on these capabilities, current modes of land, air, sea, and cyber warfighting would be significantly constrained if the ability or access to use the space assets was either hindered or denied. The systems currently in space cost billions of dollars and have limited lifetimes. Furthermore, the technology onboard is outdated soon after the systems are launched and often prior to their deployment, particularly when it comes to the information-related systems on board.

The greatest challenges the US faces in the acquisition and launch of additional advanced, hardened, and secure space assets are their massive cost coupled with their enormous weight, the ability to provide lift, to supply extended power, and to manage heat. For example, today it costs approximately $20K per pound to send a satellite into geosynchronous orbit and about $10K per pound to send the space shuttle into orbit.[9] Furthermore, at this point in time, any country or nonstate actor with the money to do so can remove the functionality of US spacecraft.[10] Dennis M. Bushnell, chief scientist at the National Aeronautics and Space Administration (NASA) Langley Research Center, agrees and argues that our nation's "space vulnerabilities are absolutely hideous."[11]

Vulnerabilities

The US retains the strategic advantage in space today; however, nations around the world are gaining ground in various areas such as research and development, asset acquisition and deployment, and ASAT weapon employment. According to *The Joint Operating Environment 2008* document published by the US Joint Forces Command, "Over the past several decades the US has enjoyed unchallenged dominance over the dark realm beyond the atmosphere." This statement is true. However, defense experts also concur that the increasing proliferation of launch and satellite capabilities, as well as the development of ASAT capabilities, has begun to level the playing field. Other countries are leveraging the benefits of space for both commercial and military applications, and the US already confronts increased competition for its use. Nothing illustrates this point better than the recent launch of a small satellite by Iran. This will increasingly be the case over the coming decades.[12] A review of commercial satellite use for public imagery consumption asserts that "(t)he number of sources for satellite imagery continues to grow, fueled not only by government customers in the USA and worldwide, but by an explosion of public usage."[13] The implications are clear: the Joint Force will have to be prepared to "defend the space-based systems on which so many of its capabilities depend."[14] Following an August 2008 visit to the US Space Command, retired General Barry J. McCaffrey predicted that "the next administration will have at most a year to analyze a series of difficult strategic and investment space decisions before US global superiority will start rapidly eroding."[15]

Congress recently arrived at some of the same conclusions. A 2008 *House Report on Challenges and Recommendations for US Overhead Architecture* deduced that "(t)he US is losing its preeminence in space." In the report they wrote that there is a "narrowing gap between US capabilities and emerging space powers such as Russia, India, and China." The report further added that

> (s)pace continues to play an increasingly important role in supporting the national security interests of the US. As the number of threats increase, the nation must continue to deliver space capabilities that provide policymakers and the warfighter with the information they need. The next few years are a defining moment for the US...decisive action is required to chart a successful course to preeminence in space.[16]

The problems of maintaining preeminence and viability in space are complex and varied, and alternative solutions must be found.

Space programs at the National Reconnaissance Office and in the US Air Force have been plagued with multibillion dollar cost overruns and lengthy delays. Former Director of Central Intelligence (DCI) and former Secretary of Defense Robert Gates are concerned about the availability of services from space, especially when threats to the nation's space assets are growing. These threats include China's successful shoot down of one of its own satellites in 2007 and significant advances in directed-energy technology that can blind, disrupt, and destroy satellites. While serving as the DCI, Gates "advocated unsuccessfully for a mix of the large, multipurpose intelligence satellites and small, easily launched, single-purpose, limited-orbit-time capabilities that we could throw up with a number of different launchers."[17] The technological advances to accomplish Secretary Gates' proposal are closer than ever before but they require out-of-the-box thinking, a commitment to technological change, and a willingness to expand research and development at a time when we are fighting two land wars while battling forces of terrorism around the world.

One such out-of-the-box thinker is Ivan Bekey. In his book *Advanced Space System Concepts and Technologies: 2010-2030+* he contends that if we use "linear extrapolation with respect to space capability several decades into the future" the prospect for space will be "very gloomy."[18] Using this linear train of thought, he expects that the cost of launch will be close to what it is today; spacecrafts with the same function and performance will weigh about the same; spacecraft cost will continue to be tens of thousands of dollars per kilogram; power consumption will continue to be costly and limited; military spacecraft will continue similar roles and functions; and communications spacecraft will continue to be expensive with short life expectancies and quick obsolescence once launched.[19] These prospects will not afford the US the capacity or ability to make significant advancements in space. Linear thought, coupled with the current and emerging global threats to US space supremacy, have the potential to bring the nation to a critical juncture quickly in space, if the US is not there already.

The US may be at a critical juncture in the dominance of space. Following an August 2008 visit to Air Force Space Command, General Barry R. McCaffrey, USA (retired), Adjunct Professor of International Relations, US Military Academy, highlights the following in his After Action Report Bottom Line.

- The US Air Force has owned the space domain for 50-plus years with no serious threat to our dominance of the high frontier. That golden era has come to an end.
- The control of space is central to all US Joint Operational Forces and netcentric warfare. We lose 35 years of modernization if we lose space.
- If US orbital assets and control are put in jeopardy, then our Joint ground-sea-air combat effectiveness is degraded by an order of magnitude.
- This US space dominance superiority gap is rapidly narrowing. Both nations and nonstate actors have now obtained or are leasing space capabilities (Russia, China, India, Japan, the European Union, Israel, Taiwan, Brazil, Argentina, Algeria, Morocco, Saudi Arabia, and others).
- Several nations and nonstate actors have created active, effective ASAT offensive warfare capabilities. (Alternative Options: kinetic impact weapons electronic jamming, laser heating or pulsed laser mechanical effects, chemical attack of orbital surfaces, ground attack against control sites, intense radio frequency energy, nuclear direct attack with gamma rays and neutrons, attack with indirect nuclear effects above the atmosphere, intense beams of neutral particles.)
- The Russians (April 1980), the US (September 1985), and the Chinese (January 2007) have clearly demonstrated in the unclassified world a direct kinetic kill ASAT capability.
- Space is becoming more crowded and more dangerous. There are 450 active foreign spacecraft in orbit today. (300-plus are communication satellites in geostationary orbit.) In 2010 there were more than 600 foreign spacecraft. Satellites are now being launched from 12 known foreign launch sites as well as from sea launch locations.
- Space is becoming cheaper, smaller, and commercial."[20]

General McCaffrey also came up with several key judgments during his visit about the near-term space environment. Those judgments are:

- The total number of foreign satellites in orbit and their capabilities will dramatically increase in the coming decade with both peer group competitor states and nonstate actors posing a new and dangerous threat to US space dominance. The European Union will have a commercial capability that will rival that of the US.
- Adversaries to include criminal organizations and terrorist groups will acquire from third parties the capabilities to destroy, deny, and deceive US space systems.
- Several countries to include the current Russian and Chinese capability will pose a direct kinetic threat to US on-orbit assets.
- Russia will become the dominant international leader in military space capabilities during the coming decade.
- The US will lose the ability to conduct covert military operations as we are denied concealment and deception by the wholesale proliferation of high-quality imagery and signals intelligence satellites in the possession of our adversaries.
- The capability to conduct electronic attack against our satellites will be a tool in the hands of terrorists and other nonstate actors if we do not rapidly invest in new hardening and other defensive technology.
- Terrorist and state actors will actively prepare to attack US ground satellite control capabilities.
- All international commercial, civil, military, and government actors will become centrally and absolutely dependant on global high-quality satellite communications and GPS capabilities. This is an opportunity and a threat at the same moment.[21]

General McCaffrey finished with the assessment that "many of these conclusions are destabilizing to US national security. Most of these rapidly emerging new realities can be mitigated or turned to our advantage by smart investments and newly invigorated national leadership and creativity." The US is at a crossroad and it is imperative that leaders reexamine and restore the nation's commitment to space. General McCaffrey proposed that "it is time for a new assessment of the strategic risk we face and a renewed sense of energy to modernizing and changing the strategic posture of our global forces."[22]

Referring back to Bekey's assessment, with respect to linear thinking, the nation ought to refrain from using this default way of thought and take an alternate approach to ensure the US has the capacity and ability to make significant advancements in space. Basing predictions on past technological progress, futurists and scientists contend that humanity will witness exponential progress in the coming years. Assuming their calculations are correct a variety of options become possible. Our nation can seek to do the following.

- Drastically reduce the cost of launch from what it is today
- Dramatically improve the function and performance of spacecraft
- Significantly decrease the cost of power consumption and increase spacecraft longevity
- Expand the roles and functions of military, civil and private spacecraft
- Decrease cost of communications spacecraft while expanding life expectancies and currency

Alternately the nation can seek to significantly reduce the cost of a spacecraft from the tens of thousands of dollars per kilogram it costs today for the function and performance the spacecraft currently provides. Or better yet, the nation can seek to exponentially improve the functions and performance of the spacecraft so that the spacecraft's capabilities far outweigh the cost. To accomplish this, the US will need to capitalize on current scientific breakthroughs and disruptive technologies. Fortunately the rapidly advancing technologies that have the ability to transform and revolutionize virtually every industry to include space are literally on the horizon.

Advancing Technologies—Genetics, Robotics, Information Technology, and Nanotechnology

There are numerous rapidly advancing, disruptive technologies that have the capacity to impact US national security. However, the ones with the ability to truly transform and revolutionize our world as we know it today are genetics, robotics, information technology, and nanotechnology. These new technologies, coupled with the premise that the world is becoming flatter, are empowering individuals around the world to participate in globalization by figuratively shrinking the world to a minuscule size. Rapid globalization has proliferated advancing technologies, flattened the world, and impacted its polarity.

Thomas L. Friedman asserts that we are now in the third great era of globalization. The first, Globalization 1.0, started in "1492—when Columbus set sail, opening trade between the Old World and the New—until around 1800...shrinking the world from a size large to a size medium." The dynamic force for global integration was the brawn, muscle, horsepower, wind power, or steam power a nation possessed. The second era, Globalization 2.0, started roughly around 1800 through 2000 and "shrank the world...to a size small." The dynamic force in Globalization 2.0 was multinational companies powered by falling transportation and telecommunication costs. Friedman argues that in 2000 we entered Globalization 3.0, which "shrank the world ...to a tiny size and flattened the playing field at the same time." His central thesis is that the dynamic force for global integration is the power for individuals to collaborate and compete globally with the newest applications of software and the global fiber-optic network tying everyone together. The transformational piece of this era is that it is "shrinking and flattening the world...and empowering individuals" around the world in countries like India, China, Latin America, Russia, and the Middle East to participate in both the beneficial and harmful aspects of globalization.[23] The ongoing transformation ensures that high-tech research, development, and consumer products are made available to people in all parts of the world, thus furthering technological advances even faster. This ongoing transformation is equally applicable to the space industry as nations around the world are entering the space domain by accessing widely available space-enabled services, establishing launch capabilities, and developing satellite manufacturing bases, among others. The current world financial crisis may slow this progress temporarily but the forces at work are simply too compelling to dramatically change the results.

Another futurist, Ray Kurzweil, contends that the first 50 years of this century "will be characterized by three overlapping revolutions—in Genetics, Nanotechnology, and Robotics" or GNR. He believes that we are already in the beginning stages of the Genetics revolution, that the Nanotechnology revolution "will enable us to redesign and rebuild—molecule by molecule—our bodies and brains and the world in which we interact," and that the most powerful impending revolution is the one in Robotics. [24] Kurzweil refers to the legendary information theorist John von Neumann's ideas that "human progress is exponential rather than linear" and that "exponential growth is seductive, starting out slowly and virtually unnoticeably, but beyond the knee of the curve it turns explosive and profoundly transformative." He contends that most long-range forecasts of what is feasible in the field of technology dramatically underestimate the power of future developments because they view history in a linear manner vice exponentially. He argues that "we won't experience one hundred years of technological advance in the twenty-first century; we will witness on the order of twenty thousand years of progress...or about one thousand times greater than what was achieved in the twentieth century."[25] While Kurzweil cites information technology as a vital component of this revolution, another theorist incorporates information technology as one of the critical drivers.

Joel Garreau also explores this ongoing revolution and contends that four "intertwining technologies are cranking up...." They are the technologies for genetic, robotic, information, and nano processes. He explains that these four advancing technologies "are intermingling and feeding on one another, and they are collectively creating a curve of change unlike anything we humans have ever seen."[26] This curve of change will transform and revolutionize every field of technology, to include space technology.

The curve indicates that the amount of new technology introduced in the 1800s was significantly smaller than the amount of technology introduced in the 1900s. Furthermore, the curve denotes that the amount of technology that is expected between 2000 and 2025 is significantly greater than what was achieved in the 1900s. The other part of the equation is that as the cost of technology is being driven down, the access to the technology is being driven up allowing more and more people around the world the opportunity to use it or exploit it. Figure 1 depicts the curve.

Another factor in the ongoing revolution is based on Moore's Law which still stands today. It states that the processing power per price of computers will increase by a factor of 1.5 every year. This is not expected to change or end in the next two decades.[28] Additionally, Garreau points out that every year the cost-performance ratio of Internet services and modems is doubling, the Internet backbone bandwidth and the size of the Internet itself is doubling, and acceleration based on Moore's Law is proliferating. Because of this acceleration in information technology, other transformative technologies such as genetics, robotics, and nanotechnology are beginning to spawn and rapidly accelerate as well.[29] This also has a profound effect on virtually every technology, to include those technologies employed in the space domain.

Genetics, robotics, information technology, and nanotechnology are truly transformative technologies with the potential to impact US national security both positively and negatively. But of the four, nanotechnology, the underlying technology that makes other things possible, is the key to future space viability and dominance. So what is nanotechnology and why are nanotechnology-enabled space systems ideal for the space domain?

Nanotechnology and Space Applications. The origin of the word nanotechnology dates back to 1987 when K. Eric Drexler published *Engines of Creation: The Coming Era of Nanotechnology*. The concept itself emerged in the early 1970s.[30] But even before then, the famous scientist Richard Feynman foresaw the concept of nanotechnology in 1959 when he gave a now-celebrated talk "There's Plenty of Room at the Bottom" in which he saw the advantages of ultraminiaturization in computer electronics.[31] His foresight of what nanotechnology has now

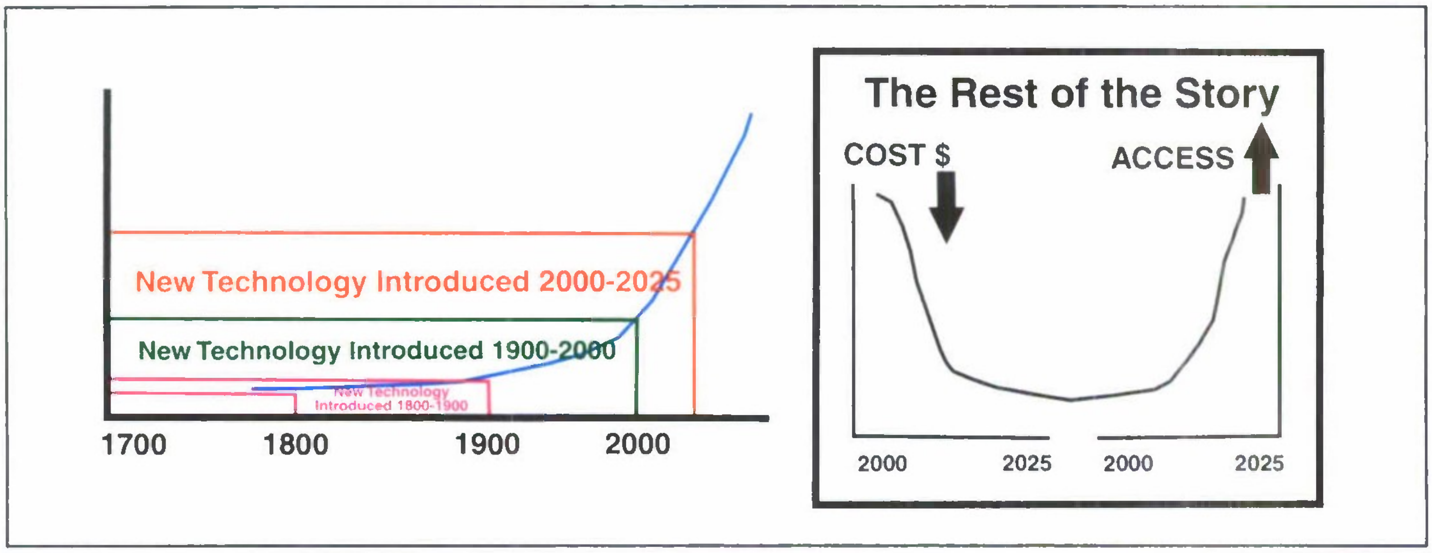


Figure 1. The Curve[27]

evolved into was remarkable and a superb example of nonlinear thinking that is a guide to how future space systems need to be considered.

Nano is the Greek word for dwarf and technically equates to one billionth.[32] One nm is one-billionth of a meter or, in more easily understood terms, one nm is 10,000 times smaller than the width of a human hair. There are several different meanings to the concept of nanotechnology but two are most prevalent. The first "is a broad, stretched version meaning any technology dealing with something less than 100 nm in size." The second is closer to the original definition: "designing and building machines in which every atom and chemical bond is specified precisely."[33] Put another way, nanotechnology is "specifically the technology we predict when the tide of technological progress washes against the shore of atomic physics (the quantum mechanics of electrons, with nuclei considered as unchangeable, primitive particles)." "Nanotechnology is not a set of particular techniques, devices, or products. It is, rather, the set of capabilities that we will have when our technology gets near the limits set by atomic physics."[34] In simplest terms, nanotechnology consists of "research and technology development at the 1-to-100 nm size; creating and using structures that have novel properties because of their small size; and the ability to control or manipulate at the atomic scale."[35] Nanotechnology's appeal is that "unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules."[36] There are many consumer products already out in the market that have capitalized on nanotechnology.

Current widely available nanotechnology-enabled products are faster computers, higher density memory devices, improved baseball bats, lighter weight auto parts, stain-resistant clothing, cosmetics, and clear sunscreen.[37] These products are modest and evolutionary in nature. However, the best is yet to come. According to J. Storrs Hall in his book *Nanofuture: What's Next for Nanotechnology*, nanotechnology has the potential to lead the next industrial revolution.[38] A similar forecast is made by Michael Laine. He believes that the discovery of nanotubes will revolutionize this time in history. Nanotubes are "a world-changing technology. Every age has been defined by the material building blocks available…such as stone, bronze, iron. The next age might be defined as the carbon age."[39]

Nanotechnology is real, world-changing, and has had an effect on a wide variety of materials and processes, which have ideal properties and great potential for employment in space and significant implications for space viability and dominance. Some of the materials and processes with space applications include nanoparticles (ultrafine powders); carbon nanotubes or buckytubes (strips of graphite rolled up into a cylinder, 40 to 60 times stronger than industrial steel); nanolithography (a process used to make electronic microchips); nanomanipulation (the ability to manipulate on the nanoscale which has been done in two dimensions for over a decade and scientists are now working toward third dimension); nanoelectronics (the most advanced capabilities that can be synthesized by self-assembly); nanomemories (the process of reading and writing data at molecular densities); nanobatteries; and the process of self-assembly (atomically precise pieces sticking together using chemistry or molecular biology).[40]

Materials enabled by nanotechnology, or nanomaterials, are ideal for space and are "great candidates for spacecraft applications."[41] "In spacecraft high temperature resistance and material strength is critical since rocket engines, thrusters, and vectoring nozzles often work at much higher temperatures…Satellite life is mostly set by the amount of fuel they carry. In fact, more than a third of onboard fuel is spent by partial and inefficient fuel combustion. Combustion is poor because onboard igniters wear out fast and don't perform."[42] Nanotechnology-enabled space applications under development include the following.

- Carbon nanotube materials which are lightweight and will reduce the weight of satellites and spaceships while increasing the structural strength. The materials can be used to build lightweight solar sails that "use the pressure of light from the sun reflecting on the mirrorlike solar cell to propel a spacecraft."
- Nanomaterial, like nanocrystalline tungsten-titanium diboride-copper composite, that offers "a chance to increase igniter life and performance."[43]

- Nanosensors that monitor "the levels of trace chemicals" in spacecraft for performance measurement and can be deployed in a network to "search large areas of planets" for traces of water or other chemicals.
- Infrared sensors. Infrared sensors are already used in space for satellite-based earth and atmosphere imaging research, satellite navigation, optical data communication, and astronomy instrument sighting. This technology will be improved upon by the development of a variety of nanostructures.[44]
- Bio-nano robots in spacesuits. Bio-nano robots will be used for integration into two layers of the suit. The outer layer could self-heal if punctured and the inner layer could monitor vital signs and provide medication in the case of an emergency.
- Microelectromechanical systems (MEMS) devices. MEMs devices will be used in thrusters for spacecraft and could be used for acceleration of nanoparticles "reduc[ing] the weight and complexity of thrusters..."[45]
- Atomic Force Microscope (AFM)-based nanorobotic systems. Systems used for improved efficiency in manipulating nano-objects with "broad applications for nano-imprinting, manipulating nanoparticles, DNA molecules, and assembling nano devices."[46]
- Nanostructured optoelectronics. This type of technology will "offer space applications in optical satellite telecommunications and sensory technology (such as infrared sensors). Optical wireless data links are important for intrasatellite communication as well as optical intersatellite links. Smaller and lighter devices having a higher bandwidth compared to common microwave communications are always needed."[47]

Nanotechnology-enabled optical technology (described previously) is key to data relay processing such as providing high data rates with low mass, low-power terminals, and secure, interference-free communications. One-way and bidirectional optical links between satellites is already being successfully employed by the European Space Agency's Advanced Relay Technology Mission among others.[48] So the secret is out. Nanotechnology-enabled materials, processes, and applications can make a world of difference. So who is investing in this relatively new, revolutionary technology?

Today, many US government, industry, and academic institutions are investing in the application of nanotechnology-enabled materials, processes, and applications. Back in 1998 an interagency working group on nanotechnology was established in the US. The first government-sponsored nanotechnology program, the US National Nanotechnology Initiative (NNI) was established two years later. The National Science, Engineering, and Technology Subcommittee was created under the National Science and Technology Council's Committee on Technology to coordinate efforts and, subsequently, the Nanotechnology Coordination Office was stood up to synchronize federal nanotechnology efforts. The *21st Century Nanotechnology Research and Development Act* was enacted in 2003 which authorized appropriations for research and created the National Nanotechnology Advisory Panel calling for a review every three years by the National Research Council of the National Academies. The *NNI Strategic Plan 2007*, updated from the 2004 version, highlights the fact that NNI will receive reviews by the President's Council of Advisors on Science and Technology and the National Research Council.[49]

Each year the President proposed additional funding for nanotechnology and Congress has granted it. Since the NNI's creation, \$8.4B has been appropriated for nanotechnology research and development to "foster continued US technological leadership and to support the technology's development with long-term goals of: creating high-wage jobs, economic growth, and wealth creation; addressing critical national needs; renewing US manufacturing leadership; and improving health, the environment, and the overall quality of life."[50] While the goals are admirable, the \$8.4B over a decade or so is not nearly enough.

The NNI involves 25 federal agencies and has four main goals which are listed in the *NNI Strategic Plan 2007*, updated from the 2004 version. The goals are to "advance a world-class research and development program; foster the transfer of new technologies into products for commercial and public benefit; develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and support responsible development of nanotechnology."[51] The NNI has eight program components. They include "fundamental nanoscale phenomena and processes; nanomaterials; nanoscale devices and systems; nanomanufacturing; instrumentation research, metrology, and standards; major research facilities and instrumentation acquisition; environment, health, and safety; and education and societal dimensions." Since 2006 the Department of Energy has established five new Nanoscale Research Centers "to support the synthesis, processing, fabrication, and analysis at the nanoscale..."[52] The DoD is listed as one of the primary collaborators on the first four components and a secondary collaborator on the remaining components.[53]

The Defense Advanced Research Projects Agency (DARPA) is also a dominant player in sponsoring nanotechnology programs around the country. Its role is to maintain the technological superiority of the US military and prevent technological surprise from harming national security through the funding of high-risk, high-reward research and development projects to include those having to do with space employment as well as nanotechnology-enabled projects.[54]

With respect to dual-use technologies for the defense industry, the Air Force, Army, and Navy research laboratories have developed their own unique approaches such as establishing the Air Force Research Laboratory (AFRL) Nanotechnology Initiative, the Army Research Laboratory Nanoelectronics Laboratory, and the Naval Research Laboratory Institute for Nanoscience. Work at AFRL and associated programs have "expanded the existing Air Force materials processing and characterization infrastructure" and have "accelerated the development of engineered nanoscale materials for morphing vehicles, alternative energy generation and storage concepts, and improved propellants" among other contributions.[55] Furthermore, the NNI notes that the power of nanotechnology has the "potential to transform and revolutionize multiple technologies and industry sectors, including aerospace...homeland security and national defense, energy,...(and) information technology..." among other technologies and industries. The DoD is listed as having a central role in all of the above "high-impact application opportunities" where critical research will significantly advance those applications. The DoD is also listed has owning a supporting role in all other application areas.[56]

However, according to the US Joint Forces Command, "the present culture and bureaucratic structures of the DoD place major hurdles in the path of future innovation and adaptation."[57] If the DoD is unable to innovate and adapt the current scientific breakthroughs and disruptive technologies, then the military will be unable to capitalize on the rapidly advancing technologies that have the ability to transform and revolutionize US Armed Forces, to include space forces. But other government agencies are beginning to see the vast potential of a future space domain enabled by nanotechnology.

In 2004 the National Aeronautics and Space Administration (NASA) was reportedly "spending more than $40B a year on nanotechnology investigations."[58] The Center for Nanotechnology at NASA Ames Research Center is researching the application of nanotechnology "to reduce the mass, volume, and power consumption of a wide range of spacecraft systems including sensors, communications, navigation, and propulsion systems."[59] The Johnson Space Center Nano Materials Project is working on nanotube composites to reduce the weight of spacecrafts.[60]

A good deal of work is being done outside of the government as well. Arrowhead Research Corporation is a California-based company commercializing new technologies in the areas of life sciences, electronics, and energy. One of its subsidiaries, Unidym, Incorporated is focused on the manufacture and application of carbon nanotubes (CNT) in an effort to provide "carbon nanotube (CNT)-enabled products, bulk materials, and intellectual property to a wide range of customers and business partners."[61] Some of their products include various CNT materials, transparent conductive films, printable transistors, fuel cell electrodes, and solar cell development. Unidym bases their technology platform on four key technologies, high-purity, electronics grade CNTs, a network of CNTs allowing both flexible and rigid substrates, specialized technology processing, and platforms for component and device design.[62] With their 2007 merger with Carbon Nanotechnologies Incorporated, the company is considered a leader in "bringing carbon nanotube-based products to market."[63] The LiftPort Group and Elevator 2010 groups are working toward making a space elevator constructed of carbon nanotubes a reality.[64] The California NanoSystem Institute (CNSI) was established in 2000 through a California state initiative and opened a new state-of-the-art facility at the University of California Los Angeles (UCLA) in 2007. It is a unique research center whose mission is to "encourage university collaboration with industry and to enable the rapid commercialization of discoveries in nanosystems." [65]

Many projects being worked at UCLA and in conjunction with other institutions are directly space related. For example, Professor Richard Wirz's project, satellite flying formations, is conceptually not out of bounds. Wirz explains that precision formations can provide observational aperture size much larger than those for single spacecraft, therefore allowing image resolution well beyond current capabilities. When combined with small and miniature spacecraft and propulsion technology, the precision formations should allow significant increases in spacecraft capabilities and survivability without additional launch requirements. If his project is fully funded it could be a reality in 10 years, if not funded then surely in 25 years. Wirz contends that the US dominates space now but it is also the nation's Achilles heel.[66] Professor Yang Yang is working on polymer solar cells which "have shown potential to harness solar energy in a cost-effective way" and on the electronic properties of graphene, which "make it a promising candidate for next-generation nanoelectronic devices" both of which can potentially be used in the future on satellites.[67] The Massachusetts Institute of Technology (MIT) Space Nanotechnology Laboratory is "developing high performance instrumentation for use on spaceflights."[68]

There are many more academic institutions and government agencies charging forward with this technology. But they are not only in the US. Other nations now maintain and sustain advancing nanotechnology initiatives. US leaders should be concerned.

Global Competitors. To date over 60 nations have established similar efforts to that of the US NNI. In 2006 the estimate for global investment in nanotechnology was around $12.4B with $6B of that supplied by the private sector. While the US "appears to be the overall global leader" for now, the reality is that other countries are investing heavily in research, development, and application in nanotechnologies based on the US model, and may already have the upper hand in specific areas.

Approximately 4,000 companies and research institutes are working on nanotechnology developments worldwide. Of those, 1,900 are in the services industry and over 1,000 companies are manufacturing products. The worldwide nanotechnology markets are projected to grow from $300B in 2006 to more than $1T in 2015.[69] As of 2007, the leading nations in nanotechnology development are the US, Japan, China, and Germany, with China being one of the "world's leaders in terms of newly established nanotechnology firms."[70] Russia just stood up their version of NNI and pledged over $1B per year toward the initiative. The global requirement will be for two million skilled workers in the nanoscience and nanotechnology field worldwide with at least one-third of those "needed in the US to maintain global competitiveness."[71]

Sixty-three percent of US business leaders in the nanotechnology field believe that the US is the world nanotechnology research, development, and commercialization leader; however, they contend that the lead is narrowing.[72] Using purchasing power parity exchange rates, in 2006 the top ten nations investing public funding into nanotechnology research and development in priority order were the US, China, Japan, South Korea, Germany, France, Taiwan, the United Kingdom, India, and Russia. The nation's leading private sector investments in 2006 were the US and Japan, together accounting for nearly three-fourths of corporate investment.[73] While the US led all other nations in scientific journal paper publication in 2005 with 24 percent of the world output, China was the only major competitor coming in second with 12 percent of the world's output. The US dominance remains today but it also represents a decline from publishing 40 percent of the world's papers in the 1990s. The European Union led the US in terms of quantitative analysis comparison of published papers but the European Union's share is in decline. China's share is rapidly increasing and is projected to surpass that of the US, if it has not already. The following chart indicates China's growth in competitiveness, which has now surpassed the US and Japan, both of which are on the decline (see Figure 2).

The nations with the highest commitment to nanotechnology were South Korea, China, and Japan with the European Union and the US falling below world averages. A testament to the quality of research and development in the US, the papers from the US were most frequently cited. Furthermore, the US led in the area of patent grants.[75] According to the US Patent and Trademark Office, more than 4,800 patents have been identified under the nanoclassification heading.[76] Statistics tell only part of the story. The observations of space and nanotechnology experts are also important to assess. The ongoing research and development, travels, and joint publications of these professionals provide critical insight into the capabilities of the competitors as well as the potential of future nanotechnology-enabled space systems.

From the perspective of scientists and engineers at The Aerospace Corporation (a federally-funded research and development center supporting the Space and Missile Systems Center, US Space Command among other governmental organizations), the US is currently leading the world in government funded nanotechnology research and development and is ahead in nanotechnology-enabled solar cells and structural materials. Dr Donald A. Lewis, Principal Director of the Strategic Awareness and Policy Directorate (Project West Wing), and his team assess that Japan is a major player in research and development and is ahead of the US in nanotechnology-enabled battery development.[77] China is working diligently and deliberately in nanotechnology-focused research and development while Russia is not far behind. The European Union is also making significant strides.[78] Experts in academia provide important insights and observations as well.

According to Dr Jim Heath, the Elizabeth W. Gilloon Professor and Professor of Chemistry, Director of NanoSystems Biology Cancer Center at the California Institute of Technology and a Feynman award winner, the US is in the lead with respect to nanotechnology research and development; however, the lead is not so clear anymore. Dr Heath believes this is the case because the nation has been risk averse in the past decade and is now betting on sure things. He is certain of the inevitable that nanotechnology-enabled systems will be used in space. The biggest question is whether it will be by the US or someone else.[79]

Dr Gregory Carman, a professor in the Department of Mechanical and Aerospace Engineering at UCLA, suspects China will overtake the US in technology research in the near future. His observations come from his many visits to China and his contact with Chinese students in the US and Asia. Ten years ago Chinese students wanted to stay in the US; but now that occurs far less. In the past China's equipment was rudimentary, but during his last visit in 2007 he observed that they are now using state-of-the-art equipment. Furthermore, researchers in China now receive financial incentives to produce. Chinese publications and papers often duplicate the US but they are still quite good. He believes that in terms of technological research, the Chinese will surpass the US in one to two decades.[80] The good news is that proponents in US academic institutions and the private sector of nanotechnology's benefits are trying to do something about the nation's dwindling lead. This is a critical task and one that must be tackled if the US is to remain technologically competitive, viable, and dominant in space.

Unidym executives also believe that the US remains the leader in nanotechnology research and development for now, and that their company holds the competitive edge in the nation by integrating various technologies. Unidym executives believe that, in addition to their regular foreign competitors such as China, Russia, and the European Union, the Middle East has

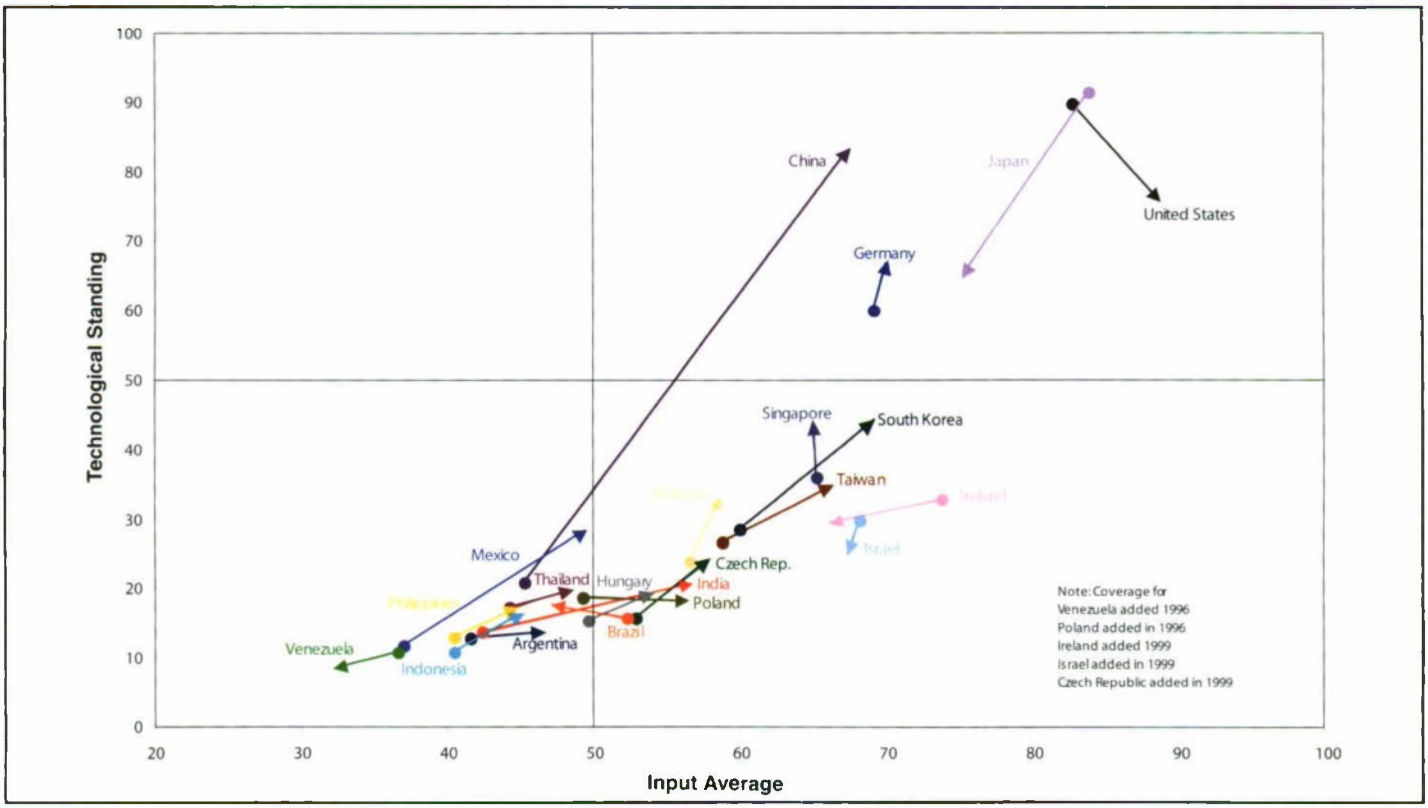


Figure 2. Change in Competitiveness 1993 - 2007[74]

become a competitor with Dubai investing vast amounts of money into nanotechnology. They cite that Korea is developing a *carbon valley* based on nanotechnology-enabling materials which is similar to California's Silicon Valley. They assess that the gap between the US and the rest of the world will narrow in five years with China leading soon after that.[81]

Nanotechnology advocates in virtually all areas of the government, academia, and industry assert that this technology is bound to make "substantial contributions to national defense, homeland security, and space exploration and commercialization.[82] It will require a workforce that understands nanotechnology, electronics on the micro and nano scale, and the ins and the outs of the space industry. Why is the employment of nanotechnology in space application so critical? Will China, Russia, or some other nation achieve space dominance? Or will the US be able to retain this critical strategic advantage? A closer examination of what a nanotechnology-enabled future in space will look like is critical to answering this question.

Space Tomorrow (2035)—Enabled by Nanotechnology

An ambitious, aggressive, and innovative plan backed by federal commitment of dollars and resources could afford the nation an opportunity to capitalize on the benefits of nanotechnology and allow the US to retain its lead in nanotechnology. With the application of nanotechnology-enabled space systems, the US will have the ability to retain its dominance in space and sustain the viability of employing space-enabled technology in national defense.

Near-Term Possibilities

Within the next 15 years, a great deal is possible for application of nanotechnology in space. NASA predicts that the "scientific and technical revolution has just begun based upon the ability to systematically organize and manipulate matter at nanoscale." And that the *payoff* is anticipated within the next 10 to 15 years." According to NASA:

- Advanced miniaturization is key to enabling new science and exploration missions. Ultra small sensors, power sources, communication, navigation, and propulsion systems with very low mass, volume, and power consumption are needed.
- Revolutions in electronics and computing will allow reconfigurable, autonomous, *thinking* spacecraft.
- Nanotechnology presents a whole new spectrum of opportunities to build device components and systems for entirely new space architectures. Examples include networks of ultra small probes on planetary surfaces; microrovers that drive, hop, fly, and burrow; and collections of microspacecraft making a variety of measurements.[83]

In a December 2008 presentation to the defense industry NASA scientists further concluded that

> Nanotechnology can have a significant impact on materials for aerospace applications by enhancing durability, improving properties, [and] enabling multifunctionality. Applications of nanostructured materials can enable significant reductions in vehicle weight—fuels and emissions, improvements in safety and durability, [and] enhancements in performance.[84]

Another initiative is the creation of The National High Reliability Electronics Virtual Center (NHREVC). This is a Web-enabled virtual center for use by multiple organizations and sites from government, industry, and academia across the nation to address the multidisciplinary challenge of electronics lifetime assessment. The center's initial focus is on electron devices with active element sizes smaller than 100 nm, specifically the reduction of risk associated with the employment of the emerging technologies. The motivation for the center is rooted in a widely-held belief that "the DoD and intelligence community must actively adopt emerging electronics" because "obsolescence is driving us to new technologies..." and "hi-speed, low power consumption parts promise a major competitive advantage over our adversaries." The NHREVC's participants include The Aerospace Corporation, The AFRL, universities, commercial industries, Office of Naval Research, government labs, federally-funded research and development centers, and others with expansion to include more participants in Fiscal Year 2009 and beyond. They base their direction and focus on technology insertion roadmaps of the National Security Space, Missile Defense Agency, and NASA.[85]

A report on *Nanotechnology and US Competitiveness* from The Congressional Research Service predicts that within the next five to ten years evolutionary changes based on nanotechnology will occur in the fields of medicine, protective clothing, energy, water purification, higher-density memory devices, agriculture production, environment protection, and remediation. [86] These changes will also occur in the space industry. In 2006 participants at the CANEUS [Canada-Europe-USA-Asia] Conference concluded that "nearly every space program worldwide has found remarkable and successful roles for micro and nano technologies (MNT)" such as the creating of lighter weight, smaller-sized, less-power-dissipated, lower-cost materials for outer space, aerospace, and military applications.[87] DARPA is working on a "concept of fractionated spacecraft, where a traditional monolithic satellite is replaced with a cluster of wirelessly interacting modules that deliver comparable mission capabilities and dramatically enhanced flexibility and robustness."[88]

Concrete advances are being made around the world as well. Surrey Space Center at the University of Surrey, United Kingdom has already moved in this direction and invented SpaceChips as the foundation for a single-chip satellite, which will include "imaging, a solar cell, antennas, a digital radio, a central processing unit, and power control circuitry on a die that measures just 18 by 20 millimeters [mm]."[89] European Aeronautic Defence and Space Company's Astrium Ltd division has developed Micropacks for Space Microsystem Technologies (MST) which will be used to create suites of MST commercial off-the-shelf sensors for assembly and integration "into 3D modular multilayer ceramic package[s]."[90] The benefit will be "the easy inclusion of additional sensors, hardware like MEMS gyros, scientific instruments, and advanced micropower and data communications networking techniques, as well as a microcomputer on a chip....MEMS devices figured heavily in spacecraft propulsion, thrust and rocket designs of all types."[91] Many more nanotechnology-enabled probabilities and possibilities are on the horizon.

Peter Pesti compiled a comprehensive document titled *Roadmap of the 21st Century* that consists of reports from Goldman Sachs, PricewaterhouseCoopers, the United Nations, and the US intelligence community; DoD roadmaps, a nanotechnology expert survey, and a semiconductor roadmap; and predictions by scientists, authors, and futurists. The list includes a number of nanotechnology-relevant forecasts with space applications. The near-term possibilities with space applications are listed in Table 1.[92]

Longer-Term Predictions

The *Roadmap of the 21st Century* nanotechnology-relevant predictions with space applications envisioned in the longer term beyond 2035 are listed in Table 2.[93]

To make these near-term possibilities and longer-term predictions a reality, there be must innovation, out-of-the-box thinking, and a focus on the exponential possibilities. Ivan Bekey, author of *Advanced Space System Concepts and Technologies: 2010-2030+*, believes that "disruptive innovation" vice incremental improvements will revolutionize the changes in space.[94] He contends that the highest leverage technologies should be developed to make this occur. They are as follows.

- Adaptive piezoelectric reflector membranes, actuated by electron beams
- Coherent cooperating distributed or swarmed spacecraft of all sizes
- Buckytube matrixless and composite structures and spacecraft components
- Long lightweight, high strength long-life tethers, wire and nonconducting MEMS FEEP [field emission electric propulsion] integrated micropropulsion assemblies
- Formation flying techniques with submillimeter relative position accuracies
- Spectrally split, multiple matched bandgap cells in concentrated solar power arrays
- Liquid crystal spatial light modulators with more than 1 mm of time delay correction
- Micro-particle stream heat radiators
- High capacity information transmission, processing, and storage to meet all needs"[95]

By 2010	- NRAM (nanotube ram, always-on high density computer memory) - Smart and adaptable surfaces at the nanoscale as building block for Biodetection - Quantum dots: nanosized imaging agents for analysis/diagnosis inside
By 2015	- Commercially available array of nanotubes: Biosensors for detection of single molecules based on nano arrays - Existing materials such as polymers replaced by nanostructured biomaterials - Sensory augmentation using sensory implants, nanoparticles - Targeted drug delivery based on nanoparticles - Optical tweezers: nanotools for manipulation inside cells - Commercially manufactured nanoelectronics chips using DNA or peptides - Nanotools and parts created by DNA - Nanowalkers, nanoworms, nanofish

Table1. Near-Term Possibiiities with Space Applications

By 2025	- Nano-enabled space vehicles with 10 to 1000 times better performance than today - Nanofactories creating space vehicles with --Ion drives with 750k We/kg specific power --Speed 0.5 AU per day --9.8 m/s2 accelerations - Ability to go from Earth to Mars in 1 to 3 days, Earth to Saturn in 20 days - Inexpensive carbon nanotube fiber with over 50GPatensile strength - Nanoengineered machines applied to manufacturing and process-control applications - Sensory augmentation using sensory implants, nanoparticles, etc. - Actuated diamond tools and Nanoparts created - Nanobiotechnology: Fundamental processes of the cellular cycle understood - Biological energy conversion systems used in artificial micro/nano systems - Nanotech based organism colonies - Introductory nanofactory - Nano-machine for theranostics (therapy and diagnostics) used inside body - Everything monitored and tracked by nano-RFID tags with build-in memory - Billion CPU personal nanocomputers
By 2035	- First orbital country in space, nanotube structure many km in diameter at L5, population 100,000+ - Nanotechnology plants created - Human cells interfaced with nanotech - Nanobots scan the brain from inside - Full immersion virtual reality with nanobots, from within the nervous system - Nanotechnology weapons used in war, over 500 million dead
Beyond 2035	- Space elevator based on carbon nanotube built - Nanotech based virus communicable between machines and people, sent over the Internet - Real toy soldiers using nanotechnology - Nanobots swarm projections used to create visual-auditory-tactile projections of people and objects in real reality - Nanoproduced food will ensure availability of food no longer affected by limited resources, bad crop weather, or spoilage

Table 2. Nanotechnology-Relevant Predictions with Space Applications Envisioned in the Longer Term Beyond 2035

Bekey further speculates that "...the introduction of Buckytube materials," into the manufacture of both spacecraft and launch vehicles, "could result in total weight and cost reductions of factors of 100,000 or more from today's levels." "Weight, which is today the major determinant of space system cost, will become essentially immaterial in the future."[96]

Bekey is right when he states "we must be willing to think unconventionally, big, far-term, and high risk" by investing in disruptive technologies so that "space will become just another place." This will create a "whole new ballgame for defense space" as well as for commercial space. In terms of defense and space, he predicts that in the future:

- Global force projection from space will be ubiquitous and devastatingly effective.
- Complete situational awareness will exist from geosynchronous at theater to global scales.
- Many crews will be removed from harm's way by performing functions from continental United States (CONUS) locations.
- Precision weapons will be delivered globally from CONUS.
- The size of, and need for, logistic tails to support operations costs will be greatly reduced.
- Space radar will mostly replace Airborne Warning and Control System (AWACS), Joint Surveillance Target Attack Radar System, Satellite Access Request, and SPACETRACK.[97]
- Spacecraft development, deployment, and operations costs will approach those of aircraft.
- Some space systems will be incrementally funded, emplaced, and upgraded.
- Most of the advanced ideas of the Scientific Advisory Board's *New World Vistas* will be fielded.

But:

- The US will not have decisive technological advantages over others.
- Commercial infrastructure and services will dominate space activity.
- Congress will insist that DoD use these capabilities.
- We will have to learn to observe, fight, and win in this environment."[98]

Other space and nanotechnology experts make similar assertions that nanotechnology will enable radical changes in the space industry. Allan Rogers predicts that NASA spaceprobes will weigh 10 kilograms (kg) or less down from the current weight of hundreds of kilograms, soon to be down to 100 kg.[99] In a paper presented at the Fourth Foresight Conference on Molecular Nanotechnology, Thomas Lawrence McKendree studied "chemical rockets for putting payloads into Earth orbit, single and two stage architectures, synchronous and rotating skyhooks, solar sails, solar electric ion engines, and large inhabited space colonies." He calculated "how well those systems would perform when simply using micro and nanotechnology (MNT) technical performance parameters." He concluded that "In *all* cases, MNT offers the possibility of significant system improvements."[100]

Another potential application is the development of a space elevator (mentioned earlier). Bradley Edwards, president of Caron Designs, Inc. predicts that the space elevator will be built using carbon nanotubes (CNTs) and will allow quick space entry. He added that "the same material could reduce the mass required for the lifting equipment on a space elevator, and also lighten solar power satellites and space stations." [101] These and other nanotechnology-enabled space applications are limited only by imagination, innovation, ability, and dedication to overcome the challenges.

Addressing the Challenges

What will US defense capabilities be in 20 to 25 years from now in this radically different environment? What should DoD, or more precisely the Air Force, do now to address those potential challenges? One answer is wargaming. The US Air Force Future Capabilities Game 2007 is a wargame designed to "shape military capabilities to best respond to emerging future warfighting environments and national security challenges." These wargames are used to "explore new concepts and capabilities and help prevent technological, strategic, and/or operational surprise." The report identified trends and shocks that are likely to erode traditional military advantages. The primary drivers include the following predictions: "a flattening technology gap will reduce US military advantage...computing capability will greatly enhance cyberspace capabilities...(and) rising energy and US manpower costs will force the US military toward energy-efficient and automated systems."[102] The wargame predicted that the following long-term challenges to capabilities are likely: "Deteriorating space security...growing anti-access (land, sea, and air) capabilities...increasing number of weapons of mass destruction by more nations...a rapidly growing information-based global society...(and) the blurring of lines between major combat operations and irregular warfare..."[103] Because the undertaking is so difficult, of the five long-term challenges predicted by the wargame, the US has placed insufficient emphasis on and action toward addressing the deterioration of space security and expanded capability. Nanotechnology may hold the key to overcoming these challenges.

The next step is to study accelerating technologies, forecast their impact in the future on the military, and determine what leaders should do today to address the encroaching challenges. The Air Force's Blue Horizons Program is a headquarters-sponsored, long-range planning effort lead by exemplary faculty members and comprised of volunteer Air War College and Air Command and Staff College line officers within the top 12 percent of their peer group. The research program is designed to mesh with the quadrennial defense cycle. The program focuses on how accelerating technological change interacts with a shifting strategic landscape to produce massive dynamic change. This change then acts as a catalyst to create a very disturbing disruptive threat to the US and a serious challenge to the Air Force's future dominance. The 2007-2008 Blue Horizons Program studied nanotechnology, biotechnology, directed energy, and cyber through 2030 and rooted its findings in a quantitative analysis methodology.

Of the multiple 2007-08 Blue Horizons findings, the conclusions on nanotechnology held that nanotechnology is the easily forgotten game changer. Furthermore, nanotechnology is now being added to make systems better and nanotechnology will become a stand-alone system in 2030. The team also came up with four alternate futures for 2030 represented by a Peer

China, a Resurgent Russia, a Failed State, and a Jihadist Insurgency scenario. These alternate futures provide a plausible tool to understand future challenges and logical extrapolations based on extensive research. The 2008-2009 program specific task is to "develop a prioritized list of concepts and their key enabling technologies that the Air Force will need to maintain the dominant air, space, and cyber forces in the future."

Based on the previous research presented in this article and borrowing heavily from Bekey's implications, the following five assumptions are offered about what nanotechnology-enabled space capabilities could provide the US 20 to 25 years from today. First, the US will employ satellites that possess the capability to perform up to 1,000 times better than the satellites deployed today. Second, the US military will possess the option of global force projection from the domain of space. Third, the US will possess the capability to achieve and maintain complete situational awareness in CONUS for assets located in space. Fourth, the US will have the capacity to execute the majority of its warfighting capabilities from CONUS using space-enabled technology. Fifth, the US will have the ability to deliver precision weaponry from CONUS via assets in space. Because the capabilities listed in the third, fourth, and fifth assumptions will be primarily space-based, they will be in the hands of the warfighter either in the CONUS, on the battlefield, or alternately anywhere the warfighter requires access to those capabilities.

Applying the promise of nanotechnology-enabled space capabilities to the 2007-2008 Blue Horizons Alternate Futures work provides interesting implications for the US 20 to 25 years from now. The following provides a brief glimpse into what the future may hold with a Peer China, Resurgent Russia, Failed State, and a Jihadist Insurgency.

In the case of a future Peer China scenario, Beijing possesses a greater gross domestic product than the US. Its success in exporting high technology product will likely continue to dominate the world,[104] and its global competitiveness far surpasses all other nations to include the European Union. In the case of a future Resurgent Russia, Moscow becomes a key supplier of world energy. The nation grows into a major world economic player as a result of its rapid wealth from hydrocarbon exports; and its autocratic and corrupt leaders demand and seek a role on the world stage.

In the Peer China and Resurgent Russia scenarios, both nations are likely to have attained significant wealth, possess the resources and capabilities to further refine the employment of nanotechnology-enabled space systems, and continue to possess the desire to attain or retain space dominance or supremacy at all costs. The implications are that if both China and Russia dominate space and the US does not, the US would become dependent upon either or both of these two nations for land, sea, air, and cyber defense capabilities as well as other commercial and private services such as television broadcasting, telephone services, commercial aviation and shipping, train transportation, police and fire emergency services, personal vehicle navigation, finance and banking, product tracking, and agriculture. Consequently, the US would benefit by aggressively developing nanotechnology-enabled space systems today, as China and Russia are likely to also develop these systems in an effort to dominate the high frontier in the future.

In the case a future Failed State Scenario using Nigeria as a case study, Nigeria continues to maintain the largest population in Africa with a growing Islamic population in the North following Sharia Law; institutional corruption is rampant throughout, the nation is a haven for transnational criminal enterprises; and the state's failure could ignite wars between and within neighboring countries.

In the case of a future Jihadist Insurgency Scenario using Saudi Arabia as a case study, the vital oil resources and military are taken over by the Jihadists; fear over Muslim holy cities falling into the hands of radical Muslims is heightened; the increasing population growth, coupled with a poor economic outlook is fostering discontent; and low-level insurgency provides for a strong potential for expanded religious, ethnic, and tribal conflict within the state and region.

In closer examination of these two cases, it is not likely that Nigeria or Saudi Arabia will possess nanotechnology-enabled space systems; but they will be the users of such systems. However, the likelihood exists that rogue nonstate actors or terrorists being harbored in these two states would certainly have the potential to access these capabilities. And, as a result, the rogue nonstate actors or terrorists would have the capacity to endanger the viability of the US space force and thereby challenge US national security. In these two scenarios the US would benefit by aggressively developing nanotechnology-enabled space systems today to greatly enhance its future space capabilities and have the ability to project force globally via space. Furthermore, the US would benefit by having the ability to gain the intelligence edge with complete situational awareness and by being able to execute a vast array of warfighting capabilities with true precision weaponry from anywhere in the CONUS or elsewhere using space assets while limiting the placement of troops in harm's way.

In any of the four scenarios the US would benefit greatly if the nation would capitalize on, leverage, and develop nanotechnology-enabled space systems in an effort to ensure the viability of space and maintain dominant space forces in the future. One approach is to seek ways to exponentially improve the functions and performance of spacecrafts so that its capabilities far outweigh the costs. Current advances in the research and development of nanotechnology and nanomaterials are already poised to make this happen; and this will probably happen very soon.

Conclusion

It is hard to imagine life in the US without the daily conveniences enabled by space, which have become routine and mundane to most. It is even more difficult to envision the nation's defense capabilities without the advantages of space. If we lose control of space, we risk losing command of US forces, control of netcentric warfare, and 35 years of modernization of US Armed Forces.[105] The nation must continue to deliver space capabilities that provide warfighters and policymakers with the vital information, intelligence, and capabilities they need. According to the Defense Science Board and the Air Force Science Advisory Board, there is no viable alternative to the unique capabilities that space systems provide.[106] Threats to US national security are increasing and will never cease.

In addition to demonstrated, direct kinetic kill ASAT capabilities, several nations and nonstate actors have created or are working on active, effective ASAT, offensive warfare capabilities such as kinetic impact weapons electronic jamming; laser heating or pulsed laser mechanical effects; chemical attack of orbital surfaces; ground attack against control sites; intense radio frequency energy; nuclear direct attack with gamma rays and neutrons; attack with indirect nuclear effects above the atmosphere; and intense beams of neutral particles. The challenges are many and they are real.

The greatest challenges the US faces today in the acquisition and launch of additional advanced, hardened, and secure space assets are the massive cost, coupled with the enormous weight, the ability to provide lift, the ability to supply extended power, and to manage heat. The potential solutions are numerous and varied. However, the US must employ innovative, out-of-the-box thinking, renew its commitment to the advanced research and development of disruptive technologies such as nanotechnology, and restore its commitment to dominance in space in order to resolve the challenges.

Nanotechnology is real and world-changing. It has had an effect on a wide variety of materials and processes, which have ideal properties and great potential for employment in space. Nanotechnology is the underlying driving force in the expansion of space viability and dominance. Some of the nanotechnology materials and processes with space applications include nanoparticles; CNTs or buckytubes; nanosensors; infrared sensors; nanolithography; nanoelectronics; MEMS devices; nanomemories at molecular densities; nanobatteries; bio-nano robots; Atomic Force Microscope-based nanorobotic systems; nanostructured optoelectronics; two dimensional nanomanipulation with three dimensional nanomanipulation on the horizon; and the process of self-assembly. Furthermore, the employment of nanomaterials such as CNTs or buckytubes in launch and spacecraft materials have the potential to dramatically reduce the total weight and cost by factors of up to 100,000.[107] Nanotechnology can make a world of difference.

The payoffs in space will be expansive in next 10 to 15 years. Nanotechnology-enabled spacecrafts and systems will possess significantly enhanced flexibility, robustness, safety, durability, and performance capabilities while experiencing concurrent reductions in costs. They will include ultra small sensors, power sources, communication and navigation, and propulsion systems. The payoffs will deliver dramatically reduced emissions, mass, volume, heat, and power and fuel consumption. They will include single-chip satellites with multifunctionality and easily reconfigurable, modular, autonomous, thinking spacecraft able to assess and react to the environment. In the longer term, the nanotechnology-enabled systems will likely provide self-assembled spacecrafts; space systems with 1,000 times the performance of today's systems; weapons systems enabled by nanotechnology; and CNT space elevators. The properties of nanotechnology-enabled materials and systems are ideal for space. Nanotechnology will be routinely employed in space. Which nation, federation or conglomeration of nations, corporation, academic institution, or team will be the first to capitalize on this technological revolution?

Since the inauguration in January 2009, the new administration has yet to address the importance of space to US national security. However, prior to the November 2008 presidential election, then President-elect Barak Obama, responded to the top 14 science questions facing America. Three of those twelve questions were on the topics of space, national security, and innovation. With respect to space, President Obama pledged to reestablish the National Aeronautics and Space Council to oversee and coordinate civilian, military, commercial, and national security space activities and work toward a 21[st] century vision of space that constantly pushes the envelope on new technologies. Regarding national security, President Obama promised to ensure that our defense, homeland security, and intelligence agencies have the strong research leadership needed to revitalize US defense research activities and achieve breakthrough science that can be quickly converted into new capabilities for US security to include renewing DARPA. With respect to innovation, President Obama vowed to increase support for high-risk, high-payoff research portfolios at the nation's science agencies and invest in the breakthrough research to transform defense programs.[108] The general direction of the response was correct. Now the muscle must be put behind it. The US must take decisive action before the nation's security posture is irrevocably weakened.

The US would benefit greatly if the nation would capitalize on, leverage, and develop nanotechnology-enabled space systems in an effort to ensure the viability of space and maintain dominant space forces in the future. Aggressive development of nanotechnology-enabled space systems by the US today has the potential to facilitate future space viability and dominance in 2035 and beyond. Space is no longer the *final* frontier. Space is the frontier of the *future*.[109]

Notes

1. The term "future frontier" was first seen in Bill Douhitt's "Space: The Once and Future Frontier," *National Geographic* (Collector's Edition), 2009.
2. *National Geographic*.
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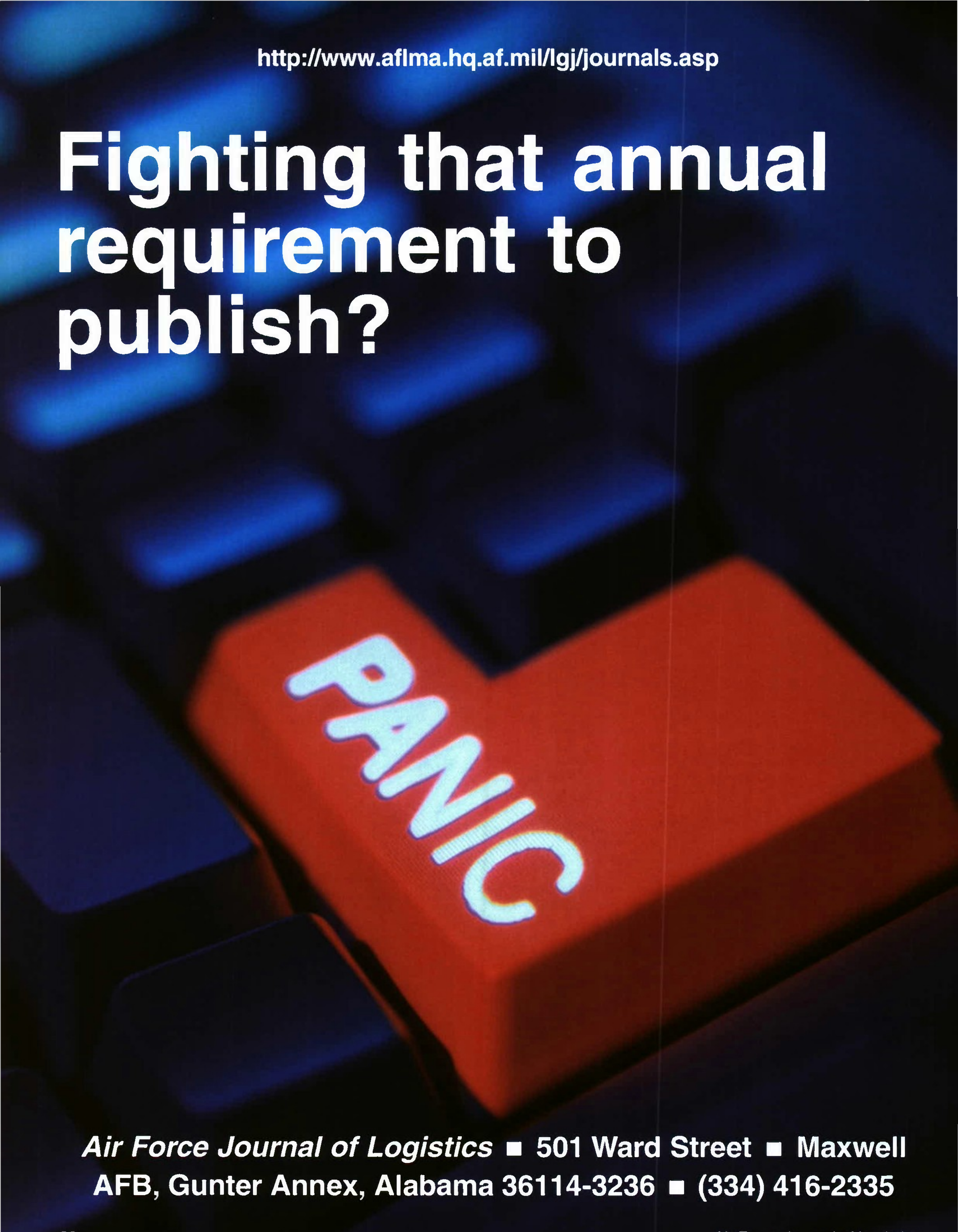
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There are many examples of senior leaders who failed to understand technology or disregarded its relevance to the battlefield. In some cases this was due to conservatism, pride, or even sheer stupidity, but in most cases it was due to an intelligent, well meaning leader inadvertently falling into a decisionmaking trap.

contemporary issues

Preventing Technological Failure in Future War

Special Operations Training Center: Does 3-Level Maintenance Training Belong?

Contemporary Issues in this edition of the Journal presents two articles: "Preventing Technological Failure in Future War" and "Special Operations Training Center: Does 3-Level Maintenance Training Belong?" In the first article Colonel Day contends that the challenge of avoiding technological failure and decisionmaking traps in the future intensifies as the environment becomes more complex and the processes of change continue to accelerate. He makes the case that staying current on future trends requires constant vigilance. Leaders must proactively face the future and its challenges, and seek the knowledge to prepare for it. The implications of not doing so could prove disastrous. The hope for the future lies in having adequately prepared leaders who understand their own shortcomings and the traps they are prone to, organizations that are set up for cognitive and structural diversity, and the right investments of our current resources to ensure the possession of the necessary technologies and weapons to wage war successfully in the nano-battlefields of tomorrow.

In the second article Colonel Miglionico asks the question "should the Air Force Special Operations Command (AFSOC) incorporate 3-level aircraft maintenance on-the-job training (OJT) as part of the Air Force Special Operations Training Center (AFSOTC)? He contends the current method of providing on-the-job training (OJT) for 3-levels using out-of-hide resources is adequate at best and needs improvement. If resourced properly with ample equipment and manpower, without degrading the existing aircraft maintenance organizations' productivity, then AFSOTC is a viable option for ensuring 3-level OJT. He provides a roadmap to do just that.

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Preventing Technological Failure in Future War

Allan E. Day, Colonel, USAF

Introduction

What today is a wild notion, based on science fiction, may suddenly mature into a useful technology with undreamed of capabilities.

Because of the growing complexity of "weapon systems"... and difficulties in disseminating this information, the potential for a technological failure (and technological surprise) not only lurks in the shadow but also becomes larger with time.

–Azriel Lorber, *Misguided Weapons*, 2002

Making good decisions can be hard. There are many examples of senior leaders who failed to understand technology or disregarded its relevance to the battlefield. In some cases this was due to conservatism, pride, or even sheer stupidity, but in most cases it was due to an intelligent, well meaning leader inadvertently falling into a decisionmaking trap. While the concept of decisionmaking traps is not new, the future environment is introducing an entirely new set of challenges that are dramatically altering the way decisions are made on the battlefield. In this rapidly changing, technology charged environment, the effects of decisionmaking failure will be amplified and ramifications far more severe.

To prevent failure, leaders must first understand the environment by staying engaged through self-study. They must become familiar with terms associated with and the implications of concepts such as nanotechnology, quantum computing, biomimetics, artificial intelligence, and nanobots. Linear thinking must be replaced with intuitive leaps to account for the exponentially changing global environment. They must understand how the new flattened world gives rise to threats and opportunities across the spectrum from state actors to empowered individuals.

This article provides insights into the world of nanotechnology and its impacts on the future battlefield environment that will drive decisionmaking today. The first sections serve as a short tutorial on the future environment. In the first section, the basics of nanotechnology are discussed along with working definitions of terms used throughout the rest of the article. The second section looks at the interaction of nanotechnology with a number of other fields such as biomimetics, genetics, robotics, information, energy, and artificial intelligence.

Following the discussion on nanotechnology in different scientific fields, section three provides a discussion about the changing future environment. It provides a discussion of linear versus exponential thinking, the effects of globalization on nanotechnology research, and the growth of India, China, and Russia as competitors for dominance in the nanotechnology market by 2035.

Section four then pulls the concepts together to explore the converging trends and the implications on the 2035 battlefield. It then provides a short discussion of four

competing views about what the future will be like. This general discussion of the future environment will also provide insights into the second and third order effects of nanotechnology on the future 2035 battlefield based on nanotechnology advancements and their implications for national defense. With the basics of nanotechnology understood and the implications and effects of nanotechnology considered for the future battlefield, the next step is to consider how senior leadership must respond.

Section five looks at decisionmaking traps that could lead to technological failure by disregarding, misapplying, or misunderstanding technology. This is not failure of technology, but instead it is human leadership failure to inadequately respond to or understand the game-changing nature of advances in technology. The section describes nine different traps, giving examples from past history, and then goes on to provide concrete ways to steer around each of the decisionmaking potholes.

Section six gives recommendations for disaster-proofing senior leadership against making bad decisions, especially those leading to technological failure. It looks first at important aspects of preparing leaders for success in this new environment, then looks at developing better organizational strategies, and finally ends up exploring the best options for investing resources to keep the United States (US) in a position of technological leadership.

As the environment becomes more complex and the processes of change continue to accelerate, the challenge of avoiding technological failure and decisionmaking traps in the future intensifies. Technological trends coupled with globalization will drive the world's economies not on a linear slope, but on an exponential trajectory. Ubiquitous communication, massive data storage, unfathomable computer processing speed, intrinsic artificial intelligence, miniaturization to the atomic level, along with the pervasiveness of the Internet will continue to converge to drive technological improvements to a level many are afraid to consider today. Leaders must not shirk this challenge; they must face the future and seek knowledge to prepare for it. If leaders fail to make the right choices today, the ability to gain victory in future battles will be lost.

What is Nanotechnology?

Although this article is about leadership decisionmaking, leaders must understand at least the basics of nanotechnology and terms related to its use as it will have a major impact on nearly every aspect of the future battlespace. Thus, to make informed and wise decisions regarding the future, leaders must know about nanotechnology. Although it is not necessary to be experts on the cutting edge of science, leaders must understand enough about emerging technologies to visualize its potential uses and recognize its dangers. The following three sections will serve as a short tutorial on nanotechnology to assist a senior decisionmaker in understanding the underpinning technology fueling the future.

Article Acronyms

AI – Artificial Intelligence
MEMS – Microelectromechanical Systems
NEMS – Nano Level Equivalent Machines
Nm – Nanometer
US – United States

Nanotechnology is defined as "an ability to fabricate structures of individual atoms, molecules, or macromolecular blocks in the length scale of approximately 1-100 nanometers (nm)."[1] It is applied to physical, chemical, and biological systems. Nanotechnology differs from other technologies in three key and unique characteristics: size, fabrication techniques, and interdisciplinary nature.

First is size. Nanotechnology is the next order of magnitude smaller than microtechnology. In the 1980s and 1990s the cutting edge of technology was in microelectromechanical systems (MEMS). The scale of MEMS is from 1-100 microns (10^{-6}).[2] MEMS enabled numerous electronic, biological, and mechanical breakthroughs. The nano level equivalent machines, NEMS, are a thousand times smaller (10^{-9}) than MEMS.

The second unique characteristic of nanotechnology is its method of fabrication. While MEMS are manufactured using the same etching and building up techniques as the semiconductor industry, NEMS are so small they go beyond the ability of standard photolithography to gain the precision required for manufacturing.[3] This process is significantly more challenging. Two approaches are used—the top-down approach and the bottom-up approach. These will be explained in more detail later.

The final unique characteristic of nanotechnology is its interdisciplinary nature. The fact that all matter consists of atoms brings home the unique nature of nanotechnology. When building a structure atom by atom, the macro scale result can cross the traditional stovepiped scientific boundaries. Scientists can arrange atoms to form a new structure with properties that could be useful for new vehicles, energy gathering, or even the human body. In addition, traditional biological molecules like DNA can be used to construct molecular electronic circuits to build the next generation of quantum computers.[4] At the nanoscale, all fields of science are equal and there are no stovepipes.

Top-Down/Bottom-Up Approach

Computer chip manufacturing is a classic example of the top-down approach. The ability to get more power from the same silicon wafer comes from the ability to pack more and more transistors in a smaller and smaller area. In the span of a few decades technology has gone from vacuum tube to integrated circuits that provide the power *under the hoods* of modern computers. Getting to the nanometer scale in integrated circuits is becoming more and more challenging using typical top-down silicon manufacturing techniques.

This challenge is illustrated by Moore's Law. In 1965, Gordon Moore, the founder of Intel, predicted that the number of transistors on a single silicon wafer would double every 24 months and this became known as Moore's Law.[5] Moore foresaw that with increasing precision, smaller and smaller photolithography mask structures could be developed to enable smaller spacing between transistors on an integrated circuit.[6] As the spacing becomes closer, the computing capacity per unit space on the silicon wafer increases. The greater the computing capacity, the more complex computations it can make in an ever decreasing space.

Military leaders must keep an eye on the trends with respect to computing power as it is the great underlying enabler for the design and use of all major weapon systems. Differentiating between what is possible and what is probable is a key part of decisionmaking calculus each leader must understand.

In contrast to the top-down approach, the bottom-up approach to building computers involves manipulating atoms and engineering materials from the bottom up just as nature does. Thus, instead of trying to shrink lithography technology to ever smaller limits, it uses the properties of atoms and molecules themselves to generate switches and transistors. This nanotechnology is what most refer to as *molecular* or *quantum electronics* and is the "primary contender for the post-silicon computation paradigm."[7]

When dealing with particles on an atomic scale, the effects of Newtonian physics such as gravity, magnetism, and electricity "are no longer dominant, the interactions of individual atoms and molecules takes over."[8] According to Lynn Foster, author of *Nanotechnology: Science, Innovation, and Opportunity*, moving to a level of 100 nanometers and smaller, "the applicable laws of physics shift as Newtonian yields to quantum."[9] The power and hence the challenge, is taking advantage of the quantum effects and drawing them into the macro world.

Aluminum provides a simple example of how properties change at the atomic level. If a thin sheet of aluminum is cut into small pieces, the properties of those pieces are similar to that of the bulk aluminum until the nanometer level is reached—when the pieces of aluminum will spontaneously explode.[10] This fundamental change in properties of a material at the atomic level is being studied by scientists in the fields of chemistry, physics, materials, medical, and so forth to develop novel approaches to solving previously impossible tasks.

While the top-down approach will eventually have to reach a physical limit, the bottom-up approach has no such limitations. Building structures atom by atom opens up the doors to fantastic possibilities in any field given the right tools to manipulate the atoms.[11] One of the most exciting emerging technologies is molecular self-assembly. This involves building molecules using engineered viral strains and basic human self-assembly elements to grow certain molecular structures.[12] In the arena of electronics, building circuits using this approach is likely the next paradigm beyond integrated circuits.[13]

Foster articulates five reasons molecular electronics will be the next paradigm for the continuance of Moore's Law. The first reason is size. In 2002, IBM built a "three-input sorter" to "arrange carbon monoxide molecules precisely on a copper surface." This circuit is "260,000 times as small as the equivalent circuit built in the most modern chip plant."[14]

The second reason is power. Transistors are inefficient and generate excessive heat when performing operations. This is in contrast to human brains that are "100 million times as efficient in power and calculation as our best processors."[15] While human brains only operate at 1 kHz, they are "massively interconnected and folded into a 3-D volume."[16] This means that the measure of merit is not necessarily going to remain clock speed, the number of calculations per second, but may move to the number of calculations per unit volume. The third reason is manufacturing cost. Manufacturing molecular electronics can be built through "spin coating or molecular self-assembly of organic compounds."[17] Instead of being engineered from the top which requires ultimate precision, molecular self-assembly will not necessarily be ordered and precise as top down precision is understood today. The atomic forces themselves will dictate the shape and form of the circuitry as it builds from the bottom up. The ability to start a process and allow the circuitry to *build itself* could significantly decrease manufacturing costs.

The fourth reason is low-temperature manufacturing. Since much of molecular manufacturing may involve the use of biological molecules, the manufacturing process will proceed at room or body temperature versus "1000 degrees in a high vacuum"[18] required for silicon processing. This opens up the possibility to use cheaper plastic substrates to grow these molecular electronics.

Finally, Foster writes that the molecular electronic solutions are inherently digital and nonvolatile. This is far superior to the top-down, inherently analog, and leaky solutions that try to approximate digital methods and nonvolatility.[19]

One can see that nanotechnology will form the basis of most of the technological advances in the future. The ability to form materials and structures atom by atom will have wide ranging applications that have serious military and national security implications. Maintaining awareness of this exploding research area must be a part of every leader's crosscheck.

Converging Research with Nanotechnology

Because of its atomic-level character, every field of science has been impacted by nanotechnology. One of the most unique aspects of this power of the small has been the convergence of scientific fields. Scientists have rediscovered the homogeneous nature of science at the molecular and atomic level. This means discoveries at the atomic level in biology, engineering, or chemistry can be directly translated over to other fields like medicine. Medical needs, such as helping wounded soldiers, can drive teams of researchers together from a number of disparate fields to arrive at solutions to complex problems.

This section looks at a series of key areas where nanotechnology could have its greatest impact on the future battlefield environment. These key areas include biomimetics, genetics, robotics, information, energy, and artificial intelligence. Senior leaders must stay *tuned in* to developments in these nano-fields to make informed and accurate decisions about investments and what these technologies mean for the US and her enemies.

One particularly telling example of the crossover between different fields of science is biomimetics. The science of mimicking systems found in nature with things made in the laboratory is known as biomimetics. It has produced a whole host of technological breakthroughs through the years. For instance, the repellency and self-cleansing aspects of lotus flowers inspired new coating technologies now called the *lotus effect*. Scientists used the concept of echolocation discovered in bats to develop sonar and radar as well as sonograms to view inside humans.[20] In ancient times the study of birds inspired flights of fancy such as that of Daedalus in Greek mythology and early aero engineers such as da Vinci whose *Codex on the Flight of Birds*,[21] provided his translation of bird flight into machine technology.

Today, miniaturized aeronautics and computer technology have spawned the ability to build flying machines that even da Vinci never dreamed of. The merging of energy, propulsion, computation, and aeronautics on the micro level has resulted in aero vehicles the size of dragon flies with mosquito-sized vehicles on the way.[22] The ability to produce miniaturized flying vehicles opens the door to miniature payloads as well. In his review of many of these amazingly small air vehicles, William Davis has explored the potential military uses of nano air vehicles which measure less than 7.5 centimeters and weigh less than 10 grams.[23]

The future missions of nano vehicles are only limited by one's imagination. Clearly intelligence gathering, surveillance, and reconnaissance will be key mission areas. But many others can be imagined. For instance, with a structure made of explosive material, the nano air vehicle could be the ultimate in precision weapon when coupled with object and face recognition technology (available today) and autonomous control. A nano air vehicle could be released and sent to find its target in a nonpermissive, Global Positioning System (GPS) jammed environment. These nano air vehicles could also be equipped with biological and chemical sensors for use in a battle damage assessment or for post-weapons of mass destruction (WMD) clean up operations. In a failed state scenario, a swarm of nano air vehicles could provide insight into the spread of disease and even administer inoculation.[24]

Biomimetics is also spawning research into better understanding the human being—everything from decoding the human genetic fingerprint, to replacing war damaged or defective body parts through robotics, to mapping the brain functions. The miniaturization of transistors and computing technologies has been used to mimic the synaptic firing of brain components.[25] By mapping the brain's functions, replicating its most basic components, and using massive computing speeds similar to those of the brain, it may be possible to produce a working brain made of silicon chips. Several research centers, such as IBM's Blue Brain project, Howard Hughes Medical Institutes's Janelia Farm, and Harvard's Center for Brain Science, are working on this challenge.[26] The further along this path of brain replication the researchers go, the more possible it becomes to degrade or improve the function of the brain which will have significant battlefield implications. And this example represents just one small area when compared to the vast promise that comes from nano science. While biomimetics seeks to understand how to replicate any part of nature including humans, human genetics research hones in on the fundamental molecular processes that produce the human body and allow it to function.

In 2003, the Human Genome Project completed its 13-year effort to understand and sequence humanity's most basic genetic building blocks.[27] While a detailed discussion of genetics is beyond the scope of this study, a basic understanding of the key elements and the impacts of the completed genome project is warranted, as the force of this massive undertaking will be felt for years and will impact military operations.[28]

From a biomimicry standpoint, understanding the basic functions of human life can help replicate and manipulate the human body's most important components using artificial means. Scientists have been able to grow engineered human tissue using adult stem cells to form body parts that can be transplanted into a human body without the use of antirejection drugs. Military researchers have recently found a way to regrow the tip of a finger with plans to regrow damaged limbs.[29]

The more researchers work to solve the puzzles, the more synergy and the faster the solutions come. One of the goals of the genome project was to provide the information gained to the private sector. This puts the power to do research, create new tissue, discover cures, and understand how life can be extended into the hands of the world. As in most things, the power to do great good is coupled with the power to do great harm. Where some see an opportunity to improve humanity, others see an opportunity to hold humanity hostage or gain an advantage by creating new incurable diseases or other destructive effects using this same technology. Therefore senior leaders must stay cognizant of the advances in genetics since much data and capability will flow from the medical side to the military side with ramifications from the tactical to the strategic level of operations. With increased understanding of how humans are put together, scientists have sought to build robotic imitations that replicate various functions of the human.

Robotics is already impacting the battlefield and will only become more important in the future as robots get smaller and more capable. This fact means senior leaders must understand the fundamentals of robotics and keep up with the breakthroughs as they happen. Macro level robots are already a standard part of the requirements to do DoD's mission. They are used for aerial reconnaissance, forward sensing around corners, on ordnance disposal teams, and even for performing remote surgeries.[30] Remote surgery can bring lifesaving capability to anywhere in the world. The ability to have the world's best available doctor perform a vital surgery via satellite link using a medical robot is not the stuff of science fiction, it is here today—in fact it has been in use for nearly a decade.

The real excitement (or potential concern) in robotics begins to take shape at the micro scale and below. On this scale scientists are already working on swarm technology to control vast hordes of miniature flying and ground based sensors. Below the micro scale to the truly nanoscale robotics, the possibility of another nanotechnology Holy Grail, self-assembly, comes closer to reality. Professor Carlo Montemagno, of the University of California, Los Angeles has brought together biotechnology and nanotechnology in a very unique way. He used rat heart cells to *grow* muscular tissue over a silicon nanostructure to produce miniscule robots less than a millimeter long that "can move themselves without any external source of power."[31] According to Montemagno, these robots are living organisms that grow and multiply because they are alive.[32] On an even smaller scale researchers are developing nanoscale robots, or nanobots, that can move in a specific direction along a path. For example, scientists from the University of Oxford "have created a two-legged, nanoscale robot that can walk unaided along a single strand of DNA more efficiently than all previously created nanobots."[33] The ability to create a robot of this size now opens the door for other research to combat disease or mitigate chemical or biological effects at the cellular level.

In the medical world, nanotechnology is being used to find and target particular bad actor cells. Scientists are using nanoscale crystals that emit different colors of light when irradiated with energy, to find cancer cells even in very small concentrations. Once found, these cancer cells can be specifically targeted. While still a few years into the future, nanobots are being developed to be injected into the human body to target and apply a dose of chemotherapy cure directly to these malignant cells. This type of precision strike could dramatically improve cancer treatment success rates and reduce the devastating effect of cancer treatment on the human body.

From a national security standpoint, nanobots that can find and target malignant cells would also be capable of targeting other cells. The possibility of self-replication combined with programmable nanobots that target certain types of human cells creates a very challenging scenario to consider for future adversary tactics. While much of the research on self-replication and nanorobotics is still in its infancy and primarily in national level laboratories, the next topic, information technology, is not. It has already moved down to the nonstate actor and individual level.

Information flow has changed in both form and forum over the past two decades and will continue to change in the future. Staying connected has gone from writing letters (now known as snail mail), to sending e-mail, to texting. Social interaction that used to be handled face-to-face or over the phone, has now moved to writing on cyberwalls[34] at social Web sites like YouTube, Facebook, Twitter, and others.

While much that takes place using these cyber-walls is harmless fun interaction, these same cyberwalls have become key to understanding how networks grow and respond to inputs.[35] Most of the news networks now have a Web presence because print news and even broadcast news cannot keep up with the flood of information available on the World Wide Web.

As terrorists and other adversaries move operations to the Web, they can become stealth entities, coordinating actions, striking, and withdrawing without leaving many clues to follow. Because of the availability and the low cost of these information tools, they are available to anyone with an Internet connection and a minimal knowledge of how to operate in the info sphere. Terrorists have used cyberwalls to organize themselves and uplink gruesome footage of brutal killings, beheadings, and other despicable activities to bring attention to their cause.

As more personal, medical, and professional information becomes digitized and available online, vulnerability to cyber attacks from state and nonstate actors increase. A recent example of the devastating nature of a coordinated cyber attack was when Russia brought down key Georgian Web sites just prior to invading in the fall of 2008.[36] In November 2008, cyber attacks on the Pentagon resulted in a DoD-wide ban on external multimedia and USB drives in DoD systems because there was evidence that an infected USB drive inserted into a DoD system caused a vulnerability. These two recent high-visibility attacks highlight just how vulnerable digital media can be to a knowledgeable adversary. Thwarting these attacks is a full-time job for cyber warriors because new and innovative threats are being developed every day. There is no doubt information protection will have to be a major portion of every major decision carried out today and in the future. Without secure information flows, decisionmakers will become severely handicapped.

Nanotechnology may provide both a problem and a solution to information protection. Information protection today relies on data encryption. Today encryption keys are 128 or 256 bits long, forcing a computer to solve for every permutation and combination of potential options to arrive at the key. Quantum computing will break this paradigm as it could break today's best encryption keys in a fraction of a second. This will be a total disaster for the information security of the entire world once the first quantum computers arrive on the market.

Nanotechnology research has also provided a potential solution called quantum entanglement. In quantum entanglement, pairs of photons, or qbits, are linked to each other such that a change in state of one photon of the pair results in the same exact change in the state of the other photon of the pair regardless of the distance between them. How this phenomenon works is still unclear, but researchers are developing *uncrackable* quantum encryption codes using quantum entanglement.[37]

With quantum entanglement, data may be secure from hackers, but the cyber war will continue as new viruses, Trojan Horses, and other malware continue to probe US cyber defenses for even the smallest defects. The ability to maintain a leading edge in nanotechnology research and to respond quickly and effectively in this emerging infosphere, will determine failure or success in future wars that use this technology. The willingness of one leader to accept risk in the information sphere can have a dramatic effect on the entire network. Because the US and other nations rely so heavily on the information networks and require them to sustain daily operations in peace and war, this is an area every senior leader must understand. As information networks enable more of the world to engage in the market, the quest for energy will become greater as well.

Energy generation and storage will play a major role in future conflicts. As globalization brings more people out of poverty and into market economies, the energy requirements to fuel the massive worldwide industrial complex will double the current requirements by 2030.[38] The rapid growth of China, India, Russia, and other smaller nations will drive an ever increasing need for these limited resources and lead to conflict. Nanotechnology is playing an increasing role in solving the future needs for energy generation and storage, but without significant investment, energy will still be the major source of conflict in 2035. Senior leaders must stay tuned to changes in the energy landscape to ensure the US can meet its energy demands in the future regardless of where conflicts arise. After energy, the final area that will directly impact the battlefield and hence, the decisionmakers of the future is artificial intelligence.

In many ways, the quest for artificial intelligence (AI) brings together all the concepts discussed thus far—biomimicry, genetics, robotics, information, and energy—to inform research into making intelligent machinery. The ultimate goal of most AI researchers is to achieve a machine that can match or exceed the thinking capabilities of a human. Once this happens, human decisionmaking will be challenged by machine decisionmaking.

As nanotechnology enhancements bring more computing power and these ever more powerful computers become more pervasive, they also become much more indispensable. Today's society already relies on *intelligent* machines to take in volumes of data from multiple sources, collate it into logical informative categories, and provide the optimal course of action. Massive supercomputers model the effects of nuclear detonations and the spread of weapons of mass destruction, as well as provide the optimal courses of action based on all source intelligence.

As machines become more capable of making projections and are seen as providing better outcomes than even the smartest humans, their results will be used as the benchmark to measure human performance. Today, many human-centric processes have now been obviated by machines. As the number of human operators and analysts gets reduced, senior leaders will be compelled to rely almost solely on synthetic analysis from a computer.

As more biological processes are modeled and programmed into software, the ability to mimic nature will continue to advance. Already machines have been programmed to simulate numerous scenarios to test human skills. Advanced AI research has enabled the move to virtual training. The ability to produce synthetic realism in flight simulators, law enforcement training, and surgical procedures training has both reduced the costs of training, but it also has increased its effectiveness. Virtual training is now becoming ubiquitous and has taken over for *hands-on* training in many areas. The Air Force has even used computer simulation to provide interactive cultural awareness training to all of its personnel.

As the artificial environment becomes more realistic through advancements in AI converged with nano-enhanced tactile sensors, robotics, and information technology, the ability to provide realistic scenarios between dispersed personnel can only increase. While this will surely enable training opportunities, it will also enable dispersed adversaries similar capabilities to converge their disparate numbers on a single domain for training and in some cases, execution.

As scientists get closer to creating a machine that thinks equal to or better than a human, the battlefield environment will become much more challenging for anyone not having this type of capability. The ability to leverage the advances in AI and virtual reality training will be the mark of a successful future leader. To leverage this type of technology, one must actively follow its development. Senior leaders must maintain a close watch on progress in AI as it is advancing in both the private and public sectors and could easily emerge in the hands of an adversary and bring a significant advantage at low cost.

Exponential Thinking and Globalization

In the future, leaders must think differently if they are to be effective decisionmakers. The combination of exponential acceleration and globalization will drive a dramatically different future that many senior leaders are unwilling or afraid to consider today. The smug attitude behind the phrase, "I am an analog guy living in a digital world" will not suffice in this future environment. According to Stephen Shambach, Director of Leader Development at the United States Army War College, "strategic leaders must possess a broad understanding of relevant military technologies and understand how advancements in each of these technologies can be incorporated … to permit continued advancements in combat effectiveness and efficiency."[39] He goes on to state that technology is like a two-edged sword—with increased capabilities come new and different vulnerabilities. Thus, the fact that technological breakthroughs can enable more effective combat power for the nation is coupled with the fact that this same increase in technology can drive asymmetric advantages to America's enemies. Here is where the understanding of the future convergence of the exponential growth of nanotechnology and globalization becomes critical for senior leadership.

Law of Accelerating Returns: Linear versus Exponential Thinking

Most humans think linearly. Senior leaders are notorious for making pragmatic, ploddingly linear decisions especially when faced with breakthrough technologies. Bureaucracies exacerbate the problem as they are driven to maintain status quo and prevent disruptive course corrections even in the face of direct evidence for dramatic change. Why? From observations in the past, it is easier to project the future using a linear extrapolation from today and use that same line of thinking in the future. When two points on a straight line are known, one can solve for the future. As a method of making future prognostications, straight line projections tend to be forgiving, kind, and comfortable. That is why they are used so frequently. Unfortunately, they are also very dangerous when the future end state is not anywhere near the linear end state.

Leaders must learn to think exponentially. Exponential growth curves are not as kind or calming and are much less forgiving when considering future projections. Whereas slight changes in assumptions and small miscalculations can have small effects on the end state in linear projections, these same slight missteps will produce radically different end states on an exponential curve. Figure 1 shows a comparison of different growth curves.

Note the difference between the linear growth line and the two exponential growth lines. The exponential lines begin with a low slope that in the short term looks linear, but at some point, the technological

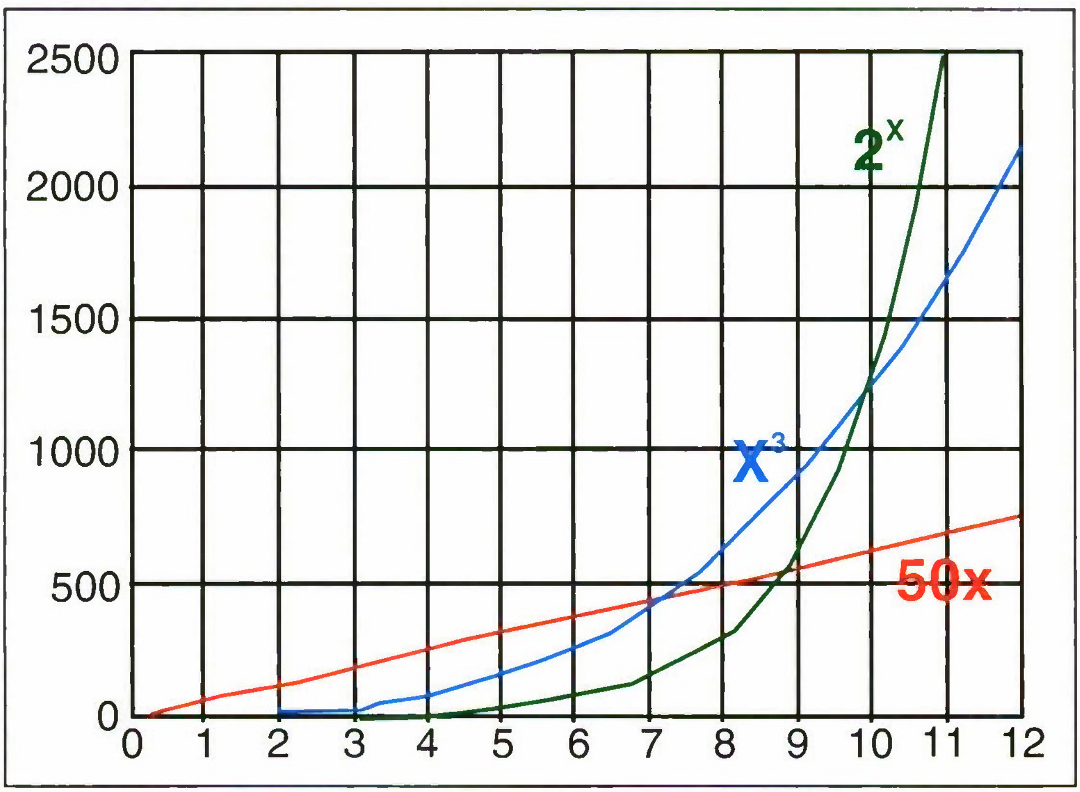

Figure 1. Exponential versus Linear Curve Comparison[40]

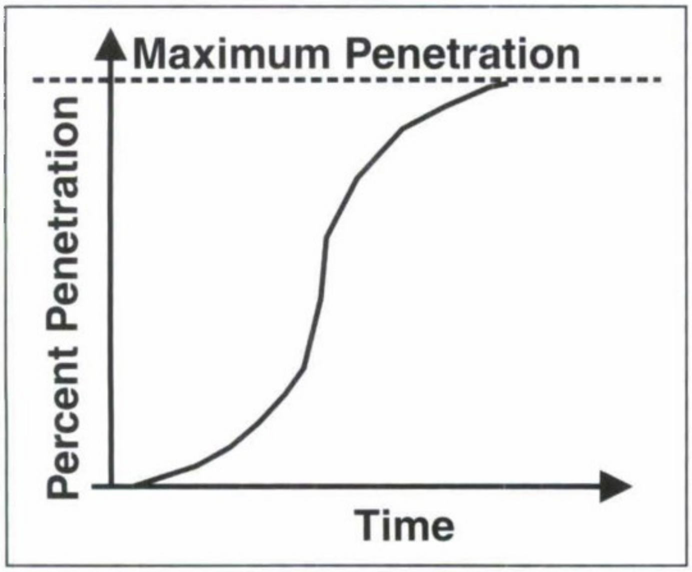

Figure 2. Generic S-curve

maturity reaches the point where it takes off on the exponential rise. Assumptions made during the *linear* portion of the growth curve will not just be a little wrong; they can be catastrophically deceiving when considering the eventual end state. Another aspect of an exponential growth curve is that small actions taken or investments made in the beginning of the growth curve can have dramatic effects on the eventual outcome.

When it comes to understanding the exponential growth of technology, one must also understand the concept of S-curves. The generic S-Curve shown in Figure 2 depicts simple market penetration of a new technology.

The lower end of the S-curve shows the time a new technology spends in invention, development, and market evaluation. As a new technology is adopted over time, it moves along the S-curve and gains market penetration slowly. At some point, the technology hits a Gladwellian *tipping point*[41] and takes off. The market penetration rises rapidly until market saturation or arrival of a competing technology. The curve flattens, illustrating a time of diminishing returns.

Figure 3 provides a labeled depiction of this same curve describing time versus commitment.[42]

It can be seen that as time moves to the right, commitment to a new idea or technology grows slowly at first as the awareness spreads. Once the concept becomes understood, it can take off and be adopted by more people until it becomes an institutional concept. For example, the Microsoft Suite of programs began slowly 26 years ago and has followed this cycle to the point that it is now institutionalized across the entire world. To maintain its growth, Microsoft needs to continue building new innovative products that will extend its curve. S-curves are useful for showing other trends such as applied effort versus advancement as shown in Figure 4.[43]

This type of curve shows significant effort is required to advance a technology in the early stages of its life, then, just after the tipping point, a technology will advance rapidly without a significant investment in effort. After market saturation, the curve bends over and begins to flatten. Significant effort is then needed to push that particular technology further. Also shown in Figure 4 is an illustration of what happens when a new breakthrough in technology in a related field causes an advancement of momentum. This new advancement continues the previous S-curve as it starts at the tail and continues to advance from there.

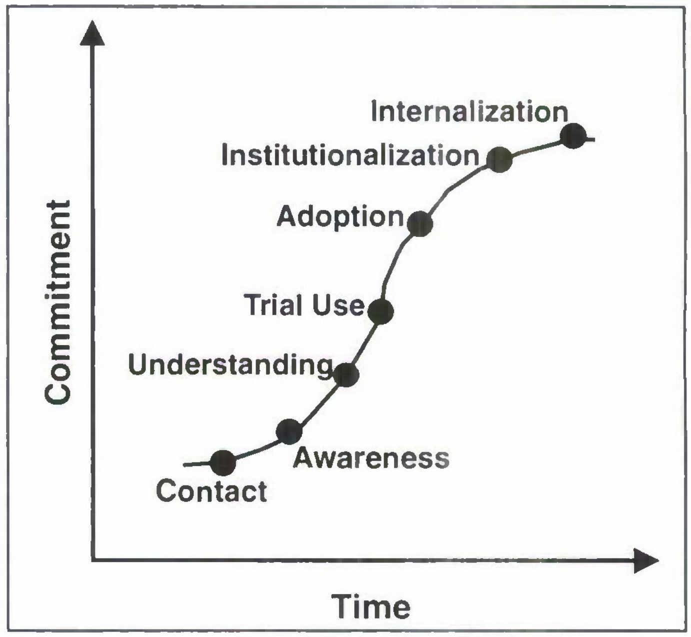

Figure 3. Labeled S-curve Stages of Commitment Over Time

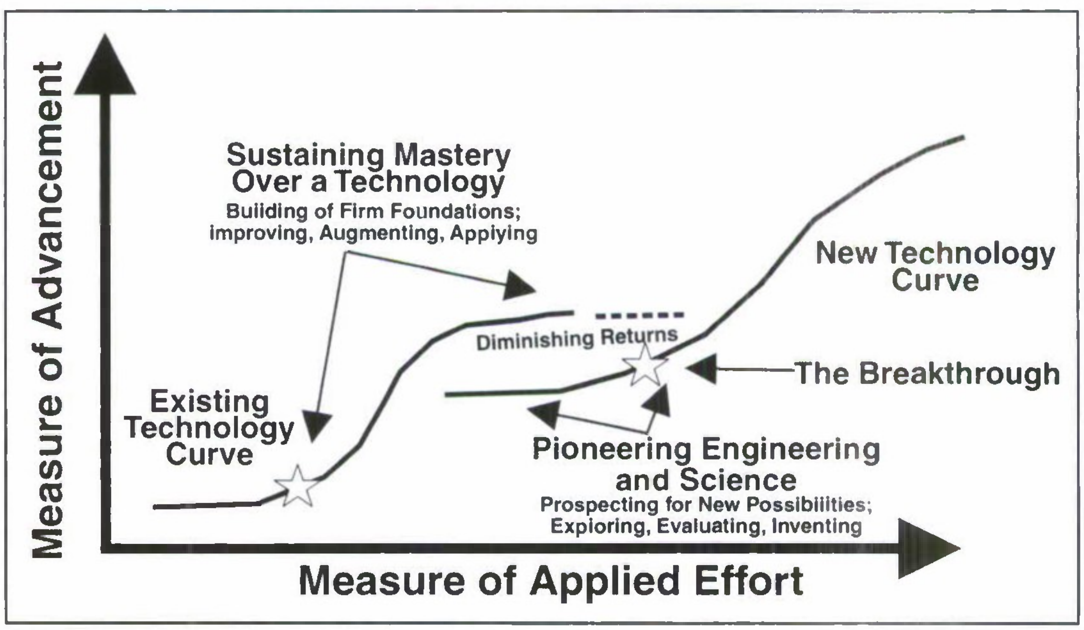

Figure 4. Cascading S-curves

The result of this type of S-curve cascade is an exponential curve as each successive S-curve is propelled faster and reaches higher than the previous S-curve. The end result is an acceleration of advancement for key technologies. As the S-curves cascade, it takes less effort to gain more advancement to a point when the resulting exponential curve can theoretically reach a point of vertical growth when a technology could advance without applied effort or human intervention.

Based on the accelerating S-curves model, the future cannot be predicted using simple linear extrapolation. Exponential thinking forces leaders to think of the future as a complex interaction of multivariable equations that will drive out certainty and insert risk in their projections. Risk is inherent in every problem, but the ability to define risks and reduce them will be directly proportional to one's ability to think exponentially. Not only must senior leaders think exponentially, they must think globally.

Globalization Effects: Low-Cost Manufacturing and Cheap Technology

Globalization is defined as "the process by which the people of the world are unified into a single society and function together."[44] Thomas Friedman describes it as a "flattening" of the world. While there are other descriptions that may apply, in its most basic form, globalization entails the interconnectedness between people around the world.

The process of globalization has been enabled and enhanced by many factors, but Friedman points out one of the biggest factors was the massive $1T effort to "wire the world" with fiber optic cables.[45] Fiber optic communication coupled with ubiquitous, low cost computers, telephones, and market-driven competition served to draw more and more of the world's population onto the Internet. Once there, business interactions became possible and companies reached offshore to outsource their service sectors to cheaper labor markets. For example, the ability to tap into thousands of graduate students and computing experts at bargain prices across the oceans in India and Malaysia caused companies like Dell and HP to outsource their call centers. Many other companies have followed suit.

Globalization will continue to have a dramatic effect on the future environment—economically, technologically, socioculturally, and politically.[46] The recent economic meltdown experienced in America had an equally deleterious effect on the rest of the world's financial markets due to this massive interconnectedness. Similarly, the entire world watched the 2008 American presidential election with rapt attention as they knew it would have a direct effect on them as well.

The impact of globalization on the future operating environment of 2035 can be looked at through a number of different lenses. The following analysis will focus on the *nature* of globalization and how it will change the world stage in the future and thereby impact the decisionmaker's global frame of reference.

Globalization's power and impact has had its most visible effects in the economic realm through the lowering of trade barriers and enmeshing of markets. In his book, *The World is Flat*, Thomas Friedman provides insight into what he sees as a progressive flattening and shrinking of the world. He suggests the world has moved from Globalization 1.0 which, from an American perspective, began in 1492 when Columbus sailed to the Americas to open trade routes. This phase of global integration dealt with states expanding their trade agreements between other states. From 1800 to 2000, Friedman suggests a new era, Globalization 2.0, began with the industrial revolution and the advent of multinational corporations. As transportation and telecommunication capability increased during this phase, the cost of transporting goods and communicating between countries decreased dramatically, accelerating the rise of a vast global economy. At the end of this era, we see the beginning of e-businesses as the Internet becomes ubiquitous. Beginning in 2000, Friedman describes a distinctive change in the nature of globalization to what he calls Globalization 3.0 or the rise of the empowered individual. This new environment is built around a flattened world and underpinned by "the combination of the PC, the microprocessor, the Internet, and fiber optics."[47]

Looking at the move from Globalization 1.0 to Globalization 3.0, there are a number of obvious trends. First, each phase has become more specific—from state-to-state interaction, to multinational corporations, to empowered individuals. Individuals can now interact using text, video, and avatars (virtual digital representations) with other entities (human and machine) all over the world via high speed fiber optic networks.[48] Second, the rate of change has also increased. Globalization 1.0 lasted just over 300 years. Globalization 2.0 was 200 years. If the trend continues, there could be a more specific globalization phenomenon beyond Globalization 3.0, where the empowered individual becomes the empowered machine-enhanced human or cyborg in 50 to 100 years. This merging of machine and man fits with observations from the above discussions of biomimicry, robotics, and genetics. Ray Kurzweil predicted this combination of man and machine nearly 20 years ago and called it the "singularity."[49]

The move from Globalization 1.0 to 3.0 also shows the rise of three nations that many predict will rival or surpass the United States' share of the global marketplace—India, China, and Russia. This has serious national security implications. How should America look at these emerging superpowers? Basically there are three options—threats, customers, or opportunities.[50] The negative view would see these rising powers as threatening competitors with aggressive intentions that could destabilize the world balance of power. This view would put them on an axis of evil list and potentially drive them further down an adverse path. A second, more encouraging view would see these three populous nations as an opening to a larger trade market with a huge and growing potential customer base. The third view would see the growing power and influence of these three nations in their regions as an opportunity. The interconnectedness of all nations could facilitate burden sharing. Taking this more positive approach to research, development, manufacturing, and security with each rising state actor able to *pull its own weight* to benefit the whole, could result in a more peaceful multipolar world.

United States' leaders must be cautious of treating all rising powers as threats. In just over a decade the formerly opaque nations like China and Russia have become more translucent as they open up their borders to new trade opportunities brought forth by globalization. If former arch enemies can become members of the World Trade Organization and active partners in the global marketplace, then any country can. While the US must keep an open mind to opportunities, it must also keep both eyes open. The US cannot look past clear threats from these or other rising powers nor can it assume a rising power is automatically a threat. US leaders must have a balanced approach to foreign policy in this flattened world, but they must also understand how the nonstate actors like international corporations and individuals are being empowered by this new environment.

Ubiquitous communication and globalization has redefined how international corporations and businesses form and organize. Businesses no longer need to have large office buildings to operate. Individuals can organize into flexible organizations that form themselves based on the problems they come together to solve. Expertise can be harnessed from anywhere in the world to tackle tough problems. Companies now can keep a very small cadre of core business managers and outsource key expertise as required. In this type of fast paced environment where deals are made, problems are solved, and money changes hands all in the digital realm, the ability to maintain dominance using conventional thought processes and linear thinking would put a country woefully behind the power curve. Individual leaders must be enabled and empowered to operate in this new, more horizontal environment. While globalization brings with it many opportunities, it also brings many challenges. The leaders that stay engaged and informed about the rapidly changing global environment will be effective and relevant; those that do not, will no longer have the capability to lead effectively.

Future Key Players in the Nano Marketplace: India, China, Russia

India, China, and Russia have come to realize the value of nanotechnology and are using their education prowess, in varying degrees, to wrest control of the nanotechnology market from the United States. Senior leaders must understand the nature of the rise of these key players to make accurate decisions about the future global environment.

India is increasing her nanotechnology research budgets and seeks to increase her economic well-being, but also wants to use nanotechnology to serve her people. India invested $250M in starting a national nanotechnology initiative to coordinate national efforts. From the private sector, the cofounder of Hotmail, Sabeer Bhatia, has invested heavily to "build a multibillion dollar nanocity" in northern India.[51] Rachel Parker, a University of California Young Scholar points out that the focus of the nanotechnology research in India is not on weapons technology, but is primarily on social assistance for India's preindustrial age population. Nanotechnology research will focus on improving agriculture, health, and poverty as well as reducing air, water, and soil pollution.[52]

According to Alexis Madrigal's reporting on Chinese nanotechnology, China aims to "leapfrog the United States in technological development" by 2020.[53] Forbes.com writer, Josh Wolfe, suggests that China is putting her money behind her desires. In 2005, China was number two behind the United States in nanotechnology research investment reaching the "equivalent of $1.11B, compared with $1.57B in the United States."[54] China also came in second to the United States in the number of "published, peer reviewed journal articles on nanotech."[55] China's large numbers of students in the United States and elsewhere have undoubtedly fueled her innovation and prolific publication capability.

Russia has realized the potential for nanotechnology only recently and has begun a massive effort to catch up. In 2007, the Russian president signed off on the start of a multibillion dollar effort to build a world class nanotechnology infrastructure by 2015.[56] Russia is trying to overcome the 10 to 15 year head start that the West has had in this vital technology arena. To leverage other expertise, Russia signed a nanotechnology cooperation agreement with China in November 2008, which is sure to kick start its program. Russia has also put in place a massive ramp in planned yearly spending that goes from $730M in 2008 to $1.48B in 2015. There is no doubt Russia wants to be a player in the global nanotechnology market and is posturing to get there quickly.

It is clear from the discussion that all three of these emerging major powers have seen the significant opportunities available with nanotechnology. In addition, each country has invested heavily in building their capabilities to achieve parity or overmatch with US capabilities. The key take-away for US leaders is this is a very competitive field and one that has war-winning implications. The US senior leaders must readily accept the responsibility to understand and maintain a working knowledge of the disparate fields of nanotechnology to enable success in the future. It is clear that others are already doing so. While the US enjoys a significant head start in most of the areas of technology discussed in this article, a few years of low investment in key technologies could change the entire race.

Nanotechnology: Future Implications and the Nano-Enabled Battlefield

[Our adversaries] may develop disruptive technologies in an attempt to offset US advantages. For example, the development and proliferation of anti-access technology and weaponry is worrisome as it can restrict our future freedom of action.

–National Defense Strategy 2008[57]

[a]n officer's effectiveness and chance for success, now and in the future, depend not only on his character, knowledge, and skills, but also, and more than ever before, on his ability to understand the changing environment of conflict.

–General John R. Galvin[58]

Views of the Nanotechnology Future

Senior leaders serve the national interest by preparing for the future. As stated previously, predicting the future is challenging especially when considering the rapid worldwide advance of technology and innovation. Leaders must understand how their outlook of the future can influence their decisionmaking. The following discussion will provide a framework of four disparate views of the future. These views can assist the senior leader in identifying how they or others around them may be predisposed to a certain set of decisions based on their view of the future operating environment.

Joel Garreau, in his book *Radical Evolution*, provides four main scenarios or viewpoints to describe the future.[59] These viewpoints—singularity, heaven, hell, and prevail—are espoused by prominent futurists to describe the coming nano-enabled future and its impact on the human world. Each has strong advocates that espouse their viewpoints with an almost religious fervor. When viewing the future nano-enabled battlefield from each of these perspectives, it is possible to see how the second and third order effects of nanotechnology could play out in the 2035 environment. As senior leaders consider each of these futures, it is not important to completely agree with a particular future, but to see where their own preconceived notions of the future falls within these scenarios. This could lead to discovery of a bias that could then affect decisionmaking.

The first view of the future is called the Singularity and is espoused by Ray Kurzweil.[60] Kurzweil is one of the 21st century's most revered futurists because of his past accuracy and his ability to bring together complex and disparate technological trends and build them into a viable futurescape. In *The Singularity is Near*, Kurzweil provides insight into the acceleration of technologies that are driving this future world. He describes the future when humans and machines will merge in the "Singularity." At that time, "there will be no distinction ... between human and machine or between physical and virtual reality."[61] The basis of his argument is the exponential growth curve. In a 2001 article entitled, "The Law of Accelerating Returns," Kurzweil states that the economy will continue to drive the technological advances.

> My projections result from a methodology based on the dynamics underlying the (double) exponential growth of technological processes. The primary force driving technology is economic imperative. The technology is moving toward machines with human level intelligence (and beyond) as the result of millions of small advances, each with their own particular economic justification."[62]

These advances come from across the spectrum of sciences—biology, chemistry, physics, robotics—all converging to eventually allow humans to live forever beyond the singularity. This is not a godlike immortality of the physical being, but is the ability to map, store, and recall all of the information from a person's brain. Or to put it into Kurzweilian terms, today, when the "human hardware dies, the software of our lives dies with it," but in the future, people will be able to store and restore their "mind files" which are their "personalities, skills, memories" to allow their software-based selves to live on forever.[63]

The second view is termed the Heaven scenario. As its name entails, the Heaven scenario sees the coming nano-enabled world in a positive light. Kurzweil is one of the main proponents of this viewpoint. He sees the press toward the singularity as not only inevitable, but wholly a positive thing. From his standpoint, the future is characterized by nearly "unimaginable good things" happening in the world. Through nanotechnology poverty and disease will end while improving the capabilities of the human being. New nano-enabled humans will be more beautiful and wise than they are today and have characters defined by "love, truth, and peace."[64] The predictions of the past that seemed impossible are not only possible, but are "routinely exceeded."[65] The growth of technology, while rapid, remains in control.

The third view is called the Hell scenario and is Heaven's evil twin. The main proponent is, oddly enough, William N. Joy. William Joy is the cofounder of Sun Microsystems. While he agrees that the future will be driven by the same technology espoused by Ray Kurzweil, his prediction of the outcome is exactly the opposite. Bill Joy read some of Kurzweil's early work that described a future where machines gain intelligence and become autonomous thinkers. As these machines also have the ability to self-replicate, they can easily go from being human servants to becoming human masters. From Joy's perspective, the coming evil is inevitable. New threats like nano-enabled bioterrorists and self-replicating nanobots will directly threaten the existence of the human race.

The characteristics of the Hell scenario are that "unimaginably bad things" begin to happen. Large portions of the human race are destroyed along with much of the biosphere. The horrors from "science fiction are routinely exceeded." Technological advances continue to propel both state and nonstate actors against each other as they clamor for a better position in a hostile world. In the Hell scenario, humans will no longer have the control and power to stop the increase of technological advances.

The final view is aptly called the Prevail scenario because it is hopeful yet cautious. The main proponent, Jaron Lanier, is best known for inventing and propelling "virtual reality."[66] According to this viewpoint, the future world is driven by humans, not machines. Humans continue to find a way to surmount seemingly impossible obstacles, even nano-enhanced super viruses. The acceleration of technology may or may not continue on its meteoric rise based on choices humans make to pursue or not pursue a particular technology. Uncertainty is a vital part of this scenario, because it provides the ability for humans to interact with the growth of technology, not sit back and watch it take control over the world. As John Smart, founder and president of Acceleration Studies Foundation, stated in his lecture at the Air War College, humans will still have the "ability to put up roadblocks" to negative change.[67]

A Look at the Nano-Enabled Battlefield

No matter which view of the future one favors, it is obvious that nanotechnology will change the face of warfare. The new environment will require a leader to be more technically aware and able to make decisions faster using machine assistance to collate huge amounts of data into actionable information. The trends toward unmanned systems will continue to grow. The convergence of biomimetics, genetics, robotics, information technology, energy, and artificial intelligence will bring more machines to the battlefield and may obviate the need for human presence on the front lines by 2035. The emergence and spread of robotic vehicles and machine-enhanced humans will dramatically change the decisionmaking challenges for the human leaders. If one considers just the concept of mini unmanned aerial vehicles (UAV) and enhanced humans, they will see the massive changes required in the leadership mindset for the future.

In the world of UAVs, the push will be to make them smaller and stealthier. As they become more pervasive, they will need to be more independent to ensure they can operate in this ever tightening airspace.[68] In the coming decades, micro air vehicles the size of a music box will become nano air vehicles the size of a dragon fly. According to Timothy Coffey and John Montgomery, the smaller the techonology goes the more challenging the physical requirements are going to be. Specifically, "power and propulsion become the dominant components of the weight budget."[69] Beyond that, scientists must solve the difficult challenges of low Reynold's number flight and materials constraints if these UAVs are going to fly. Already several researchers have had success at producing micro air vehicles with some flying vehicles weighing less than an ounce.[70]

While highly-coordinated swarms of nano air vehicles the size of mosquitoes may not be possible until beyond the 2035 horizon, most certainly micro air vehicles will be commonplace on the battlefield.[71] A micro air vehicle could provide a whole host of options for battlefield commanders such as optical, infrared or multispectral reconnaissance, close-in jamming, chemical or biological sensing, and signals collection.[72] The convergence of robotics and nanotechnology into a micro air vehicle will allow many, low-cost sensors in the same air space. As deconfliction algorithms and swarm technology are developed, a single operator will be able to control massive numbers of smaller vehicles. The new battlefield will be able to be surveyed without putting people at risk. Battle damage assessment will be quick and effective. In addition, a disease-ridden failed state could be surveyed with these micro air vehicles to determine what diseases are there and even provide a map of the spread of the disease. These types of capabilities will become more and more available as the cost of the technology decreases.

The cutting edge micro and nano air vehicles will come into the market at prices much lower than today's multimillion dollar Global Hawk, Reaper, and Predator. While each individual mini air vehicle may not match the capability of today's high flying macro UAVs, the combined effect of the swarm will provide a broader, multispectral view of the battlefield with much better resolution because they will be able to fly closer to the earth. Micro air vehicles will become commonplace by 2035—proven, reliable, and pervasive, but being replaced by more powerful, highly advanced, nano air vehicles. While nano air vehicles will initially be more costly than micro air vehicles, they will be but a fraction of the cost per vehicle of today's technology.

The low cost of these vehicles will allow them to be sent into nonpermissive, antiaccess environments and their size and materials characteristics will enable them to operate without fear of easy detection. It will be much less catastrophic if some of these tiny vehicles are lost compared to a loss of one of the large multimillion dollar systems in use today. Their ability to fly close to the ground will also reduce the costs of high tech surveillance camera equipment required today on high flying UAVs. They could also be loaded with nano particle bombs to take precision strike to a whole new level.

It is clear that nano enabled UAVs will bring a host of new capabilities to the battlefield. Along with these capabilities, they bring massive amounts of data that must be collected, collated, and presented in a way that allows the decisionmaker to understand the battlefield and make decisions in a rapid manner. A leader's effectiveness will rest on their ability to leverage technology to enhance their understanding of the battlespace and to tighten their decisionmaking processes. Miniature UAVs are only one small example of what the rapid advancement of technology will bring to the battlespace. Another example that could add even more complexity to the decisionmaking calculus is the emergence of enhanced humans.

The world has shown its tendency to push the edge of human capability in sports, recreation, and beautification. With nanotechnology, the ability to enhance the body will increase dramatically. Instead of drugs and liposuction to enhance performance and beauty, bodies may be sculpted using nano-enhanced bone and muscle structure. What today is a prosthetic to enhance a wounded war veteran's ability to achieve independence, a blind person to regain sight, and an epileptic to gain control of their bodies, could turn into superhuman cyborg-like upgrades. Further, the ability to understand and replicate brain functions in silicon could lead to enhanced access to knowledge and intelligence through embedded or wearable silicon components. With ubiquitous wireless communication, computers will no longer be needed to check the Internet. Instead, information may be directly sent to a nano-enhanced person's neural network.

The implications of nano-enhanced humans and cyborgs on the battlefield are legion. With ubiquitous sensing via the quantum dot-sized sensor nets and nano and micro air vehicles, there will be no place to hide. A person's location will be known or found in very little time. If nano-enhanced soldiers are put into battle against unenhanced soldiers, the fight will be swift and sure defeat for the unenhanced. A nation state or non-nation state possessing this type of army would dominate the world quickly.

The implications of nano-enhancement will be felt across society. In the classroom and business arenas the enhanced versus unenhanced battles will result in *unfair* contests. Will schools segregate or hold contests for the growing disparate populace? Will the gap between the haves and the have-nots generate more conflict? What will a free market system look like when there is a significant performance gap between enhanced and unenhanced people? Is the free market really free when it is controlled by nano-enhanced cyborgs against the will of the unenhanced masses? These questions must challenge leaders to think about the implications of new technology before going down an irreversible path.

The future battlefield will become increasingly complex with undefined boundaries as the Internet enables massing of effects from anywhere in the world. It will likely incorporate state and nonstate actors who have the ability to deliver effects using the same or similar technologies now at the disposal of only the United States. The potential for a disruptive breakthrough in technology is not just available to governments, but also to individuals with technical knowhow, a few low-cost tools, and access to the Internet. According to Michael Paquette, "advances in nanotechnology are also occurring at breakneck speeds." Today, high school students can do what used to be done only by PhDs. "Once nanomaterials are readily available, it is only a matter of time before pieces of information published for a peaceful purpose are used to accomplish something nefarious."[73]

The key challenge for decisionmakers will be tightening the decision loops without falling into decisionmaking traps. As the *playing field* becomes flatter with near peer competitors, the pace of decisionmaking will need to increase to stay ahead of the adversary. As the sensors get smaller and more ubiquitous, the information to make a decision will be even more voluminous than it is today. While victory will still go to the side that can see, understand, and act the quickest to bring forces to bear at the decisive point, the decisionmaker of the future will have vastly more technical complexity to deal with than any time in the past.

Decisionmaking Traps Leading to Technological Failure

In too many cases technological failures and surprises stem from too human characteristics such as self-satisfaction, *disdain for the enemy, obtuseness, and conservatism, or in other words, stupidity and lack of professionalism.*

It must be accepted as a principle that the rifle, effective as it is, cannot replace the effect produced by the speed of the horse, the magnetism of the charge and the terror of cold steel (British cavalry training manual, 1907).

–Azriel Lorber, *Misguided Weapons*, 2002

Making decisions can be hard to do. In the past, many well educated, well meaning leaders have made well intentioned decisions that turned out to be absolutely wrong. While there are a host of reasons for decisionmaking failures, many of these failures could have been avoided if the senior leader had been aware of decisionmaking traps and had developed strategies to avoid them. Decisions in today's complex environment have never been more consequential. A senior leader's ability to make sound decisions about how to shape the future is critical for preparing to fight the nation's wars in 2035. The nano-enhanced battlefield described above will be infinitely more complex than ever before, putting a high premium on good decisionmaking techniques.

Being able to glean the kernels of truth and goodness from the volumes of *chaff* is a skill all leaders must hone. Researchers have found that human brains have subconscious routines or heuristics, to help "cope with the complexity inherent in most decisions."[74] It is these heuristics and mental shortcuts that help us sort the wheat from the chaff, but they can also lead us to make poor, potentially catastrophic decisions.[75] Leaders must find a way to make decisions without falling into a decisionmaking trap. In particular, when considering how to make investments in technology for the future, leaders must be aware of the decisionmaking traps that could lead to technological failure (a concept defined below). While these traps are not new, the ramifications of falling into them are magnified in the rapidly changing nano charged environment. Bad decisions will hurt more. Thus decisionmakers need to be aware of the traps and develop ways to avoid them.

Technological failure, as defined by Azriel Lorber in his book, *Misguided Weapons: Technological Failure and Surprise on the Battlefield*, "involves the lack of comprehension of the effect that certain weapons, or the lack thereof, may have on the conduct of warfare."[76] According to Lorber, a technological failure "may also involve the lack of awareness of the science and technology involved in a particular weapon."[77] One of the most critical aspects of technological failure is that it highlights "people and their attitudes toward the ever-changing world of technology."[78] Lorber makes a clear delineation between technological failure as defined above and other types of failures such as "engineering failure, poor design or workmanship, mechanical breakdowns, [or] shoddy maintenance" as these are failures of the machine itself. Technological failure is not a failure of the machine, it is a distinctively human failure. Lorber provides a cogent list of the root causes of technological failure based on historical examples.[79]

- Conservative thinking, mistrust of new ideas, and inability to adapt to changing environments
- Misunderstanding of the technology involved or its relevance to the battlefield
- Poor management and bad leadership
- Preconceived notions by very important persons, sometimes accompanied by overconfidence and arrogance
- Meddling by higher authority, sometimes because of political ideology

While many will look at this list and see a characteristic of a former boss or colleague, a more important view will be the perspective one takes on this list when looking in the mirror. It is important to remember that most technological failure does not come from unpatriotic, poorly educated, inept leaders. Instead, it stems from upbringing and experience—especially as it pertains to making decisions about technical subject matter.[80] Scientists and engineers tend to understand what is really possible in technical fields and are less prone to technological failure, but senior leaders tend to come from the operational world—not science and technology. Thus, operational senior leaders making the decisions about technological investments tend to lack the requisite knowledge and experience and are more prone to technological failure. This is not to argue that all senior leaders should be scientists and engineers, as this would likely cause operational failures.[81] Instead, the real issue is how to prevent technological failure. Understanding the fundamental decisionmaking traps as they pertain to technological failure is necessary to avoid inadvertently falling into them. This section will cover nine decisionmaking traps that could lead to technological failure. Eight of these traps were identified by Hammond, Keeney, and Raiffa,[82] and one by Lorber. This discussion will entail a brief description of each of the traps along with examples and some suggestions to avoid them.

The Anchoring Trap

The anchoring trap comes from the tendency of people to give more weight to what they hear first. For instance, when getting advice about going to a job interview, most people will advise, "First impressions are very important." Research has shown that what people hear and see first colors their ability to be objective about the information to follow. This trap is especially pernicious when time is short and a decision has to be made quickly. In these situations, the decisionmaker may only have a small amount of information to go on—making the first impression potentially the only impression. More likely than not, the first impression will not tell the whole story and that could lead to a poor decision.

A simple everyday example of this type of trap would be when getting into a bidding process for a major purchase like a car. The first number the buyer provides tells the seller their desire for the vehicle, their willingness to bargain, and sets the zone for negotiation. Similarly, when senior leaders provide information to Congress or give public briefings on acquisition programs, they must take care to ensure the information is correct as Congress and the media can be quite unforgiving. If a senior officer goes to Congress and briefs that they need 183 F-22s to meet their mission requirements for one year, then comes back the next year and briefs that they need 381 F-22s, they had better have exquisite justification for the change, or they have lost credibility. Credibility is easy to lose and very hard to regain.

To avoid the anchoring trap, one needs to consider the sender's and receiver's points of view. From the sender's perspective, they need to package their information to ensure all sides are covered and the information is accurate. Assumptions must be clearly spelled out to the decisionmaker right up front. From the receiver, decisionmaker's perspective, they need to *open the aperture* of their decisionmaking lens. Remember the old adage, "No news is as good or as bad as it seems when you first hear it." Senior leaders must have the patience to get another perspective if at all possible. Taking a *10,000 foot* view of the problem can be helpful. Force yourself to step back away from the details of the situation and try to take the opposing view to see what other possible outcomes could result. Finally, having a trusted advisor who is outside the situation can provide an objective viewpoint.

The Status Quo Trap

The status quo trap is set by the organizational culture and is akin to mental inertia or just plain laziness. If the culture is such that risk taking and effort, despite failure, is rewarded, the status quo trap will not be evident. On the other hand, if employees and leaders are penalized for taking risk and failing, despite their best efforts, the organization will quickly adapt and root out all risk of failure. Large bureaucracies tend to drive a culture where there is one set way to do business and innovation is not looked upon in a positive light. Those that try to *buck the system* are shut down and put back in their place. In fact, one's ability to *toe the line* in some organizations is the measure of merit for promotion and advancement.

Changing course requires action, decisions, and ultimately risk. Risk brings the opportunity for reward and regret. Many decisionmakers, especially those in risk-averse cultures, will choose to forego the chance at a reward to minimize the opportunity for regret. Those that believe they are in an unforgiving, *one mistake* organization will be prone to falling into this trap.

History provides a number of examples of the status quo trap, but the story of Colonel James W. Ripley is one of the best. Colonel Ripley took over as head of the Union's Ordnance Department in 1861. Although Ripley was a career ordnance staff officer and "a good organizer and logistician," he knew next to nothing about the "importance of weapons' technical/tactical performance in the field." Ripley was a stickler for "standardization and economy" in his tightly run supply system, but was against *newfangled* ideas like "breech-loading rifles, Gatling machine guns, [and] observation balloons."[83] Colonel Ripley's bias for the status quo was one of the main frustrations for the Union army. In fact, this stranglehold on technological advancement was still in effect in 1876. When Custer's troops faced Crazy Horse and Sitting Bull, the Union troops had single shot weapons and the Indians had Winchester repeaters.

Senior leaders must have an open mind to newfangled ideas. To avoid the status quo trap they must decentralize decisionmaking and flatten organizations. Decentralization and flattening requires delegating authority and accepting risk. Leaders must set the vision for their organization then delegate their authority until they feel uncomfortable, then delegate a little bit more. Lean towards empowering subordinates to take risk. Expect failure. As leaders, one must realize innovation comes from failure. No one learned to walk without falling down numerous times. Establishing a culture that encourages and rewards risk, within reason, will have the potential to be innovative and leading edge. The culture senior leaders establish in their organization affects the grooming of those rising through the ranks. If they choose to leave a legacy of fear of failure, they will produce a generation of risk-averse bureaucrats who cannot meet the challenges of the fast-paced future environment filled with newfangled technologies.

The Sunk-Cost Trap

The sunk-cost trap is one that causes leaders to want to keep *throwing good money after bad*. When poor decisions of the past lead to a project failure and all logic suggests the project should be canceled, this trap causes one to argue against logic. The more money that has been spent on a project, the more difficult it is to terminate it. Instead of cutting losses, decisionmakers tend to want to *increase its functionality* and spend more money to keep from acknowledging failure.

In 1866, the Prussians handily defeated a nearly equal-sized force of Austrians at Sardowa. While there were multiple reasons the Prussians were victorious, one of the main reasons cited in an 1868 account of the battle was that the Prussians had a decisive technological advantage.[84] Most of the 20,000 Prussian troops were equipped with Dreyse needle guns, while the Austrians had muzzle loaders. The needle guns fired six rounds a minute versus only two per minute for the muzzle loaders. The fact that the Prussians had a technological advantage was not a technological failure, but *why* they had the advantage gets to the heart of technological failure.

Nikolous von Dreyse developed the needle gun around 1838 and demonstrated it for the Prussians. Seeing the speed at which it could fire and the fact that the soldier could fire from the safer prone position was enough to get the Prussians to purchase the rifle right away. In 1851, the Austrians got a similar sales pitch and chose not to purchase the needle gun. In their opinion the rapid fire aspect of the weapon would exhaust the ammunition supply. Even more important to their decision was they had just sunk a significant investment into retooling their musket factory "for more efficient production."[85] Thus the sunk-costs of older technology outweighed the opportunity to gain a leap in technology and that resulted in the Austrian defeat at Sardowa 15 years later.

Senior leaders must be able to maintain big picture objectivity. To avoid the sunk-cost trap, they must establish objective measures of success and failure at the outset of a proposed acquisition or project and then have the courage to act as required. To gain an objective viewpoint, have a disinterested third party take a look at the situation at regular intervals to provide an unemotional evaluation. Audit agencies are good resources to call on for this type of perspective. Money and time spent on a project in the past is just that—history. To make an objective decision about the current health of an acquisition or project, leaders must disregard sunk-costs and look solely at the requirements versus the solution to determine whether the need justifies further expenditures or if a different path is warranted.

The Confirming-Evidence Trap

The confirming-evidence trap is particularly insidious as it plays into one's biases. It causes one to see supporting evidence for positions they want even when it is not there and to disregard evidence that counters what they want, despite its relevance. This trap can also be set by any or all of the three previous traps. For instance, if the first impression of a person is negative, the tendency is to find evidence of more negative things despite the person's best efforts to the contrary. Similarly, if one is convinced the status quo is the *right* way of doing business, they will find evidence to confirm their convictions even if there is a more efficient and effective way to do business. Finally, if one is a program manager for a failing program, his or her reputation and livelihood could be wrapped up in sustaining the program despite its faults. The loss of objectivity could cause one to seek evidence to confirm the positive health of their program despite objective measures to the contrary.

Any one of the examples above will also work for this type of trap. For instance, Colonel Ripley would most likely not have established an objective set of measures for the tactical success of the weapons he was purchasing versus those he denied. Instead, his measures of merit were likely logistical effectiveness and cost efficiency. Therefore, when he sent his reports to his superiors, everything would have shown *green* and healthy despite the lack of support to the Union troops.

To avoid the confirming-evidence trap leaders must maintain objectivity. To do this, they can employ trusted third parties to provide an objective assessment based on facts outside their biases. They need to establish a healthy organizational climate that allows for difference of opinion and disagreement. To foster this type of environment they need to be able to check their motives objectively through self-analysis or through the use of trusted agents. Further, they need to learn how to ask questions that do not drive a particular answer. This is hard to do as people are hardwired to play to their own biases, but they must fight the temptation. The use of an unassociated facilitator to run a potentially contentious meeting can be helpful. Meeting at an off-site location in casual clothing can also be helpful to increase objectivity and trust within an organization.

The Framing Trap

The framing trap stems from the fact that how a problem is stated can and will drive the solution to the problem. The solution can be biased on purpose or subconsciously. This type of trap is readily evident in how contracts are written or how new personnel is hired. If one has a particular solution or company in mind when writing a contract for bids, it could provide a distinct advantage to the desired outcome. In addition, if one already has a person in mind to fill a particular job, they can bias the requirements to ensure that particular person comes out on top of the rating criteria. Further, if a leader is from a particular Service component, they will likely take a view of the battlefield from their Service's perspective.

In March 2002, the Army planned its first conventional operation in the Shahi-Kot Valley in Afghanistan named Operation Anaconda.[86] The goal was to take out a concentration of Taliban and Al-Qaeda fighters operating in the valley. The mission was given to the Army, who planned it as a ground centric operation. The Army planners chose not to involve the Air Force in their operational planning until after it was too late to effectively use the Air Force assets. As a result, the action was a dismal example of the lack of Joint operations and resulted in many of the enemy escaping from the valley to fight another day.

In this example, the problem was given to the Army who framed it as a ground offensive. If it had been framed as a Joint fight by air and ground forces, the planning efforts would have been inherently more Joint and the results would have been much more coordinated and smoothly executed.

If a leader wants to solve a problem without unnecessarily biasing the solution, they must provide a neutral problem statement. They must establish objectives and the end state, and then let the problem solvers do their job. For instance, if they are seeking to buy a weapon system to carry out a mission, they must be careful to provide only the objectives and key performance parameters. If they use the words "ground vehicle," they have then biased the solution against anything from an air or water perspective. Further, if they state that the vehicle must be manned, then they have disregarded all unmanned capabilities. While establishing clear requirements and boundary criteria, leaders must guard against inadvertently limiting the range of solutions based on their personal biases. Using a third party observer or even having their proposed problem statement checked by other experts in the field is an excellent check and balance that will lead to better outcomes.

The framing trap also works in reverse. As decisionmakers consider a range of proposed solutions to a particular problem, it is helpful to look for how the problem statement was framed. Look for biases and predisposed solutions. Many times leaders find that a viable solution set was not considered due to how the problem was originally framed.

The Overconfidence Trap

The overconfidence trap causes leaders to take an overly positive view of their leadership prowess and forecasting acumen. This trap is inherent in organizations known for their success and longevity. Over time, success can build up a sense of superiority and overconfidence that can lead to prideful decisionmaking. The Bible provides an apt adage to consider: "Pride goes before destruction and haughtiness before a fall." When leaders consider themselves impervious to error, they have fallen into the overconfidence trap.

The Battle of Crécy in 1346 is an early, but classic, example of technological failure due to overconfidence (or arrogance). The key take-away from this battle is how an English force primarily made up of trained peasant infantry could achieve a resounding victory over the French forces primarily made up of upper class cavalry when the French forces outnumbered the English forces by a margin of at least two to one with some accounts suggesting a six to one advantage.[87]

One of the key differences was their weaponry. The French were armed with crossbows and the overmatched English were armed with longbows. A seemingly minor difference in technology, but it was a major difference in capability. The simplistic longbow could be made in a few hours, but could be fired four to five times faster than the crossbow and was lethal at much greater range.[88]

What makes this battle a technological failure by the French is not that they lost to a much smaller British force armed with longbows, but that this wasn't the first battle where they were beaten by a smaller British force armed with longbows. The battle of Flanders in 1337 had a similar result to that of Crécy and for the same basic reason. The French were men of nobility and considered the British peasants armed with longbows as inferior. They kept this overconfident attitude despite being soundly defeated at Flanders, Crécy, and later at Sluis in 1340, Poitiers in 1356, and finally Agincourt in 1415 all at the hand of the peasant longbowmen.[89]

The arrogance and resulting inability of the French nobility to think of the English as more than a peasant army, colored their decision to not transform their army's weaponry and tactics. The history of that decision is written in the blood of the thousands of French fighters on the battlefields of the Hundred Year's War.

To avoid the overconfidence trap requires humble introspection on the part of the decisionmaker. Senior leaders must be open to criticism. Establishing an organizational structure where one can get unfettered feedback from subordinates, peers, and superiors will provide the feedback necessary to maintain a level view. These same feedback sources will provide good venues for discovering issues dealing with one's organizational construct, but the climate must be one that is open to criticism. An external audit by a third party is useful for determining if an organization's confidence is well placed. Finally, developing a series of advisors and trusted agents within an organization and outside of it will ensure decisionmakers get the unvarnished truth.

The Prudence Trap

The prudence trap is a characteristic of risk adverse organizations. These organizations want to *play it safe* and avoid making mistakes. They also tend to be ploddingly slow decisionmakers. Large bureaucracies tend to fall into this trap due to their desire to maintain the status quo. They tend to shun innovation and quell disruptive behavior. The inertia from these types of organizations not only makes them difficult to change, it can make them cautious to the point of irrelevance.

Too often bureaucracy within the Pentagon is guilty of this trap. The entire process of staffing a proposed change through the myriad of offices to reach a decisionmaker tends to remove the energy for change. As radical, edgy proposals go through the chain of bureaucracy, their sharp edges get rounded off and polished as each layer tries its best to put its own personal spin on the document. All too often the proposal that ends up on the decisionmaker's desk is a much watered down instrument for change. While not all offices work like this, the overall effect of such a large bureaucracy is to maintain the status quo with minor adjustments on the fringes.

To avoid the prudence trap begins with thinking differently about change. The top of the organization must start the process because the bureaucracy is set up to maintain a steady state condition. The first step is to delayer the decisionmaking process. The more horizontal an organization is, the more able it is to change and adapt. The second step is to delegate as low in the organization as possible. Get the lowest level supervisors actively making decisions and getting involved. Third, accept more innovation risk. Leaders need to trust their people and reward disruptive innovation. If they stifle change and disruptive influences, their organizations will quickly learn "not to make that mistake again." Be prepared to hear the unvarnished truth. Minimize the number of touches on a document coming through the process for signature. Find ways to remove or consolidate the reviewers so there is not an endless list of folks that need to see a document on the way up to the boss. While prudence can be a good thing, it can also cause one to fail as they let golden opportunities pass by while the bureaucracy churns.

The Recall Ability Trap

The recall ability trap causes a leader to put more emphasis on recent events than history—because that is freshest in their minds. In contrast to countries like India, China, England, and Japan that have fastidiously maintained detailed paper filing systems, America is very poor at maintaining corporate memory. On the one hand, this provides the opportunity for advancement unfettered by historical precedent; on the other hand it can lead to shortsighted decisionmaking.

For instance, the short two-year military command tours drive a constant turnover of corporate memory at the organizational command level. This provides a level of churn in an organization that can cause unhealthy and poor decisionmaking. As each new leader takes over an organization with the desire to leave his or her mark, the organization is unable to maintain a steady course. Officer assignments for senior field grade officers tend to be two years or less. Wing command tours in Air Mobility Command are now routinely less than 18 months. This type of rapid turnover prevents organizations from maintaining momentum. Further it can detract from strategic planning as everyone must shift priorities as each new commander comes to roost.

To prevent the recall ability trap requires a major investment in knowledge management, a reduction in turbulence, and a reinvestment in long term planning. As organizations move to paperless systems, the only records they will have will be electronic. The Department of Defense has made a halfhearted attempt to develop electronic filing systems, but to little avail. With the removal of the administrative career field, it comes down to the motivation of the individual to track their own history—many do not. Capturing knowledge at every level to develop an accurate history and making this knowledge readily accessible is necessary to inform future leaders and look for long-term trends.

The Mirror Imaging Trap

The mirror imaging trap is when the analyst or decisionmaker projects his or her values or culture on others. The Battle of Britain provides an example of this trap. The British had developed their famous Chain Home string of coastal radar sites to warn of incoming German aircraft. These radar dishes were huge—360 feet high and very visible.[90] The Germans noticed these massive dishes and were curious as to what they were, so in 1939 they sent a zeppelin loaded with radio receivers to investigate. After several hours of monitoring, they heard nothing and concluded the huge dishes had to be something other than radar.

This failure to recognize these radar towers was due to mirror imaging. In 1939, the Germans were more technically advanced in their development of radar. They had developed the Wurzburg radar that operated at wavelengths on the order of fifty centimeters.[91] The less advanced British radars used wavelengths of over a meter. Thus, even though the chief of the Luftwaffe's signal section, Major General Wolfgang Martini, was onboard the zeppelin, they did not hear because they did not listen to the right frequencies. The Germans only listened to the frequencies that they used. Had the Germans understood the advantage these radars gave the British, they could have put in a sustained effort to destroy them and potentially changed the outcome of the Battle of Britain.

The mirror imaging trap is challenging to avoid completely as it is so easy to project one's own values and capabilities on others. To avoid the mirror imaging trap one needs to first realize they are prone to this type of trap. Then, the decisionmaker must willingly accept peer review of their analysis and projections. As a senior leader, establish an organizational climate where peer review of consequential analysis and future projections is the norm. Leaders must check egos at the front door and be open to criticism and encourage differences of opinion because only then will true innovation take place.

Avoiding the traps described above is a significant challenge. Most leaders will not be able to do this naturally as all leaders have biases toward one or more of the traps described above. The key is to understand where these biases lie and then develop a strategy to avoid the traps. The future environment will make avoiding these traps even more challenging as it is always changing and more complex.

Recommendations for Disaster-Proofing Senior Leadership

Leaders must be prepared to think differently if they are to make the right decisions to prepare for the challenges of 2035. While 2035 may seem like a long way into the future, the generals who will lead the Service components are in the Service today and the President of the United States is already in the population. They are gaining the knowledge and experience that will shape their decisions in that future battlefield. What tools should be provided to them? What experiences and thought patterns must they have to be successful in the future environment?

To make the senior leaders of tomorrow successful, three things must be done now: prepare them for success, organize for success, and invest for success. The rest of this article will discuss these three key elements and how they are imperative for the prevention of technological failure and the achievement of success in the future battlefield.

Prepare Leaders for Success

From the very beginning of their experience in the military, the leaders of tomorrow must be prepared to understand and embrace technology and change. This means staying informed about advances in technology. Leaders must be in a continual mode of reading and staying updated in critical areas. Broadening tours to the civilian or military research facilities should be encouraged for future leaders. In addition, since time is a limiting factor, tools such as automatic electronic updates on technology advancements and book summaries[92] should be provided to all levels of the Air Force—not just general officers. The younger generation coming into the military today is already tech savvy and willing to try nearly anything to "see how it works." The Services need to provide the tools to broaden their knowledge base and nurture that innovative energy and drive in a mode commensurate with the techno-savvy capabilities of this new generation. The senior leaders of tomorrow must have access to the tools to keep themselves on the cutting edge and maintain that innovative spirit.

Fostering innovation is easier said than done. Innovation involves risk. In fact, to gain the correct organizational environment, risk-taking must be rewarded. Unfortunately in most cases, the Air Force has done just the opposite. Safety has been emphasized to the point of making people risk averse. Gone are the days of Jimmy Doolittle and Carl Spaatz who lost numerous airplanes trying new things. At the time, this was considered the cost of doing business because innovation was part of the job of every Airman. It was part of the culture of the Air Force and it allowed the Air Force to incorporate new technological advances rapidly.

The innovation spirit must be brought back. One way to do this is by giving people the freedom to fail. While there is a clear distinction between a mistake and a crime, trying to define good failure and bad failure is always going to be a leader's judgment call. One example of fostering innovation would be to develop a leadership *playground*. This can be done by making leadership reaction courses and obstacle courses readily available at the base level. With easily accessible training areas, teams of lieutenants, colonels, sergeants, and Airmen can build teamwork and keep their minds fresh by periodically working through multiple scenarios. By using cutting edge virtual technology to develop training environments, cross-function teams could rapidly devise new challenges in a virtual reality environment. Much like a flight simulator or a multiplayer gaming scenario, the same type leadership simulation experiences could be brought to the general forces. By practicing leadership decisionmaking at all levels of the organization and in complex scenarios, leaders will be better able to enter new situations with confidence. They will be allowed to fail and recover to find a better way without fear of retribution. This can go a long way to developing better decisionmaking skills.

One of the most effective methods of preventing technological failure is to remain humble by listening to others. Why is this so important? Considering the examples of technological failure discussed in the previous section, most of them dealt with some sort of pride issue—either the senior leader was overconfident of his or her own abilities or disdainful of those of the enemy. Leaders failed when they got stuck on their own ideas being the best ideas and not being willing to consider the views of others. Finally, leaders that project their strengths and weaknesses on the adversary are also failing because of arrogance and pride. This type of arrogance and pride can infect the entire organization and develop organizational biases that will result in a future of poor decisionmaking. As senior leaders demonstrate and mentor leadership for their younger officers, they need to be mindful that they are providing the shaping experiences that will last in the minds and hearts of those airmen for many years. These experiences then can translate into a decisionmaking framework that will lead to successful or disastrous decisionmaking.

Organize for Success

Organizations are a reflection of the leader and the bureaucracy that formed them. The organizational structure can install artificial barriers to innovation and ultimately barriers to success. Take for instance the A-staffs at the Pentagon. Each staff is a *cylinder of excellence* that maintains itself through the requirement that many staff packages must pass through their hallowed halls before getting finalized and sent to the mutual boss. This type of hierarchical structure found in these organizations stifles innovation on purpose. There is a built-in bias against changing the status quo and many live in the prudence trap. The leaders of these organizations are seldom aware they are getting watered-down packages without the author's original thoughts in any recognizable form.

To change this construct, mobile, cross-functional teams must be created. The team members must *live* with the organization that needs them most of the time and be available to others who need their specific expertise. To truly expand the ability to make good decisions every time, leaders must build cross *cognitive* teams—teams made up of people who do not think like they do.

Scott Page, in his book, *The Difference*, discovered that teams made up of diverse cognition actually improved problem solving capability more than any other kind of diversity.[93] Through the use of virtual reality-based communication tools, they need to be able to tap directly into the warfighters in the field and every functional area needing representation. There should almost never be a meeting that happens with only people from a single cylinder.

Virtual reality is the way business will be conducted in the next decade. With the advance of sensors that can provide full body exposure to the environment, *being there* just got a lot less expensive. Already the military is experimenting with the use of avatars for training, meetings, and advertisement. Soon, the avatars will be connected via virtual reality to their human and the humans will experience nearly everything that they would in a person-to-person meeting. This technology can be utilized for training, experiencing, and building better decisionmakers.

Decisionmakers trained in a virtual environment will have the ability to run through a complex set of scenarios and find the best way to solve the problems. These decisionmakers would have the benefit of a database of lessons learned and best practices that could be brought up as possible solution sets. While no simulation can perfectly mimic real life, virtual reality will come closer and closer to real life and will provide a distinct advantage to the decisionmakers of the future. Decisionmaking traps could be a thing of the past if leaders are adequately trained in the right behaviors through simulations and organized for success.

Invest for Success

Rapid reaction will be critical to survival in the 2035 battlefield. For instance, if a bioterror attack takes place, the ability to sense, decide, and act with incredible speed could be the difference between victory and defeat. Leadership must not only be able to make decisions quickly, they must have access to a viable set of alternative actions to solve the situation. In the case of a bioterror attack or many other rapidly multiplying challenges, the solution may not be readily available. At that point, the leader must call on the acquisition system to deliver a solution. To enable this, they need an acquisition system primed to respond to threats of all kinds. Super-empowered individuals with the capability to coordinate and mass effects could strike using nano-based weapons and cyber technology to threaten America's ability to respond. A senior leaders' ability to develop a response in time to eliminate or mitigate the threats may determine whether America remains a free country or not. The gravity of this issue means America, and specifically the Department of Defense, must invest in research and development to maintain a broad spectrum of capability in the uncertain future and invest in consequence management capability to respond quickly to surprises.

As budgets tighten, it is normal to focus more on applied science versus basic research. Said another way, if one has to make a choice between supporting the current war and supporting a possible future war, the current war funding will normally win. While logical, this type of decisionmaking has serious ramifications for the future. As the senior leaders of tomorrow reach into their bag of technology-based tools to counter emerging threats, the tools they have will be those developed by basic research today. If the research today is focused on near-term projects, the tool bag of the future could be filled with a set of ineffective, obsolete instruments.

Resisting the urge to unbalance defense laboratory research toward applied research will ensure a broad spectrum of responses for future threats. Defense labs must maintain a strong presence in niche technologies enabled by quantum computing and nanotechnology that may not be profitable for private laboratories to fund. These niche technologies just may provide the needed capability for winning wars. While the US can leverage private and university research capabilities to expand its applied research portfolio, the defense lab structure is many times the only source for war winning, defense-specific basic research. With a strong basic research backbone balanced with a strong applied research network, the US can ensure it maintains the edge against all enemies, foreign and domestic.

The name of the game in 2035 will be consequence management. With the spread of nanotechnology to nearly every corner of the world, the playing field will be much more leveled between the US and its adversaries. The US must have leaders that can think as its adversaries do to understand their goals and desires and be ready for any contingency. While 100 percent preparedness is a good goal, these leaders must also plan for surprise from innovative adversaries as the US will surely face threats no one has seen before.

An example of consequence management in action would be in combating the dark side of nanotechnology-based drug delivery. If it is possible to deliver a dose of cure right to the malignant cells as the nanobot concept goes, a nefarious group could also use the same technology to target other cell characteristics as well. They could surely isolate a portion of the molecular makeup that defines a particular part of the human race. In a hell-like scenario, a bioterrorist could unleash a targeted attack on an entire segment of the human race. The capability of the US to understand the problem, find a solution, and respond quickly through effective consequence management methods could mean life or death for many. In instances such as these, the US cannot afford long acquisition and development timelines. The US must act—and act fast.

Leaders looking to invest in the future not only need to determine the types of investment decisions to make, but also the optimal timing for those investments. Knowing that every choice in funding will force a choice to not fund something else, leaders must focus on leveraging high pay-off investments. High pay-off investments are those that will provide the most bang for the buck in the future. Looking back to the exponential curve discussed in the first section, it is evident that the best time to invest to achieve the maximum effect is early in the process. Achieving a one to two percent increase in slope on the early part of the exponential growth curve will mean a massive increase in capability as the technology matures. As an example, molecular computing and quantum encryption are on the early part of the exponential growth curve today and both of these technologies will have world domination implications for the actor that achieves the technology first.

In the world of 2035, molecular computing and quantum encryption could have the same effect as the first atomic bomb had on the world—possibly even more of an effect. The first quantum computers will be used for niche applications like crunching massive amounts of data in a very short amount of time. Their massive speed and limited spectrum of focus would be perfect for cracking encryption codes that protect the world's computer networks. The security implications are enormous and far reaching, especially if the US is not the first country with this technology. Scientists estimate a quantum computer the size of a thumb nail will have the same amount of communication power as all the computers that have ever been built. With that type of computing power, the possessor could crack any current encryption code instantly and the owner could hold the financial, military, and commercial network capabilities hostage. In the hands of a super-empowered individual, this technology could change the face of war and terrorism. Without a doubt, the United States must be the one to conquer this challenge. The funding needs to be applied and the intellectual capital spent to ensure that the US has the first quantum computer.

The second example of a high pay-off area for investment is in quantum encryption. This little understood concept is going to be the risk-mitigating technology for the foreseeable future. This technology will provide encryption security that even a quantum computer cannot break into. With the entire world economy tied to the health of the American financial and network infrastructure, the United States must be the first to achieve this technology. Without assured access the market could completely destabilize—creating a worldwide crisis that makes 2008 look very calm. Quantum encryption is a war-winning (or losing) technology and the United States must have this particular technology first.

These two examples of high pay-off investments are not the only investments for the future, but they are ones that illustrate the concept of timing and impact. As senior leaders look towards preparing for the future, they must have their eyes open for these types of high pay-off investments to ensure the future toolkits are filled with war winning capability. To grasp the magnitude of the impact of these technologies first requires an interest in learning about technology and then a method to stay informed. Future decisionmakers must purposely seek to stay engaged in technology advances to fully understand the future battlefield environment if they are to make good investment decisions.

Conclusions

Capable, well-intentioned leaders often make poor decisions that lead to technological failure on the battlefield. Sometimes it is a result of a failure to understand technology or its relevance to the battlefield. Other times, poor decisions are made because of a mindset or organizational structure that leads into a decisionmaking trap. As technology accelerates at an exponential rate, the consequences of poor decisionmaking become amplified and more far reaching. It is imperative to do everything possible to prepare leaders, set up diverse organizations, and invest resources wisely to prevent technological failure in the future. The steps taken now will have an escalating impact on the ability to succeed in the battlefield scenarios of 2035 and beyond.

The first step to preventing technological failure is to keep leaders informed about developing technologies through self-study. They must become familiar with terms associated with the technologies and understand the implications of concepts such as nanotechnology, quantum computing, biomimetics, artificial intelligence, and nanobots.

Leaders must also think differently. Instead of thinking linearly and locally, they must think exponentially and globally. They must understand how the new flattened world gives rise to threats and opportunities across the spectrum from state actors to empowered individuals. Further, they must understand how the exponential growth in technology and globalization will impact the future battlespace. With this foundation, they must then look inward to personal biases that can lead to decisionmaking failures.

Leaders must be aware of the decisionmaking traps and understand which of them they are most prone to fall into. Being aware of the traps is the first step to avoiding them.

- The Anchoring Trap: Be aware that first impressions rarely tell the whole story. Step back and consider all sides of the situation before making a decision. Call on a third party for advice.
- The Status Quo Trap: Establish a culture that encourages innovation without fear of failure. Encourage newfangled ideas.
- The Sunk Cost Trap: Maintain an objective viewpoint. Call on a third party to gain an outside evaluation.
- The Confirming-Evidence Trap: Understand personal biases. Employ a trusted agent to gain an objective outsider viewpoint. Foster a culture that allows for airing differences of opinion.
- The Framing Trap: Carefully evaluate problem statements for biases that inadvertently limit potential solutions. Gain an objective view of the problem statement from a disinterested third party.
- The Overconfidence Trap: Develop a habit of objective self-assessment. Be open to criticism. Foster opportunities to receive unfettered feedback from subordinates, peers, and superiors.
- The Prudence Trap: De-layer decisionmaking. Empower and entrust leaders at the lowest levels to innovate. Seek out the *unvarnished* truth.
- The Recall Ability Trap: Capture knowledge at every level and develop a readily accessible database of historical knowledge and lessons learned.
- The Mirror Imaging Trap: Understand personal biases. Check egos at the front door. Establish system of peer review for consequential analysis and future projections.

Organizations must prepare leaders to make good decisions by building leadership training areas either physically or in virtual reality training environments. These areas will provide leaders the freedom to innovate, fail, and correct multiple times at low cost.

Institutions have to organize for success by developing decision support structured organizations. These organizations must bring together, physically or virtually, a cognitively diverse team to solve complex problems. The more complex the problem, the more important it is to have a team of cognitively diverse experts brought together to solve it.

Finally, the Services must invest for success by funding high pay-off investments at the optimum time near the beginning of the exponential growth curve to maximize every dollar spent. These investments must encompass the technologies that will have the greatest impact on the coming battlefield environment. This will ensure future leaders have the tools they need to fight and win the wars of the future.

The challenge of avoiding technological failure and decisionmaking traps in the future intensifies as the environment becomes more complex and the processes of change continue to accelerate. Staying current on future trends requires constant vigilance. Leaders must proactively face the future and its challenges, and seek the knowledge to prepare for it. The implications of not doing so could prove disastrous. The hope for the future lies in having adequately prepared leaders who understand their own shortcomings and the traps they are prone to, organizations that are set up for cognitive and structural diversity, and the right investments of our current resources to ensure the possession of the necessary technologies and weapons to wage war successfully in the nano-battlefields of tomorrow.

Notes

1. Victor E. Borisenko and Stefano Ossicini, *What is What in the Nanoworld: A Handbook on Nanoscience and Nanotechnology*, KGaA, Weinheim: Wiley-VCH Verlag GmbH, 197.
2. According to the National Nanotechnology Initiative Website, http://www.nano.gov/nanotech-101/what/nano-size, a sheet of paper is about 100,000 nanometers thick, a human hair is 80,000 nanometers wide, and a strand of human DNA is 2.5 nanometers in diameter. To get the number of microns, simply divide by a thousand...for example, a sheet of paper is about 100 microns thick.
3. Lynn E. Foster, *Nanotechnology: Science, Innovation, and Opportunity*, Upper Saddle River, New Jersey: Prentice Hall, 2006, 37-40. Describes the limits of the current top down lithographic paradigm for achieving consistently smaller pathways. A couple examples are cost and temperature of manufacturing as well as quantum mechanical tunneling that occurs when the electronic pathways get closer.
4. Ray Kurzweil, *The Singularity is Near: When Humans Transcend Biology*, New York, New York: Penguin Books, 2005.
5. A decade later, the rate of acceleration was actually doubling at a rate of approximately 18 months, exceeding even Moore's prediction.
6. Although Moore's Law has proven true to this point, some suggest it is coming to an end. At some point, they say, we will reach the limit of the dielectric constant for silicon such that transistors simply cannot be put any closer together without the resistive walls made of fewer and fewer atom layers eventually leaking current between transistors. These skeptics see us approaching the limit of the current manufacturing capability around the year 2017. Others believe that Moore's Law will continue to hold true. They comment that its end has been predicted many times in the past and every time a critical breakthrough has come along to keep technology on the exponential slope. These people cite current research using Hafnium whose dielectric constant will allow a closer packing of components than with silicon. Research being done at Hewlett Packard Labs has led to a new technological breakthrough called the "memristor." They have shown that a single memristor can do the work of multiple transistors and thereby shrink some circuits by a factor of ten. Thus, there seems to be additional life to Moore's Law.
7. Lynn E. Foster, *Nanotechnology: Science, Innovation, and Opportunity*, Upper Saddle River, New Jersey: Prentice Hall, 2006, 38.
8. Foster, xiii.
9. Foster, xiii.
10. Foster, 41.
11. The Scanning Tunneling Microscope (STM) and the Atomic Force Microscope (AFM) are used to move atoms around with atomically thin needle tips. See Foster, *Nanotechnology*, 43, 211. New technology is spawned everyday that will allow more and more capability to manipulate atoms. STM and AFM are still very viable technologies. The purpose of this article is to explain the exponential nature of technology growth and its implications on the future leadership environment.
12. Kurzweil, *The Singularity is Near*, 116-118.
13. Kurzweil, *The Singularity is Near*, 122.
14. Foster, 39.
15. *Ibid*.
16. *Ibid*.
17. Foster, 40.
18. *Ibid*.
19. Foster, 39-40.
20. See article by Liz Kalaugher, "Lotus Effect Shakes Off Dirt," [Online] Available: http://nanotechweb.org/cws/article/tech/16392, 8 November 2002, accessed 15 May 2011.
21. See an excellent discussion of Leonardo Da Vinci's life including copies of his work and an interactive timeline for his many contributions at http://www.universalleonardo.org/work.php?id=483, accessed 15 May 2011.
22. Tom Mueller, Design by Nature, [Online] Available: http://ngm.nationalgeographic.com/2008/04/biomimetics/tom-mueller-text. A number of sources have shown the viability of micro and nano air vehicles. National geographic documents a vehicle having a weight of a paper clip using technology from a blow fly.
23. William A. Davis, "Nano Air Vehicles: A Technology Forecast," Blue Horizons paper, Center for Strategy and Technology, Maxwell Air Force Base, Alabama: Air War College, 2007, 4.
24. CSAT Reference to Failed State Scenario.
25. Rown Hooper, "Ideas Stolen Right From Nature," *Wired Magazine*, November 2004, [Online] Available: http://www.wired.com/science/discoveries/news/2004/11/65642?currentPage=all, accessed 27 December 2008.
26. Stanley R. Williams, "How We Found the Missing Memristor," *IEEE Spectrum*, 1 December 2008, [Online] Available: http://www.spectrum.ieee.org/print/7024, accessed 30 January 2009.
27. US Department of Energy and the National Institutes of Health, "Human Genome Project Information," 15 October 2008, [Online] Available: http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml, accessed 1 January 2009.
28. DNA is arranged into 24 distinct chromosomes, each consisting of 50 million to 250 million base pairs. It is in the analysis of base pair arrangements that researchers can find missing or duplicate pairs that result in chromosome anomalies. Understanding the nature and operation of these nano-level components is critical to deciphering how they self-organize and produce macro structures automatically using nano-components. As we gain a better understanding of the basic functions of each component of human life, we open the door to a myriad of possibilities in nearly every field of science. With the computing power available today, we can map a person's genome in real time finding a person's propensity for disease and abnormalities before they take place. Already researchers have isolated the genes associated with breast cancer, muscle disease, deafness, and blindness. Now that the genes for these problems have been isolated, work on a cure is possible.
29. Associated Press, "Science Finding Ways to Regrow Human Fingers," 20 February 2007, [Online] Available: http://www.foxnews.com/story/0,2933,252704,00.html, accessed 30 January 2009.
30. Norman T. Berlinger, "Robotic Surgery: Squeezing into Tight Places," *New England Journal of Medicine*, Volume 354, No 2, May 2006, 2100. In 2001, surgeons located in New York removed a gall bladder from a patient located in France using high speed telecommunications technology and surgical robotic arms manipulated from across the Atlantic Ocean.
31. Roland Pease, "Living Robots Powered By Muscle," *BBC News*, 17 January 2005, [Online] Available: http://news.bbc.co.uk/2/hi/science/nature/4181197.stm, accessed 17 January 2009.
32. Professor Carlo Montemagno, University of California, describes how the live muscle cells "grow, multiply and assemble" to form structures that move.
33. "New Nanobot Can Efficiently Walk Unaided Along a Single Strand of DNA," *Thaindian News*, 7 January 2009, [Online] Available: http://www.thaindian.com/newsportal/health/new-nanobot-can-efficiently-walk-unaided-along-a-single-strand-of-dna_100139221.html, accessed 19 January 2009.
34. Danielle Day coined the term *cyber-wall* in her unpublished English Composition 1301 paper with the following definition: A cyber-wall is an Internet page used as a marketplace, as an expression forum, or as a social connection.
35. By studying the way ideas and communication takes place in the cyber realm, decisionmakers can learn how to inform and influence their constituencies. Networking in the cyber realm can happen more rapidly than ever before and staying ahead of information flow is now nearly impossible. This truth has serious implications for decisionmakers.

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39. Stephen A. Shambach, "Strategic Leadership Primer, 2d ed, Carlisle, Pennsylvania: Department of Command Leadership and Management, US Army War College, 2004, in *Joint Strategic Leadership Reader, AY 2009*, Maxwell Air Force Base, Alabama: Air University, 2004.
40. "Exponential Growth," Wikipedia, [Online] Available: http://en.wikipedia.org/wiki/Exponential_growth, accessed 23 December 2008.
41. Malcolm Gladwell, *The Tipping Point*, New York, New York: Little, Brown and Company, 2002, 29.
42. Thomas Sterling, "The S-curve Bends Twice: A Petaflops Post-Mortem and the Computing Imperative," briefing, *Center for Computation and Technology*, Louisiana State University, 9 March 2006, [Online] Available: http://www.cct.lsu.edu/~tron/banquet4.pdf, accessed 22 December 2008, slide 13.
43. Sterling, slide 14.
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50. Friedman, 117.
51. Rachel Parker, "Leapfrogging Development through Nanotechnology Investment: Chinese and Indian Science and Technology Policy Strategies," unpublished paper, University of California, Santa Barbara, [Online] Available: http://www.law.gmu.edu/nctl/stpp/us_china_pubs/china_india_us_workshop/sec9_young_scholars/sec9_item3_parker.pdf, accessed 22 January 2009.
52. *Ibid*.
53. Alexis Madrigal, "The Chinese Government's Plans for Nanotechnology," *Wired Blog*, 17 February 2008, [Online] Available: http://blog.wired.com/wiredscience/2008/02/the-chinese-gov.html, accessed 22 January 2009.
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63. Kurzweil, *The Law of Accelerating Returns*, 52.
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65. Garreau, 131.
66. Garreau, 191.
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89. Lorber, 3-4.
90. Lorber, 60.
91. Lorber, 61.
92. Audio-Tech Business Book Summaries are approximately 60 minute summaries of the most up-to-date published technological/business books provided on CDs, as MP3 files, or e-transcripts. These types of summaries are currently provided to the Air Force's general officers only.
93. Scott E. Page, *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies*, Princeton, New Jersey: Princeton University Press, 2007, 323.

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Special Operations Training Center: Does 3-Level Maintenance Belong?

Robert "Mig" Miglionico, Colonel, USAF

Introduction

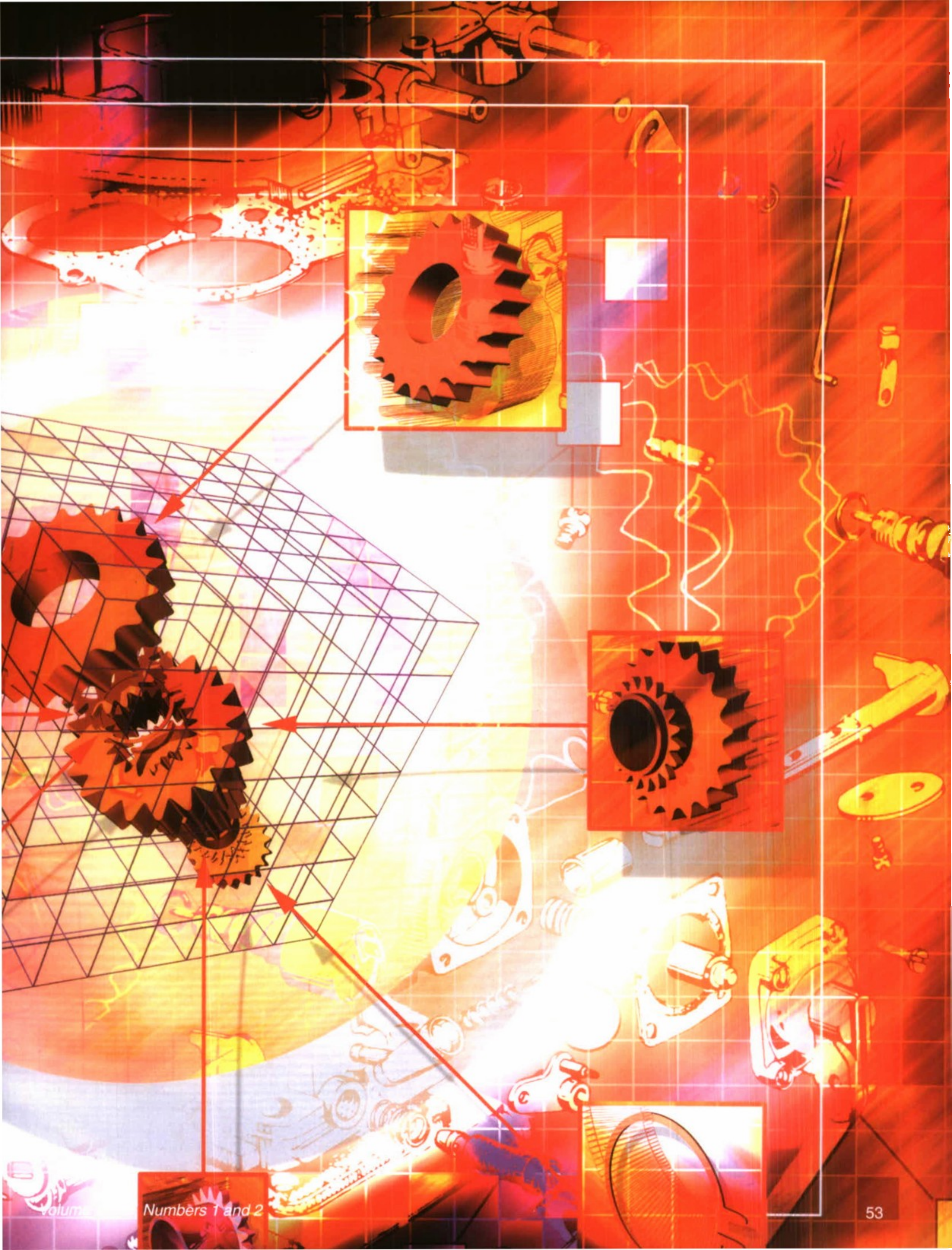
Should the Air Force Special Operations Command (AFSOC) incorporate 3-level aircraft maintenance on-the-job training (OJT) as part of the Air Force Special Operations Training Center (AFSOTC)? The current method of providing OJT for 3-levels using *out-of-hide* resources is adequate at best and needs improvement. If resourced properly with ample equipment and manpower, without degrading the existing aircraft maintenance organizations' productivity, then AFSOTC is a viable option for ensuring 3-level OJT. The fiscally-constrained environment makes proper resourcing a challenge; it makes sense to consider options that include a total force initiative that takes advantage of the Air Force Reserve Center resources—both equipment and expertise. In order to create and sustain an efficient, successful maintenance training environment and continue high levels of support for the long war, it is imperative to look *outside of the box* for a solution.

Air Force instructions require major commands (MAJCOM) to ensure OJT for 3-level aircraft maintainers upon arrival at their units from technical school.[1] However, the Air Force instructions do not mandate how the training must be accomplished. MAJCOMs differ in their approaches to training. Some MAJCOMs (like Air Mobility Command [AMC]) have a relatively formal process for ensuring the training gets accomplished. Regardless of which method a MAJCOM employs, one common theme exists throughout the Air Force: maintenance organizations are suffering from low maintenance manning and experience, and operations and deployment tempos are high. These factors result in maintenance organizations having difficulty in providing consistent, timely training while still trying to accomplish safe sortie generation both at home station and deployed. AFSOC is not immune to the difficulties seen throughout the Air Force with regard to training 3-levels. In addition, AFI 36-2232, *Maintenance Training*, states that the on-maintenance qualification training does not apply to AFSOC[2] and therefore, the command has the opportunity to determine the right process for its maintainers. The difficulties seen with high operations tempo and low maintenance manning and experience highlight the need for AFSOC to find a more efficient and effective process to ensure proper training. The newly established AFSOTC may be able to provide some much needed assistance to the AFSOC maintenance world.

Current Maintenance Training Process

Air Force Maintenance Training

The Air Force provides aircraft maintenance training to its new aircraft maintenance career field accessions. These new maintainers earn their initial 3-level qualification at Air



Education and Training Command formal training schools. Their training is general and not aircraft specific. It is incumbent upon the gaining organization to provide OJT for the new 3-level apprentice maintainers, and to prepare them for hands-on tasks for specific aircraft. OJT is two-fold: first, the 3-levels are provided training that gives them the basics necessary to be minimally productive in their particular maintenance discipline and second, they are provided OJT intended to upgrade them from a 3-level apprentice maintainer to a 5-level, journeyman status. This article will focus on the first part—OJT that elevates the 3-level apprentice from just being a *tech school graduate* to an apprentice maintainer that can perform some basic tasks. This training will be referred to in the remainder of this article as 3-level *top-off training*.

Why is top-off training important? New Airmen at technical school are provided general training. It is normal for a basic trainee to progress through basic military training, then graduate from technical school, and arrive at a base having never seen the type of aircraft he or she is assigned to work on. The basic technical school can only provide generic training; thus, it is important to provide weapon-system-specific familiarization once the Airman arrives to his or her first base. Once the Airman arrives, he or she will be put in a training status and will be in an upgrade program designed to take them from an apprentice 3-level to a qualified 5-level journeyman. The standard timeline for upgrading from 3- to 5-level is about 12 months but can vary greatly depending on circumstances and the individual maintainer. This top-off training is not designed to get the Airman to the upgraded skill level. It is simply to provide them familiarization and training so they are somewhat productive during the upgrade process. The Airman will still require supervision throughout the day; however, with proper top-off training the potential for mishaps is reduced, and the Airman may be able to assist in some tasks. This training can enhance the organization's productivity as the new 3-levels become capable on tasks such as aircraft towing, aerospace ground equipment operation, aircraft and equipment refuel/defuel, aircraft marshaling, and other tasks. Any productivity from a 3-level adds to the productivity of the organization, so it is clear that each MAJCOM benefits from having a solid top-off training program. AMC has a superb program, although it has some challenges.

Article Acronyms

AFB – Air Force Base
AFRC – Air Force Reserve Center
AFSOC – Air Force Special Operations Command
AFSOCTC – Air Force Special Operations Training Center
AMC – Air Mobility Command
CAF – Combat Air Force
CONUS – Continental United States
DOPP – Dropped Object Prevention Program
MAJCOM – Major Command
MQTP – Maintenance Qualification Training Program
MXG – Maintenance Group
OCONUS – Outside the Continental United States
OJT – On-the-Job Training
SOF – Special Operations Forces
SOS – Special Operations Squadron
TDY – Temporary Duty
US – United States
USSOCOM – United States Special Operations Command

AMC Maintenance Training

AMC established the AMC Maintenance Qualification Training Program (MQTP) and the Level I training is its mechanism to ensure 3-levels are provided adequate, useful top-off training. AMC supplemented the AFI 36-2232 training guidance and spelled out the formal requirements for entry level Airmen in flight line maintenance career fields. The AMC supplement indicates which maintainers are required to be enrolled in the MQPT program, the minimum maintenance tasks that they are required to be trained on, and the process for the enrollee to progress through the program. This level of detail ensures that the 3-levels are trained to a minimum standard level on tasks that the field deems are necessary for productivity in the maintenance organizations. The program is sound, but implementation has its challenges.

In an ideal world, there would be enough qualified 5- and 7-level maintainers to ensure safe reliable maintenance actions are performed and enough consistently available to provide training to the new 3-levels. The reality of the world today is that there are not enough experienced maintainers to accomplish the requirement. This shortage exists for many reasons, but there are two significant reasons. First, because of a standard maintenance manning level of 85 percent maintenance organizations are generally starting out behind the power curve. After several recent presidential budget directives, maintenance manpower authorizations have been reduced to what many professional maintainers consider bare minimums. Recent efforts to buy back maintenance authorizations are only slightly helpful, as most authorizations are being provided to new missions, not to fix shortages at existing units. Additionally, the increase in active-associate units (active duty Airmen assigned or aligned with Reserve or Guard units) has led to an increase in active duty authorizations. Even though there are more authorizations now, it takes several years to grow qualified maintainers to fill the authorizations. Thus, the pool of maintainers that exist now at active duty units will be decreased for the next few years to fill positions at active-associate units.

The aircraft experience level of maintainers provides the second reason for the shortage of qualified 5- and 7-level maintainers to train new 3-levels. The Directorate of Logistics (AF/A4) reduced the number of shred-outs attached to Air Force specialty codes. For example, the letter code that designated a maintainer as an F-15 crew chief was removed, and now that maintainer is coded as a more generic Combat Air Force (CAF) (fighter) crew chief. This means the CAF crew chief can be assigned to units with F-15s, F-16s, A-10s, and others. The end result is that a unit can (and does) end up with maintainers that are technically qualified as 5- or 7-level mechanics, yet they may have little to no experience on the particular type of aircraft flown by their unit. This shred-out removal affected AFSCs throughout maintenance, both from the fighter/bomber world, and the mobility world. The significance of this generalization of the experience base with respect to the 3-level training is that now the pool of experienced 5- and 7-level maintainers qualified to provide hands-on OJT to 3-level maintainers is reduced.

AMC developed a program called Focused Training to combat the shortage of trainers. In this program, they canvass the MAJCOM for volunteers for temporary duty (TDY) at units that have large training backlogs. The intent is for the volunteers to work on the flight line to free up the home unit maintainers so they can train their 3-levels. This program has met with some success, but the pool of available volunteers is low and the program is only a stopgap.

AMC's initiatives to ensure proper top-off training for its 3-levels are formal, adequate, but not easily sustained. Manpower constraints, number of maintainers, and qualification levels impact its ability to train the 3-levels. The issues that affect AMC's maintenance training are also present in AFSOC.

AFSOC Maintenance Training

AFSOC maintenance organizations, like those of other MAJCOMs, need quality top-off training for its new 3-level maintainers. AFSOC maintenance is affected by manpower shortages and experience gaps similar to other commands. Additionally, AFSOC and the other MAJCOMS may face a slight reduction in manning percentages with the onset of the new missions (Global Strike Command and active-associate units). As the worldwide manning averages decrease because of new missions, the AFSOC manning averages will decrease accordingly. This will occur despite the fact that AFSOC maintenance manpower requirements will remain high as the operations tempo at home and abroad remain high because of the long war. AFSOC maintenance recognizes the situation they find themselves in and has initiated an effort to ensure its training program is able to meet the challenge.

The 1st Special Operations Maintenance Group (1 SOMXG) at Hurlburt Field, Florida assigned one of its squadrons, the 1st Special Operations Aircraft Maintenance Squadron (1 SOAMXS) the task of developing a tailored training program. The test program is focused on getting new 3-levels top-off training and upgrade training simultaneously. The program formalized the process so that the 1 SOMXG, like AMC, will have a standardized approach to providing OJT to its new maintainers. There were no additional resources provided to the 1 SOAMXS for this test, so the internal training is still taken out of hide.[3] It still remains to be seen if the value of taking qualified maintainers off the line to focus on training only will have a negative effect on the unit's maintenance productivity. The test is still ongoing, so the cost-benefit ratio has not been determined; however, initial response from the unit commander is positive.

Will the 1 SOAMXS be able to *crack the nut* on maintenance training and be able to develop an effective training program from within its own resources? If so, their success should be replicated throughout the 1 SOMXG and 27 SOMXG at Cannon Air Force Base, New Mexico. Can potential 1 SOAMXS successes also work in the nonstandard maintenance organizations in the overseas special operations groups? If so, then there is reason to be excited and to implement rapidly. If the 1 SOAMXS cannot develop an effective training program using internal resources, then an alternative solution must be found, possibly under the AFSOTC.

Air Force Special Operations Training Center

Current AFSOTC Mission

On 1 October 2008, AFSOC established the AFSOTC at Hurlburt Field, Florida.[4] The AFSOTC commander reports directly to the AFSOC commander, and the center is one of AFSOC's six primary subordinate units.[5] The AFSOTC mission is to:

> Develop a focused recruiting, selection, assessment, and training and retention program to ensure adequate numbers of personnel specialty and equipment. Missions include: planning, support, and command and control of tasked assets executing overt or clandestine special operations to disrupt, defeat, or destroy designated targets. AFSOC will establish an AF Special Operations Training Center (AFSOTC) to focus training and separate operations.[6]

The last sentence from the United States Special Operations Command (USSOCOM) *2007 Mission Guidance Letter* above is the heart of what AFSOTC is all about. The first commander of AFSOTC, Colonel Paul Harmon, further refined his role as the single commander responsible for carrying out the guidance in the *2007 Mission Guidance Letter*; with his specific intent to "consolidate initial qualification training—warfighters fight; trainers train."[7] This commander's intent clearly defines the direction that the AFSOTC was headed. Its reason for being was to allow the warfighters to focus on the combat mission, without the burden of having to provide initial training to personnel. The AFSOTC mission was to take initial training out of the operational units' hands and to provide them trained air commandos ready to contribute to the mission once they arrive to their respective units.

The AFSOTC mission provides mission qualification training for AC-130H/U, MC-130W, U-28, combat aviation advisors, nonstandard aviation, special tactics, deployed aircraft ground element, and intelligence, surveillance, and reconnaissance (ISR) exploitation mission areas.[8] The AFSOTC organizational structure (see Figure 1) is designed to provide training for the Airmen involved in the aforementioned mission areas.[9] It is important to note that the Air Force Reserve Center has a unit (5th Special Operations Squadron) associated with the AFSOTC. This Total Force relationship is a force multiplier, providing a cross-utilization of manpower, expertise, and experience between the active duty and Reserve forces.

This organizational structure is the second iteration as the AFSOTC is going through its planned growth.[10]

Future AFSOTC Mission

The AFSOTC organization structure changed again in fiscal year 2010 as it expanded its role in aviator training (AC-130, EC-130J, PC-12, U-28) and sensor operator training.[11] The new organizational structure (see Figure 2) highlights these changes and shows the 5 Special Operations Squadron (SOS) chain of command going directly to the 919th Special Operations Wing (AFRC) at Duke Field, Florida and the association to the AFSOTC commander.[12]

The AFSOTC mission continues to grow, but the resources it utilizes are not additive to AFSOC. According to the Commander, United States Special Operations Command (COMUSSOCOM), the AFSOTC must be "resource neutral."[13] To be resource neutral, AFSOC had to move resources within the command to build up the AFSOTC. For instance, in order to establish manpower billets in AFSOTC for Combat Aviation Advisor training, the 6th SOS was required to give up 12 active duty billets to the AFSOTC.[14] This process was repeated throughout several AFSOC units so that the AFSOTC stand-up could remain resource neutral.

Understandably, warfighting units are uneasy about giving up billets, regardless of the projected benefits. The 319th SOS was

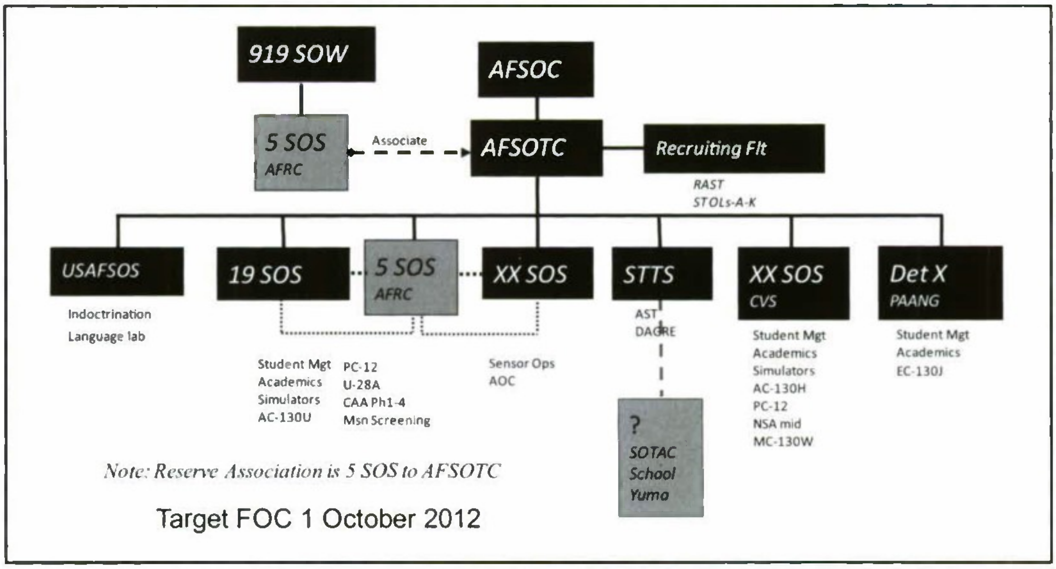


Figure 1. AFSOTC Organizational Structure

initially apprehensive about giving up some of its authorizations to the AFSOTC, but in the end the unit recognized the benefit as it gained better trained aircrews without impact to operations.[15]

Neither the AFSOTC mission, as described in the P-plan, or the AFSOTC organizational diagram, as resourced, account for inclusion of special operations aircraft maintenance training to be aligned under the AFSOTC umbrella.[16] The aforementioned documents can be interpreted as only being applicable to operations training. However, the door for expansion of the AFSOTC scope has been opened with the comments made by the AFSOC Vice Commander during the 2009 AFSOTC Change of Command ceremony, "Your mission is to recruit, assess, select, indoctrinate, train and then educate air commandos, other special operations forces and SOF enablers..."[17] The AFSOC/CV statement provides a vision that AFSOTC can have a role in training support personnel and one could interpret the comments as guidance to AFSOTC to determine how they can best train *the SOF enablers.*

3-Level Maintenance Training in AFSOTC

The special operations maintainers are clearly SOF enablers and it can therefore be argued that inclusion of initial maintenance training under AFSOTC falls within the bounds of the AFSOTC responsibility. If the boundaries of AFSOTC are such that maintenance can be included, then the question remains, should it be included? If the answer is yes, then a sight picture on how to establish maintenance training in AFSOTC must be developed. The picture should include the scope of training to be provided, allocation of resources, and the desired organizational structure to include lines of authority.

Should 3-Level Maintenance Be Included in AFSOTC?

The short answer is "it depends." Any change to the current process to train 3-level maintainers in AFSOC should result in better trained 3-levels and safe, effective, and efficient aircraft maintenance productivity at home station and at deployed sights around the globe. If a plan can be developed to include 3-level top-off training in AFSOTC and the aforementioned results attained, then the answer is a resounding Yes. If any plan to include 3-level top-off training in AFSOTC results in a less effective training program, or in a degradation in maintenance productivity, then the change should not be made. It is imperative that any change to the training process does not include reducing the experienced manpower assigned to the AFSOC maintenance units. This will be difficult to accomplish with AFSOTC remaining resource neutral; thus, it may be necessary for AFSOC to identify manning offsets from nonmaintenance organizations within the command. Assuming this can be done, the next step is to determine the scope and scale of training.

Scope and Scale of Training

The training process needs to be determined with two aspects in mind: scope and scale. First the scope of the training needs to be determined—specifically, which tasks the 3-levels should master in top-off training. Once the scope is determined, the next step is to determine the scale of the effort and which special operations maintainers to include in the 3-level top-off training. The target 3-level maintainers could range from those locally assigned (Hurlbut Field and Eglin Air Force Base [AFB]), to those assigned stateside (includes Cannon AFB), or to AFSOC maintainers worldwide (includes Mildenhall and Kadena). The scale of training will be important in determining how to resource the AFSOTC.

AMC's Level I MQTP training model provides a sound, proven plan for scoping the tasks for 3-level top-off training. The tasks listed in AMC supplement to AFI 36-2232 include a multitude of tasks that once mastered, would enable a 3-level to be productive in a maintenance organization. The tasks are more specific than what the 3-level would have accomplished at basic technical training, yet specific enough to give him or her proper familiarity with the equipment they will be working on in his or her unit.[18]

- Technical order familiarization
- Flight line safety, precaution, and security
- Introduction to aircraft and airframe familiarization and egress
- Inspect and operate portable external electrical power unit
- Inspect and use ground maintenance stands
- Dropped Object Prevention Program (DOPP)
- Defensive systems familiarization (on applicable aircraft)
- Statically ground aircraft, if applicable
- Apply or disconnect external electrical power unit
- Perform wing and tail walker duties
- Perform jacking team member duties
- Perform refuel and defuel team member duties
- Open and close engine cowling
- Remove and install aircraft maintenance access panels
- Use aircraft interphone system

- Perform aircraft marshaling procedures
- Team communications

The AMC task listing above, with the exception of DOPP (AFSOC does not use this program) should be included in the scope of tasks assigned to the AFSOTC. The timeline for the 3-levels to master these tasks, assuming they are in a focused, controlled training environment is approximately 60 days. This timeline is not problematic if the units are resourced correctly and if the trainees are from the local area. For expansion of training to those outside the local area there are more issues to consider.

If the scale of the student pool extends beyond the local area, issues such as TDY funding, billeting, and time away from home station become factors to consider before including them in the scope of 3-level maintenance top-off training in AFSOTC. Additionally, the number of 3-levels special operations maintainers in the local area, CONUS, and OCONUS will need to be evaluated to determine reasonable and doable class throughput.

If 3-level top-off training is moved to AFSOTC, the scale should be deliberately metered, similar to the way the aviation training scale is projected in the AFSOTC.[19] Though metered, a clear goal of having a standardized training program for the command under AFSOTC is desired. Including all AFSOC 3-levels in the AFSOTC training center will prove beneficial in several ways. First, an all-inclusive approach ensures a standardized training syllabus from which the instructors can train. Next, a single training center will ensure a standard level of quality and experience of trainers. Finally, an all inclusive program under the AFSOTC will provide a single commander that can champion the training effort, using economies of scale. The following phased approach to include all special operations 3-level maintainers is recommended (see Table 1).

Allocation of Resources

Determining how to resource 3-level top-off training in an organization that has no resident maintenance capability requires either a lot of funds or a lot of ingenuity. Since the AFSOTC is directed to be resource neutral, an out-of-the-box approach to resourcing must be taken. Resources would have to include personnel, equipment, and training devices. Of note, AFSOC recently purchased nine maintenance training devices and associated equipment for the Cannon AFB Field Training Detachment at a cost of $19.9M.[20] The cost of maintenance training devices could jeopardize the resource neutral requirement. There are two key points to remember when determining how to resource the AFSOTC to enable the center to take on 3-level maintenance top-off training. First, the effort should result in better trained 3-levels. Second, there must be no degradation in home station or deployed maintenance productivity. Ideally, productivity at home station and deployed locations would increase.

PHASE	3-LEVEL TRAINEE POOL	TRAINING TASKS
Phase I	Local (Hurlburt Field, Eglin AFB)	All AMC tasks (except DOPP)
Phase II	CONUS (Hurlburt Fld, Eglin AFB, Cannon AFB)	All AMC tasks (except DOPP)
Phase III	ALL (Hurlburt Fld, Eglin AFB, Cannon AFB, RAF Mildenhall, Kadena AB	All AMC tasks (except DOPP)

Table 1. Phased Approach to Include All Special Operations 3-Level Maintainers

Can all of this be done in a resource neutral environment? Yes it can, but would require a cooperative total force initiative. By using the resources resident in the 919th Maintenance Group in concert with the 1 SOMXG and AFSOTC, a workable solution is possible. With the retirement of the 919 SOW's MC-130E fleet, it makes sense to capitalize on the special operations maintenance expertise that will be left behind.

In order for the AFSOTC to provide maintenance training, it will need qualified maintainers to serve as training instructors and it will need equipment and training devices to train the 3-levels. The MC-130E maintainers in the 919 MXG are qualified to train 3-levels on the majority of the tasks outlined in the recommended maintenance task listing. Some minor familiarization training will be required to qualify the instructors on the weapons systems variations in AFSOC. Under this concept, the 919 MXG would take the lead for AFSOTC 3-level maintenance top-off training at Duke Field. The organizational structure for AFSOTC in Figure 2 is recommended.

The cost of new training devices and equipment is not likely supportable and is not necessary to train the 3-levels on the recommended tasks. Retaining one or more of the retired MC-130Es as ground trainers would meet the majority of the aircraft training device needs while significantly reducing the costs associated with acquiring new devices. Additionally, reserving some of the aerospace ground equipment owned by the 919 MXG would provide a trainer for the majority of the ground equipment tasks. The shortfall with regard to aircraft trainers is the lack of specific aircraft types at Duke Field (MC-130H, CV-22, AC-130H/U, MC-130P). The tasks that require hands-on training on specific aircraft are minimal and can be accomplished by scheduling aircraft for that purpose at Hurlburt or Eglin.

In addition to capitalizing on the 919 MXG expertise for 3-level training, there is an opportunity to enhance the maintenance training and productivity of the AFSOC units as well. In conjunction with the MC-130E retirement and stand up of the AFSOTC 3-level maintenance training, it would be useful to embed 919 MXG maintainers in AFSOC maintenance units at Hurlburt and Eglin. Their expertise will be of value in training beyond the 3-level stage and will benefit the day-to-day productivity in the operational maintenance organizations.

Conclusion

AFSOC should incorporate 3-level aircraft maintenance top-off training into the AFSOTC only if two important results can be achieved. First, the 3-level training provided by AFSOTC should be better than the current training received. Second, there can be no degradation in maintenance production at home station or at deployed locations as a result of the transfer of training responsibility. It is possible for AFSOTC to assume 3-level aircraft maintenance top-off training for the entire command, and efforts to develop a detailed roadmap should be accomplished.

Top-off training is important to the maintenance community throughout the Air Force. It is the process that can render new 3-

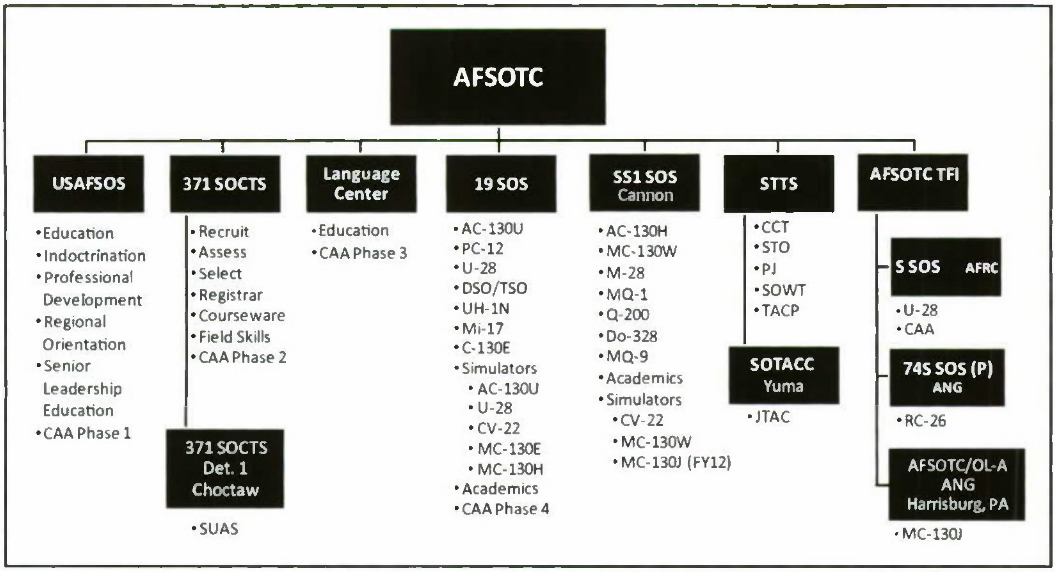


Figure 2. Recommended Organizational Structure for AFSOTC

level maintainers productive in their organizations without having to wait for them to complete 5-level upgrade training. Current Air Force instruction requires each MAJCOM provide hands-on maintenance qualification training to new 3-levels but does not provide specific, detailed guidance. AMC has formalized its program and developed a solid list of specific OJT tasks for 3-level maintainers to accomplish. The special operations maintenance group at Hurlburt Field is testing a formal 3-level training program that may be exportable throughout the MAJCOM if the benefits are deemed greater than the costs.[21] Of note, aircraft maintenance organizations are not provided manpower to accomplish top-off training—the resources come out of hide. The high operations tempo, low manning, and diminished experience levels in the aircraft maintenance communities present challenges in balancing quality training for 3-levels and sustaining safe, successful aircraft generation.

Moving responsibility for 3-level training to AFSOTC can help the maintenance community focus on maintenance productivity. The AFSOTC exists to "let trainers train, and to let warfighters fight." However, as a resource neutral organization, AFSOTC does not have excess resources to tackle new responsibilities. With out-of-the-box initiatives, AFSOTC can tackle the task of leading the charge for 3-level maintenance top-off training.

Embracing a total force initiative with the 919[th] MXG can result in the resource sharing necessary to move maintenance training to AFSOTC. The MC-130E aircraft flown by the 919[th] SOW are scheduled for retirement, creating an opportunity to take advantage of potential excess special operations maintenance expertise and aircraft. A cooperative arrangement should be secured with an AFRC to create a maintenance detachment at Duke Field, Florida associated with AFSOTC. This training detachment would utilize 919 MXG maintenance experts to provide 3-level top-off training for all special operations maintainers. Use of retired MC-130Es as ground trainers and aerospace ground equipment owned by the 919 MXG would enable hands-on training to accomplish the majority of the training tasks. In addition, the cooperative agreement should include embedding maintenance experts from the 919 MXG in the special operations maintenance organizations at Hurlburt Field, and Eglin AFB to enhance training and day-to-day operations in the active duty maintenance organizations.

There is truly a need to improve maintenance 3-level top-off training. AFSOC has a golden opportunity to utilize the newly established AFSOTC to take on this responsibility. If properly done, AFSOC can benefit from moving training to the AFSOTC. However, if proper resourcing cannot be secured, then the training should not be moved to AFSOTC.

Notes

1. Air Force Instruction 36-2232, *Maintenance Training*, 22 February 2006, 41.
2. *Ibid*.
3. Headquarters Air Force Special Operations Command, "*MC-130H Maintenance and Munitions Manpower Statement*," Hurlburt Field, Florida: HQ AFSOC/A1M, February 2008, 17-19.
4. Air Force Portal, "Air Force Special Operations Training Center," [Online] Available: https://www.my.af.mil/gcss-af/USAF/ep/globalTab.do?channelPageId=s6925EC1331650FB5E044080020E329A9.
5. *Ibid*.
6. Headquarters United States Special Operations Command, *2007 Mission Guidance Letter* (unclassified extract), Tampa, Florida: HQ USSOCOM, 2007.
7. Colonel Paul Harmon, Air Force Special Operations Training Center, "AFSOTC Master Plan," briefing, Headquarters AFSOTC, 7 May 2008, Slide 3.
8. AFSOC Programming Plan 08-03, "Establish the Air Force Special Operations Training Center (AFSOTC)," 15 August 2008, 6.
9. Colonel Paul Harmon, Slide 5.
10. *Ibid*.
11. Colonel Paul Harmon, Slides 5-27.
12. Colonel Paul Harmon, Slide 27.
13. Author's interview with Colonel Mark B. Alsid, Commander, Air Force Special Operations Training Center, 30 November 2009.
14. Colonel Paul Harmon, Slide 15.
15. Author's interview with Colonel Mark B. Alsid.
16. Major General Kurt Cichowski, "Air Force Print News Today, " speech, AFSOTC Change of Command, Hurlburt Field, Florida, 18 August 2009.
17. *Ibid*.
18. Air Force Instruction 36-2232, AMC Supplement, *Maintenance Training*, 10 March 2008, 56-57.
19. Colonel Paul Harmon, Slides 4-29.
20. Author's e-mail from Master Sergeant Maurice Plummer, Chief, Detachment 17, 317 TRS, Cannon AFB, New Mexico, 2 December 2009.
21. Although the test shows promising results, it is not yet conclusive and therefore not complete.

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We now know the dominant weapons on the battlefield are the ones that can be mass-produced, operated by motivated fighters, kept in action with spares and supplies, and used in concert with other weapons. In the words of General George S. Patton, "How easily people can fool themselves into believing wars can be won by some wonderful invention rather than by hard-fighting and superior leadership."

Rewind

Readings in Logistics

From First to *Wurst*: The Erosion and Implosion of German Technology in WWII
General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman
How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944
Murphy's Law

In this edition of the *Air Force Journal of Logistics* we continue "Rewind: Readings in Logistics." This continuing feature presents articles and essays previously published in an edition of the *Air Force Journal of Logistics* or one of the Journal-produced books or monographs. The feature includes articles that encompass three areas: historical perspectives, contemporary thought, and studies and analyses. Both the current and future content of the feature were selected for two basic reasons—to represent the diversity of ideas and to stimulate thinking. That's what we hope you do as you read the material. Think about challenges. Think about the lessons history offers. Think about why some things work and others do not. Think about problems. Think about organizations. Think about the nature of logistics. Think about fundamental or necessary logistics relationships. Think about the past, present, and future.

The feature also provides a convenient source of material for mentoring and discussing logistics and logistics issues with new Air Force logisticians.

All of the articles and essays for "Rewind" in this edition were published in *Thinking About Logistics 2009,* Air Force Logistics Management Agency, Maxwell Air Force Base, Gunter Annex, July 2009. Copies of *Thinking About Logistics 2009* may be obtained free of charge from the Journal staff.

Lieutenant Colonel Charles A. Pryor III, USAF

From First to *Wurst*: The Erosion and Implosion of German Technology in WWII

In the Beginning

At the outset of the German buildup for World War II, the Germans were, arguably, the most technologically advanced nation in the world. Despite the limitations in the Treaty of Versailles, they secretly designed and built some of the most advanced aircraft in the world. From research into all metal aircraft, such as the Junkers Ju 52,[1] to the Messerschmitt Me 262, the world's first jet fighter,[2] the Germans were on the technological front lines. Yet, in a scant 10 years, the German nation ceased to exist. After the war, with its country divided in two, the technological advances were divided among the conquering powers. Indeed, the battles 5 years later between the Mikoyan-Gurevich MiG 15 and the F-86 were more among German engineers than among the nations actually at war.[3] The reasons for the implosion of the German state are manifold, two of which are addressed herein.

From a technological standpoint, many of the German designs and innovations remain valid. They were the true innovators of some of the world's current aircraft. Indeed, the Germans pioneered the use of wind tunnels, jet aircraft, pusher propellers, metal aircraft, and rockets in an attempt to overwhelm their Allied adversaries. Under the guise of Operation Paperclip, many German scientists and engineers were brought to America to work their magic on the American industry. Despite all this talent and its potential, few of the German designs were actually used during the war. Although their relevance is unquestioned, especially in view of current American (and worldwide) aircraft, they were untapped by the German leadership.

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The German management system, especially in terms of the technological industry, was a complex and convoluted bureaucratic nightmare. Their system of committees and rings, coupled with a lack of centralized control at the top, served to undermine an economy that was resource-poor, in terms of both monetary and natural resources. This mismanagement, exacerbated by the effects of the Combined Bomber Offensive, transformed the German industry from one of the best to one of the worst, a system ready to implode had it not been helped on by the Allies. Further compounding the situation was the influence of Adolf Hitler. A man with a continental worldview and a penchant for doing things his way, Hitler was more of a hindrance to industry than a help. His constantly changing requirements led to costly and lengthy delays to the production of many aircraft. His inability to look beyond continental Europe from a practical standpoint ensured the German state never had a practical long-range bomber until it was too late. Indeed, the Germans ended the war with the same fighter and bomber with which they began the war, with only minor modifications and a dwindling ability to mass-produce them.

Many of the lessons from the German experience with technology and management are applicable today to the US Air Force. Without a doubt, today, the United States is the technological superpower of the world, yet it is plagued by many of the same problems that the Germans faced. Many of America's technological advances seem to be done for the sake of technology, rather than for an operational military need. Indeed, many of the needs of the American military may be met, in the short term, with existing technology or modifications thereto, rather than new programs. The true transformation of the American military and its technology will be a departure from the stovepipes of military acquisition, in which each Service acquires its own (often redundant) systems, to a process of standardization among the equipment used to meet each Service's needs. Furthermore, American military management is becoming as complex as that of the Germans. True, Americans have much more to worry about than the Germans; for example the whole, poorly understood realm of space. The United States tends to solve its lack of understanding with additional bureaucracy, which exacerbates the overall situation. Alignment under a specific, overarching unified command could eliminate some of the waste and ensure an interoperable, standardized force for the future. Indeed, if the Department of Defense (DoD) does not learn and heed the lessons of the past, it is doomed to repeat them.

This article examines the efforts and impacts of German technology, both during World War II and today. Furthermore, it examines the impact and folly of German management of the technological industry and that industry's subsequent implosion. Finally, this work draws some parallels between the World War II German system and the current American system, fully recognizing the difference between the totalitarian German state and the democratic American state. Despite the glaring and obvious difference between the two, there are similarities that could have a negative impact on America's ability to wage war.

Technical Marvels

At the outset of World War II, the Luftwaffe was, undoubtedly, the world's supreme air force. It had the most advanced fighter and bomber aircraft and the best trained crews. Despite this, the Luftwaffe suffered severe losses during the course of the war, including the loss of air superiority over continental Europe, which led to the downfall of the Third Reich. Its loss can be attributed to several factors, not the least of which was its inability to take advantage of, or maintain, the technological superiority enjoyed at the outset of hostilities. The technological superiority was not limited to aircraft fielded during the war but includes some interesting technical innovations that arose during the war but not fielded by the Luftwaffe. Many of these technical innovations are just now being exploited to their fullest potential. Indeed, many of the technological innovations taken for granted today were first developed in the factories and design laboratories of Messerschmitt, Heinkel, Arado, Focke-Wulf, Henschel, and Junkers. These companies—and the designers for whom they are named—were at the forefront of technical innovation during not only their time but also current times. Many of their innovations—such as canards, boundary layer control, sweptwings, variable wings, jet engines, and more—are widely used today and accepted as industry standards. By examining Luftwaffe technological innovations, we can see a clear inspiration and technological marvel that transcends the aircraft industry today and whose impact is just being realized.

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Wind Tunnels

One of the most enduring innovations of the Luftwaffe was its pioneering work with wind tunnels.[4] These devices allow an aircraft, or representative model, to be tested under conditions closely simulating those encountered during flight. By using inexpensive scale models of the aircraft, the engineers were able to determine if their design could withstand the rigors of flight across the spectrum of the flight regime. By varying wind velocity, the German engineers were able to simulate high- and low-speed flight regimens. Similarly, by varying wind velocity, they could examine high and low angle-of-attack regimes. By combining the results of these two areas of study, they could determine the robustness and feasibility of the design in relative combat situations. The essential information that arose during these tests was the feasibility of the design, answering several fundamental questions: would the wings remain attached at high speed and high angle of attack; would the aircraft stall at low speed and high angle of attack; what are the impacts of adding externally mounted items to the aircraft; what would happen to the aircraft once an externally mounted device was dropped (would it become unstable, thus unflyable); and what are the impacts on the aircraft center of gravity? These are fundamental questions concerning the flight worthiness of the aircraft that could be ascertained without having to risk the loss of a prototype or pilot.

Additionally, wind tunnels allowed for the testing of new technologies to smooth the flow of air across the wing. The Germans tested boundary area fences, leading-edge flaps, and boundary layer control, all in an effort to affect the flow of air across the wing surface.[5] With the straight, perpendicular wing style of the day, these aerodynamic controls would ensure the flow of air across the top of the wing was as smooth as possible, thus making the airflow faster and generating more lift. This increase in lift would generate more maneuverability in fighters and more load capability in bombers and more range in both types of aircraft. They tested each of these on many of their experimental designs, but the results of this work only were beginning implementation at the end of the war.

Although the wind tunnels continued to operate throughout the war, their later years' usage was confined to refinement of the V1 and V2 rocket designs. Their staffs were increased in numbers, although those numbers were not used for testing; rather, they were used to mass-produce both weapons. The wind tunnels did stop work during the war after Peenemunde was bombed during the Combined Bomber Offensive, but this was only a brief work stoppage. Once the wind tunnels were relocated to Kochel, they were operational again. Despite this extraordinary testing, the German leadership was determined, by 1944, to focus all efforts on the defense of the Reich. Thus, the tunnels were not utilized to their full potential. The efforts of the personnel assigned to the tunnels were focused solely on one weapon system, not toward testing new technologies or capabilities. This failure to take full advantage of their technological capabilities is a true failure of the German leadership.[6] Indeed, the Germans missed out on several opportunities to exploit fully the wind tunnels, especially in the area of wing design. In this case, the designs were robust and innovative but were not tested by the Germans. Many designs were not tested and developed until long after the war.

The Wings of Man

To increase range and speed, one of the most enduring German technological innovations was the sweeping of wings. During the war, the Germans experimented with a variety of wing sweeps and designs, many of which are prevalent today. Indeed, the most enduring innovation of the Luftwaffe engineers was the rear sweep to a wing, which was found on many of the experimental aircraft designed during the war period.[7] Again, with an eye toward speed and range, the rear sweptwing offers a unique way of increasing lift without increasing weight. By canting the wing aft, the actual lifting area of the wing increased because of the distance the air must flow over the wing. This is done without increasing the surface area of the wing and incurring the corresponding weight penalty, resulting in an aircraft that has greater speed, payload capacity, and range (although all three must be balanced).

The tradeoff with this, however, is limited low-speed maneuverability. The reason here is the specific area where lift is generated. As with all perpendicular and rear sweptwings, the actual lift is generated at the wingtips due to the directioning of the laminar (air) flow over the wings. With perpendicular wings, this lift is approximately abeam the center of gravity on the aircraft, allowing low-speed flight and relatively high angle of attack. With rear sweptwings, the lift is aft the center of gravity, making low-speed flight unstable, thus dangerous. Therefore, by sweeping the wings aft, they were able to gain speed, lift, payload, and range while trading off low-speed maneuverability. The question the German engineers faced then was how to keep these increases without sacrificing the low-speed regime. Their answer was twofold: increase power (without the weight penalty) and change the sweep of the wings in flight.

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One of the earliest proposals, although the Germans never flew it, was a swivel wing. Designed by Blohm and Voss, the idea was to have a single wing that would rotate from perpendicular to canted, depending on mission flight parameters.[8] This aircraft then would be able to take advantage of the low-speed characteristics of a perpendicular wing as well as the high-speed characteristics of a canted wing (less drag, more lift). This concept, although viable, was not proven until the National Aeronautics and Space Administration flew an oblique wing on the Ames AD-1 research aircraft in 1979.[9] Another wing technological approach to overcome the low-speed and high-speed maneuverability tradeoff came through the use of variable sweptwings. Familiar today for application on the F-14 Tomcat, the variable sweep technology is designed to move both wings from a perpendicular configuration at low speed to a rear swept configuration at high speed for the aforementioned reasons. A similar variation yielded the experiments into a solid delta-wing configuration, which consisted of a swept leading edge with a perpendicular aft edge and solid material in between, which yielded some successes but not until long after the war ended.[10]

One of the technological innovations the Germans actually flew in prototype was forward sweptwings. In this instance, Junkers took a conventional wing and swept it forward instead of rear. Coupled with jet engines, this aircraft more than compensated for the low-speed maneuverability liability of rear sweptwing aircraft.[11] By sweeping the wings forward, Junkers changed the lift characteristics of the wing. No longer was lift generated at the wingtips, but with forward sweptwings, lift was generated at the wing root, which was adjacent to the center of gravity. The drawback to this design was the directioning of the wingtip vortices. In rear sweptwing aircraft, the vortices generated by the wind movement across the wing (a spiraling whirlwind) are directed across the wing and behind the aircraft causing little effect to the handling. In the case of the Ju 287, these vortices were now directed along the wing toward the fuselage, making high-speed or high-angle-of-attack flight dangerous. During high speed or high angle of attack, the vortices would overcome the elasticity of the wing, causing the wing to twist off. This difficulty was not overcome until the American X-29 program in the 1980s. Although not currently used, forward sweptwing technology provides a short-term capability, one that is already proven.

All these experiments into increasing speed, range, lift, and payload were never incorporated into the German production. Many were exploited after the war, however, and remain in use today. Facing an ever-expanding war situation, Hitler issued a series of Fuehrer directives in September 1941 that curtailed work on nonessential projects.[12] Hitler's continental worldview was coming into direct conflict with his strategic expansions. By attacking Britain and later Russia, Hitler overtaxed his economic capability to conduct a strategic two-front war.[13] His economic focus switched to producing existing technologies en masse to stem the staggering losses of his overreach. In essence, he sacrificed quality and innovation for quantity.[14] This is prevalent throughout the Germans' technological innovations.

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My Grandma Wants to Fly Jets

The second technique available to the Germans for increasing the lift, speed, payload, and range of their aircraft was to couple the rear sweptwings with jet engines. These engines were able to generate much more power than their propeller counterparts and could run on alternate fuels.[15] Although Messerschmitt was the first company to produce a jet aircraft, the first to design and test-fly one was Heinkel.[16] Heinkel actually began his research with the experimental He 178 by coupling jet engines with a perpendicular wing as a planned proposal for a two-engine fighter contract. This never panned out for Heinkel,[17] but Messerschmitt was able to couple the jets with a rear sweptwing design that became the Me 262, the world's first jet fighter. Alas, the Me 262 never entered full production, primarily because of an argument between Hitler and General Adolf Galland over its specific role. Galland argued for the Me 262 to be a pure fighter aircraft, but Hitler was interested in making it a fighter/bomber. This led to a redesign of the Me 262 from fighter to fighter/bomber and back to fighter toward the end of the war.[18] The Me 262 did see some action against Allied bombers, but this was very late in the war, and it did not have much impact on the outcome of the war. Although a successful design, the Me 262 was fraught with powerplant problems. The Jumo 004, the primary jet engine of the time, had a service life of 4-5 hours before it had to be replaced, making the maintenance and logistics of this aircraft cumbersome.[19]

Messerschmitt and Heinkel were not the only ones to experiment with jet engines. Arado had an impact on the US Navy F7U-3 Cutlass of the Korean era.[20] The centrifugal jet engine developed by Focke-Wulf became the primary powerplant for the Yakovlev Yak 15, the first Soviet jet aircraft, used during the Korean war era.[21] Arado also had success with the Ar 234, the first high-altitude, jet-powered reconnaissance airplane.[22] This aircraft was the precursor to the SR-71 Blackbird and the U-2 Dragon Lady. Although these designs had impacts after World War II ended, only the Me 262 was produced in any appreciable quantity by the Germans, and this was late in the war, after the war had been lost.

The Eyes Have It

In addition to out-of-the-box thinking on aircraft design, the Germans were also the first to field and operate an instrument system, both for their own airfields (a precursor to the current instrument landing system [ILS]) and for directing their planes to a target. The first was the Lorenz beam system for blind landing, which consisted of two transmitters located on opposite sides of the airstrip runway. Both transmitted in simplified Morse code, one solely dots, the other solely dashes. The spacing of the dots and dashes was such that, where beams overlapped, a continuous tone was heard.[23] By moving left and right until the continuous tone was heard, the pilot would be aligned directly on the airstrip center line. Thus, in conditions of restricted visibility, the pilots could find their airfield. The limitations of the system were many. It did not take into account crosswinds or turbulence.[24] However, as pilots became skilled in the operation of this system, they could compensate for these difficulties and keep the continuous tone.

The other disadvantage to this was the lack of altitude information. The beams would guide a pilot to the airstrip, but in conditions of zero visibility, they did not provide altitude. This can be overcome by the directioning ability of the transmitters. Essentially, the overlap portion of the beams (the area with the continuous tone) was conical. As the pilot flew toward the airfield, the cone narrowed toward the centerline. Thus, the absence of a tone could indicate the pilot was too high, and he could compensate accordingly. All in all, it is a risky system, but it is better than nothing. Without this, the pilots would have to divert to another airstrip, one not weathered in, which further added to the distance they needed to fly. This became a significant factor during the Battle of Britain when the German fighter escorts were flying at their maximum radii. Any additional flight time or distance could prove disastrous.

The offensive adaptation of the Lorenz system was known as the *Knickebein* system. Designed to be a long-distance target designator for use during night bombing, the Knickebein system consisted of two Lorenz transmitters, one that looked at the target along the ingress line, the other at the target from the profile. The pilots, using the Lorenz system in reverse, would fly away from the first transmitter while maintaining the steady tone in their headphones. Once they were in range of the target, they would switch to the frequency of the second transmitter, while occasionally checking with the first transmitter to ensure they were still on the proper vector. When the second transmitter gave them a steady tone, they were directly over the target and could release.[25] A subsequent refinement of this system, known as the *X-Geraet*, followed the same logic as the Knickebein system, with some refinements. Instead of using the beam intersection to mark their target, the pilots would fly the original beam toward the target. The second transmitter was actually a collection of transmitters, each of which would broadcast on a particular vector. Where each beam of the second transmitter intersected the first beam, the pilots had to hack a certain distance from the target. The *X-Geraet* pilots then would drop flares to literally light the way for the planes that followed.[26]

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A further refinement of this technique was the Y-Geraet system, receiver and transmitter combination, where the aircraft will fly a designated vector and periodically retransmit a signal from the ground transmitter. A ground receiver would pick up the retransmitted signal. By calculating the phase shift, the difference in time between the transmitted and received signals, ground controllers had a picture of whether or not the pilot was on vector and could correct their pilots accordingly.[27] This type of ground control (although not the *Y-Geraet* style system) is used today by the ground tactical air control squadrons.

The advantages of these systems, despite their drawbacks, are obvious from the German point of view. They had the ability to direct and control their aircraft as well as recover them in less than optimal conditions. These systems also facilitated night bombing, which adds a psychological effect to the physical effect and destruction. From the British point of view, these systems were of import as they were easy to overcome. Radio frequencies operated over long distances are easy to disrupt once the transmit and receive frequencies are known. The Germans kept their systems simple, using dots and dashes on prescribed frequencies, but the British overcame this by inspecting aircraft that had been shot down. The British did not need to know what to listen for once they had the frequency. Using a technique known as meaconing, whereby the British flooded the various German frequencies with extra traffic, the British were able to defeat the Knickebein and *X-Geraet* systems.[28] To overcome the *Y-Geraet* systems, the British merely jammed the frequency.[29] Despite their limited operational life, these systems were the predecessors to the current ILS and radar systems, both of which allowed for night bombing. As the Combined Bomber Offensive demonstrated later in the war, the Allies were able to keep pressure on the German homeland through daylight bombing by American planes and night bombing by British planes. Without radar and ILS, these night bombings would not be possible, providing the Germans with time to reconstitute or continue production without feeling the effects of bombing.

Subsequent Aircraft Technologies

Faced with the challenge of designing aircraft that could outperform their enemies, the German engineers looked at ways to improve the speed, maneuverability, and altitude of the fighter force. The root reason for this work was the theory that to defeat the Allied bomber streams they would have to attack them at their weakest point, which was from above. Thus, they needed aircraft that could fly at extreme altitudes. In addition to their work on jet engines, the Germans looked at ways to improve propeller-driven aircraft. One of the technical solutions to this problem was fielded in their fighter force. They replaced the old radial air-cooled and liquid-cooled engines with a high-compression piston engine. Essentially a sealed, self-contained engine that was not dependent on a bladder of coolant, this engine allowed fighters to perform negative *g* or inverted maneuvers.[30] This gave them a significant maneuvering advantage when engaging enemy formations. Additionally, this engine would increase the performance envelope of the bomber fleet, allowing them to fly farther than they could with the radial engines. Alas, the performance increase in bombers was not enough to have a significant impact on the war, but the impact of the souped-up fighters was felt. The Allies were able to counter this added threat; however, the Germans succeeded, at least initially, in almost equaling the score with their fighters. Additionally, by examining defeated aircraft, the Allies were able to capitalize on German technological advantages.

Another engine modification fielded by the Germans in limited numbers was a relocation of the engine and propeller. Some of the German aircraft that flew as prototypes had pusher-type propellers. Located at the rear of the fuselage, these pusher propellers were more efficient in terms of fuel usage than traditional puller propellers. The Germans were never able to capitalize much on pusher-propeller aircraft during the war because of their management practices, but the pusher propeller is in use today on long-duration aircraft such as the Predator. Although these were significant technological innovations, ones that have endured and are still in use today, the Germans were unable to capitalize on them because of their failure to properly implement modernization and upgrade their aircraft fleet. As indicated earlier, the German industrial capability was stressed to maintain production of existing aircraft to counter the Allied mass of aircraft. This left nothing for development of new technology.

This led to an explosion of new project activity unequalled in the history of aviation, an explosion that was fueled even further in 1944 by the lifting of all patent protection.

The interwar years saw the rise of Lufthansa as a commercial airline of the Weimar republic. Headed ostensibly by Hugo Junkers, the main workhorse of the Lufthansa commercial fleet was the Ju 52, an all-metal commercial airliner. The Ju 52, pressed into service during the war as both a cargo aircraft (people and materiel) and a limited bomber, had the capability to carry more items than the previous wood and canvas aircraft. To offset the additional weight, Junkers put on a third engine. This venerable aircraft saw service throughout the war, although primarily as a cargo and troop carrier, eclipsed in the bomber role by the He 111 and Ju 88. Nevertheless, most aircraft built during the war were made of metal, thus more robust and survivable than the previous wood and canvas design. The use of metal aircraft also allowed German engineers to examine the possibility of pressurized cabins.[31] During the war, pilots who flew above a certain altitude were required to use oxygen to counteract the effects of altitude. As an aircraft rises in altitude, the oxygen concentration in the ambient air lessens. If an aircraft flies high enough, it can lead to oxygen depravation, causing the pilot and crew to black out. With the advent of pressurized cabins, the aircraft would be able to fly higher without the requisite oxygen aboard. By pressurizing the cabins, the ambient air within the cabin maintains the same oxygen concentration as it would sitting on the ground, negating altitude sickness and oxygen depravation. Although the Germans never fielded this, it is in wide use in all aircraft applications today.

Good Ideas, But...

Throughout World War II, the Luftwaffe sought to maintain its technological superiority over the Allied forces by designing capabilities into their aircraft that would allow them to fly higher and faster than the Allied aircraft.[32] This led to an "explosion of new project activity unequalled in the history of aviation, an explosion that was fueled even further in 1944 by the lifting of all patent protection."[33] The German aircraft industry was populated with some of the premier engineers and designers of the time who were able to come up with some truly revolutionary ideas for designing and building aircraft. The Germans were the first to design and use jet engine aircraft, metal aircraft, instrument navigation, sweptwing technology, and advanced testing through wind tunnels. Some of their more radical designs, such as the Gotha flying wing concept,[34] would not be realized until many years after World War II. Indeed, many of their innovations were picked up quickly by the Allied forces. Bower astutely notes:

> Since 1945, the genesis of weapons by all four Allies has been dominated by the inheritance of Germany's wartime inventions. Indeed, the Korean War can be viewed, on the technical level, as a trial of strength between two different teams of Germans: those hired by America and those hired by the Soviet Union. The aerial dogfights between the Soviet MiG-15 and the American F-86 Sabres—both designed by German engineers—dispelled for many their doubts about the expediency of plundering Germany's scientific expertise.[35]

Thus, the Germans did not lack grand and effective technological innovation. Yet, they were resoundingly unable to take advantage of this situation and were completely unable to bring these revolutionary concepts into operation. The reasons for this are manifold, but the centermost reason for their inability to exploit their technological superiority lay with the complex, convoluted, and inefficient management system in place in Germany during World War II.

Management for Dummies

One of the most overlooked practices in the business of technological innovation is the impact of management on the overall process. Management of technology is crucial to the successful implementation of revolutionary ideas and processes. Management needs to be not only knowledgeable about the designs and ideas of the engineers but also receptive to them. Management needs to provide a roadmap to what is to be accomplished. Without clear-cut direction, meaning a vision and goal, not micromanagement, any technological advance is doomed to irrelevance. An overall strategy will provide the engineers with the proper vector to direct their abilities and ideas. Furthermore, management needs to provide clear and unambivalent boundaries to the efforts of the engineers to ensure the technological innovations and ideas stay focused and attainable. Finally, the management structure needs to be streamlined and simple to allow ideas to flow not only laterally but also vertically. Binding management to a complex and suffocating bureaucracy will have the same effect on the industry as a whole.

Alas, the Luftwaffe found itself in just such a predicament during the war. It had a complicated and convoluted approval process for the technological advances forwarded, one that was wasteful of not only resources but also time. It had little strategic direction and no boundaries on the effort to advance technology. It also had the wrong people in charge of the various agencies that headed up, collectively, the overall effort. The result was a host of revolutionary innovations that would have all but guaranteed they remained technologically superior but were doomed to be merely paper tigers by the bulging management process and poor leadership. These paper tigers were exploited by the Allied powers after the war, but the Luftwaffe was unable to take advantage of them. The overall operational result was an air force that ended the war with the same equipment with which it began, quality equipment at the start but obsolete in 1945 when compared with the equipment of the Allies.

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Who's in Charge?

At the core of the management of Luftwaffe technology was Hermann Goering. As Hitler's duly appointed head of the Luftwaffe, he was responsible for ensuring the Luftwaffe had the necessary tools to prosecute the war. The Luftwaffe was responsible for determining its own requirements to ensure it could fight. Similarly, the navy and army each had that responsibility. While this is to be expected, what was lacking in Germany overall (and the Luftwaffe, in particular) was centralized control. There was no one agency in charge of military procurement. Indeed, "production was pitifully small. The fault lies clearly with the Technical Office whose lack of initiative cannot be ignored and with the Luftwaffe General Staff … which failed completely to provide the guidance expected of it."[36] Thus, there was no direction, no vectoring of the effort to ensure the proper item was developed. In other words, there was no one in charge.

Further complicating the effort was the process for placing something on contract. The Luftwaffe would award a production contract for an aircraft based solely on its design.[37] This essentially skips the research-and-development portion of modern-day acquisitions, with the Luftwaffe assuming the risk that the design will not work. In many cases, the prototypes developed did not meet expectations (or requirements).[38] Thus, large quantities of resources were spent and expended for something that did not work. This is an incredibly ineffective way to manage a contract. Further increasing the drag on the resources was the number of programmatic changes enacted. With the swift progress of the war and the swifter progress of implementing minor technological changes, the German factories and modernization centers were hard-pressed to keep up.[39]

Finally, to keep the costs from escalating beyond what was already wasted, the Germans enacted price fixing for the industry. Essentially, a contractor could choose one of three pay categories: one which they were not taxed (but had to be a low contract bid), one where they were taxed, and one where they were taxed and some of their costs recouped. The latter only could be chosen with approval from the government.[40] In essence, from a fiscal point of view, German management of the contract process was a shambles. Valuable resources were wasted by betting the design would work, and the designs were changed constantly, costing more resources and further straining an industry that was undermined by fixing prices to the advantage of the government. This poor fiscal policy was further convoluted by the complicated organizational structure of the German industry.

Early German industrial organizational structure was an attempt to maintain centralized control over industry as it attempted to shift to a wartime footing. In each of the industries of the Third Reich was one person at the head. Directly beneath the head was a main committee, made up of the industry leaders. Ostensibly, the function of this main committee was to evaluate the way each of the companies in the industry did business, select the best from each, and have all factories implement these best practices. Further refining this process, there were special committees under the main committees that dealt with specific parts of the whole. These special committees were also responsible for implementing best practices among their subordinate factories in an effort to increase standardization and efficiency and reduce cost.[41] In theory, this seems to be a sound business practice; however, management by committee (or in this case, by many committees) was not very practical. When combined with poor fiscal guidance and a lack of strategic direction, this system merely complicated the problem.

Furthermore, in 1940, a system of rings was introduced into the industry. These rings were essentially committees but not limited to one industry. These rings were concerned with items and issues that transcended all industry. For example, the ring concerned with the making of steel would have an impact on all committees who used steel (which was all of them). The system that finally evolved consisted of "4 main rings for subcontracting and 8 main committees for the finished product."[42] Each of these committees and rings had subcommittees and subrings to them, further increasing the bulging bureaucracy. Known as Self-Government of Industry, this system could be effective in the hands of a skilled manager like Albert Speer. The armament industry under Speer became more efficient and productive[43] despite the complicated system. However, under managers like Karl-Otto Saur, the opposite happened. Indeed, as Goering stated:

> Saur was a man completely sold on figures. All he wanted was a pat on the shoulder when he managed to increase the number of aircraft from 2,000 to 2,500. Then the Luftwaffe was blamed that we had received so and so many aircraft and where were they.[44]

Unfortunately, for the Luftwaffe, this thinking tended to dominate the war-production effort. The result was a gross number of aircraft (quantity), many of which were unusable or obsolete (quality).

One of the toughest challenges faced by management in a technological industry is the issue of quantity versus quality. Both are important and must be effectively blended to have a successful program. Unfortunately, for a country whose industry was poorly managed and resource-constrained and faced with an enemy with a seemingly endless supply of high-quality equipment, the natural tendency to fight mass with mass (matching quantities) overrode the necessity to instill some quality in the airplanes produced.

Quantity Versus Quality

One of the toughest challenges faced by management in a technological industry is the issue of quantity versus quality. Both are important and must be effectively blended to have a successful program. Unfortunately, for a country whose industry was poorly managed and resource-constrained and faced with an enemy with a seemingly endless supply of high-quality equipment, the natural tendency to fight mass with mass (matching quantities) overrode the necessity to instill some quality in the airplanes produced.[45] The result was a large number of inferior aircraft that could not have kept pace with the Allies, even if they were numerically similar. In mortal combat, quality is often the divide between success and failure. This was proven by the Tuskegee Airmen flying bomber escort from Italy. Although the number of P-51s sent to escort a bomber formation did not change drastically, they still escorted more than 200 missions without a single bomber loss. This is attributed to both the skill of these pilots and the quality instilled in the machines they flew. Alas, the Germans did not have the quality in their aircraft to overcome this.

By war's end, the Germans had lost the technological superiority they owned at the beginning. Although this can be directly attributed to their management system, this issue was further exacerbated by their failure to integrate the capabilities of the captured lands effectively. Indeed, rather than capitalizing on the capabilities of the workers in the conquered lands, the Germans merely plundered them and brought their populations into slave labor.[46] They failed to realize and take advantage of what was available to them. The result was a slave workforce that resented its masters. Needless to say, this was another cause of their diminished quality. Finally, as the war progressed, the Germans began conscripting just about any male with a pulse, regardless of his civilian expertise. This led to a lack of skilled workers, without whom quality suffered.[47] This is almost a double tap for quantity over quality—specifically, make the armed forces larger to counter the large force regardless of special (or needed) skills, depriving industry of the skilled workers necessary to instill quality in products sent to the armed forces.

However, equipment was not the only area in which quality suffered. As the war progressed, training for pilots was cut almost in half, primarily because of the need to have replacements for pilots lost in combat. The result was pilots significantly less skilled than earlier groups that entered combat. Poorly trained pilots, flying inferior equipment against a determined enemy on two fronts, is a sure recipe to create an even greater need for replacement pilots. In short, the German economy and industry could not keep up with the demands of a two-front, widely flung war and elected the desperation strategy of throwing everything it had into the fray, regardless of training or expertise. The result is obvious.

Although the complicated nature of industry organization is certainly a contributing factor to the inability of the Germans to exact victory, the lack of management and leadership from the top down definitely compounded the problem exponentially. Without a sound and appropriate strategy or roadmap, anything attempted has the distinct probability of failure. From the beginning, the German strategy focused on Europe and a blitzkrieg style of warfare. As Hitler's aspirations grew (and the war with them), the overall German strategy failed to take these new ideas into account.

Strategizing

From the beginning, the Nazi party rose to power in Germany under the guise of nationalism. Many Germans were still upset over the limitations imposed by the Treaty of Versailles at the end of World War I, in particular the clause that laid the blame for World War I and the resultant carnage squarely on the Germans. Additionally, the German people were adamant about reclaiming the land annexed away from them by the Treaty of Versailles. Undoubtedly, there were also some bad feelings about the French, who were seen as most responsible for the War Guilt clause. Thus, there were some strong feelings of being unfairly and cruelly treated in the aftermath of World War I. This was exacerbated further by the inability of the Weimar Republic to effectively fill the void left by the abdication of the Kaiser. The general disgruntlement of the German people led to a fierce feeling of nationalism and a desire to put someone into power who could actually do something about their situation.

Since many of the battles took place within easy distance of Germany, there was no need to delay the production of aircraft to build and stock spare parts; they would just make another airplane to replace the damaged or destroyed ones.

Enter Adolf Hitler, a recognized and decorated World War I veteran who had the charisma and rhetoric to rouse the population. Simply put, he knew what to say and had a forceful enough presence to ensure the people believed him. After his election to chancellor and the death of President Paul von Hindenburg, Hitler combined the two offices into that of Fuehrer and began to attempt to make good on his nationalism pledges. Realizing one of the reasons for the German defeat in World War I was the failure to generate the economy to a war footing, the Third Reich began increasing its economic capability.[48] Ostensibly, this was to continue the nationalistic regaining of indigenous German lands unfairly removed from them. This included the German pushes into Austria; the Sudetenland; Czechoslovakia; and ultimately, Poland. This desire to increase their *lebensraum*, or living space, was risky, however. At any point, the Allied powers (then Britain and France) could respond.

Hitler was emboldened during the operations prior to Poland by the lack of Allied response to his offensives. He assumed they would continue their policy of appeasement after the Poland campaign, especially after he signed a nonaggression treaty with the Soviet Union. Allied appeasement ended with the invasion of Poland, and both Britain and France declared war on Germany. Hitler was ready for this, however, and ordered his troops into France, occupying, in short order, about two-thirds of France.

From here, things began to go south for the Reich, despite their strong army and technological superiority. Up to this point, every campaign engaged in by the Germans had been a blitzkrieg-style campaign:[49] hit the enemy hard and fast to overcome their defenses and then bring them into the Fatherland. As such, the German economy was geared to this type battle. There was reconstitution time between the battles, giving the economy and industry time to recoup the losses. Germany's continental focus was driving its blitzkrieg strategy, and its economy was geared to this. Thus, it produced high-quality, short- and medium-range fighters and bombers in large quantities to accommodate the blitzkrieg of the enemy. Since many of the battles took place within easy distance of Germany, there was no need to delay the production of aircraft to build and stock spare parts; they would just make another airplane to replace the damaged or destroyed ones.[50] While this worked well at the outset of the war, its significance grew as the German battlespace expanded greatly. Compounding this, pilot training was limited to tactical training only,[51] as there was no need to think beyond this level. Yet, with the onset of the Battle of Britain, the Germans changed strategy, whether or not they realized it.

Strategy Shift

World War II might have ended differently had Hitler elected to maintain his *lebensraum* policy and restrict his actions to continental Europe. Nevertheless, he attacked Britain, ostensibly to ensure the British stayed out of the war. From a tactical point of view, this was a huge mistake. To attack London, his fighters (upon whom the bombers relied for protection) had to operate at the limits of their range if they were to successfully return to France. In other words, he was now fighting a strategic war with a tactical force. Hitler had arbitrarily escalated things, a precursor of things to come.

As the war progressed, Hitler would return time and again to the concept of changing things to fit his worldview *du jour*, with no apparent thought to the impact on either society or industry. The most glaring example of his inconsistency concerns the Me 262, the world's first jet fighter. Originally designed as a fighter, Hitler ordered it changed to a fighter/bomber against the advice of Erhard Milch and Galland. The resultant delay to retrofit the Me 262 to a fighter/bomber ensured that, when it was ready for use as a bomber, the need was for fighters to defend the dwindling Reich. The Me 262, again at Hitler's insistence, was re-retrofitted back to a fighter, another delay to the program that ensured it was not introduced into the war until early 1945.[52] The argument over the Me 262, in which Goering sided with Milch and Galland, marked the beginning of the end of Goering's favor with Hitler. The result was a complete lack of Luftwaffe representation at future meetings.[53]

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After the loss in the Battle of Britain, Germany took a pause to recoup its losses; then Hitler made another large strategic mistake—he attacked the Soviet Union. Once again, he escalated the war effort to strategic levels with only a tactical industry and military. The results were disastrous for the Reich. They severely overextended themselves on the Eastern Front, which ensured their already fragile logistics support was stretched too thin. Additionally, the demands on industry for a two-front war were too hard to bear. In short, production could not keep up with losses, and there was almost no way to resupply the troops because of a lack of transport aircraft.[54] Finally, the German leadership severely underestimated the Allies' drive and dedication while simultaneously overestimating their own ability.[55] This ill-equipped armed force with little reconstitution ability, fighting a war that was larger than it was prepared for or capable of, with no clear written strategy and numerous changes to the direction of the effort, would have ensured the Reich imploded. However, the Allies were not content to take the time to allow this to happen. They decided to help it on its way through the Combined Bomber Offensive.

Allied Impact on German Strategy

The Combined Bomber Offensive was a massive push by American and British air forces to provide continuous day and night bombardment of the German homeland, focusing on its industrial capabilities. The American forces were responsible for the daylight bombing, the British for nighttime bombing. The Combined Bomber Offensive almost stopped before it started, primarily because of a lack of fighter escorts for daylight raids. The massive formations of B-17 aircraft were susceptible to the German fighter aircraft, and the resulting losses almost ended this aspect of the offensive. This changed with the introduction of the P-51, a highly maneuverable and capable fighter with range to escort the bombers all the way to their targets. These fighter escorts also served a second function, that of *attriting* the German fighter force—essentially a trench-style slugfest in the air. It was extremely successful in this second role, removing German air superiority over continental Europe and ensuring Allied planes could roam the European Continent with relative impunity.

The effects on the German industry are even more telling. In addition to other targets, the Allied offensive destroyed the German transportation network, severely limiting its ability to operate a dispersed industry. Furthermore, the Allies concentrated their efforts on the critical Ruhr valley, which was the location of German stocks of coal.[56] The coal was used as a power-producing source and critical to the German war industry. The effects of these raids were felt throughout German society and industry as it placed severe hardship on its already overstressed and limited supply of raw materials and transportation. Compounding the German situation, the Allies struck many of its fuel sources. Indeed, in the after-war interrogations, Goering admitted that fuel was a significant limiting factor to production, especially in the production of a four-engine bomber. In discussing the He 177, Goering said, "I had to ground that aircraft because it consumed too much gasoline, and we just didn't have enough for it."[57] Finally, the Allied attacks had a significant impact on the German industry's depots and production facilities.[58] The Combined Bomber Offensive was more than a combination of American and British bombing techniques. It combined with the Germans' inefficient and poorly managed industry to finally break the back of the German war machine.

Summing Up

Throughout the war, the German state was unable to take advantage of many of its indigenous capabilities. Beginning with decentralized control of their procurement process and abetted by a complicated and wasteful fiscal policy, the industry simply could not keep up with the demands of the war. Furthermore, its organizational structure was not conducive to change. Its system of committees and rings with all the subcomponents thereof was an attempt to increase efficiency and reduce cost through standardization of production practices. It actually did not happen that way, as it was a system that could not grow to fit the increased need. The Germans effectively proved that management by committee does not work in a wartime situation. Compounding this further were the people they placed in charge. With a few notable exceptions, the men selected to run the industry were party lackeys who had limited experience and know-how when it came to running an industry.

Strategic direction from the state leadership was completely lacking. What began as a continental campaign to reverse the perceived unfairness of the Treaty of Versailles rapidly expanded into a global strategic battle for world dominance, all with an economy that was geared toward a blitzkrieg-style tactical engagement. German industry was never able to recover from this continental focus, dooming the strategic efforts to failure. Furthermore, the personal and direct involvement of Hitler into all aspects of the war effort only served to confuse and befuddle the national leaders. In other words, absolutely no direction was provided to guide the war effort. This led to numerous production delays as aircraft were constantly fitted and refitted to meet the ever-changing requirements. Additionally, the German leadership had two key misconceptions that may have attributed to their constant change. First, they underestimated the Allies, and second, they overestimated themselves. The added impact of the Combined Bomber Offensive served to exacerbate an already deteriorating situation and helped ensure the 1,000-year Reich lasted a mere 12 years.

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Forward to the Future

As the US Air Force begins its fourth major transformation in 11 years, there are some striking similarities between what it currently faces and those challenges faced by World War II Germany. Notable among them is a strong sense of nationalism. No one can doubt the surge in American patriotism since the 11 September 2001 events, and one cannot overlook the sense of outrage and frustration at the horrific waste of human life and American potential. Yet, a parallel can be drawn between this and the general feelings of the average German during the interwar period. The Germans felt a sense of outrage and frustration at not only the loss of land but also the humiliation that accompanied the Treaty of Versailles. In hindsight, these feelings perhaps are justified, but the results for Germany were disastrous. Fortunately, the American people are not following the same political trend, nor could we, given our process for electing our officials and the constraints and restraints placed upon them.

Currently, there is no real centralized control over the US Armed Forces acquisition program. As it was for the Germans in 1935, the US Armed Forces currently follow separate stovepipes for acquisition of weapon systems. There are separate DoD programs for ballistic missile defense among the Army, Navy, and Air Force, as well as different programs for acquisition of unmanned aerial vehicles. The acquisition programs for the F-35 Joint Strike Fighter follow the same path, each Service pursuing its own agenda to meet its own needs. This was exactly the same at the beginning of the German buildup for World War II. Each service had its own unique requirements, and each pursued them independently of the other. The result was an egregious waste of valuable and limited resources, both natural resources and dollars. In essence, they ended up paying for essentially the same thing three times. It is the same today with the American military. We have separate programs for the X-45 Air Force unmanned combat aerial vehicle and the X-47 Navy unmanned combat aerial vehicle. Both are experimental, and both operate more or less independently of the other. The end result will be two unique systems that meet specific needs without addressing the overall interoperability between systems. While the Germans were not faced with each branch of the service creating its own flying machine, the overall competition between the Services for constrained resources and the inability of the leadership to differentiate, much less prioritize, among the service requirements led to incredible waste and effort.

Similarly, the US Air Force, today, faces much the same challenge as the Luftwaffe, specifically determination of mission and needs. As the Luftwaffe vacillated between a fighter and bomber, the same struggle goes on today in the US Air Force. With the cost of each individual unit escalating rapidly (because of the investment in technology), what is the priority, fighters or bombers, given that the United States really cannot afford both? Further complicating matters is the need to build tankers and lift aircraft. While the Luftwaffe merely ignored this, to its detriment, this remains a central concern for Air Force officials. While not a concern for the Luftwaffe, the American conundrum is compounded by the oft-overlooked integration of space into the battlespace. The items placed in space are extremely expensive and difficult to make, yet, paradoxically, are always there to aid the warfighters. As long as these systems continue to perform, they will be overlooked largely by people who do not understand their mission or importance until it is too late. All these compete for limited resources, those doled out with a medicine dropper by a dubious legislative branch. This merely compounds the larger issue facing the Air Force today, that of identity.

Since 1992, the Air Force has undergone four major transformations. The Air Force has evolved from the Cold War hallmarks of Strategic Air Command, Military Airlift Command, Tactical Air Command, and Air Training Command to the current configuration of Air Combat Command, Air Mobility Command, Air Education and Training Command, Air Force Space Command, and Air Force Materiel Command.

Transformations

Since 1992, the Air Force has undergone four major transformations. The Air Force has evolved from the Cold War hallmarks of Strategic Air Command, Military Airlift Command, Tactical Air Command, and Air Training Command to the current configuration of Air Combat Command, Air Mobility Command, Air Education and Training Command, Air Force Space Command, and Air Force Materiel Command. Designed to be functionally aligned, each command was changed to be a stand-alone force capable of operating within its own unique and nonoverlapping mission areas. The Air Force then transformed to the expeditionary air forces, an idea that creates ten stand-alone composite forces to handle regional situations worldwide. In essence, the expeditionary air forces are a combination of the functionally aligned major commands of today and the geographically aligned major commands of yesterday. Each air expeditionary force contains strategic and tactical elements yet draws from the respective major commands for expertise. Finally, the Air Force is transforming to a task-force-based concept, which is essentially a subset of the expeditionary air force designed to handle a specific contingency as it arises. All this combines to leave a large uncertainty about the mission and function of an air force.

When asked exactly what it is the Air Force does, the answer depends on when the question is asked or what is going on in the world. In other words, there is limited identity within the Air Force about its mission. This is exacerbated by the fact the corporate identity seems to change with each new Chief of Staff. As Goering's Luftwaffe provided little or no unique identity and mission to its members, so the Air Force faces the same dilemma. The result has been a restructuring of the Air Force from one that can fight an outmoded form of war to one that can survive in an outmoded form of peace. American worldview, like that of the German forces during World War II, has remained stagnant. While paying lipservice to a contingency-based, flexible, expeditionary force, the Air Force remains firmly locked in the planning and budgeting of a Cold War, two major-theater-war mentality.

The one issue the Department of Defense has handled well is the creation of the unified commands. Each command is designed to be a warfighter or a functional command with expertise in either a particular area of responsibility or a particular function. There is no overlap in responsibility (except for the functional commands, which operate somewhat autonomously of the geographic commands), yet each of the unified commands manages to share resources and information without regard to which component provided it. In many ways, this mentality needs to transcend the programmatic stovepiping in each of the military branches.

The issue of technology is becoming the forefront of American procurement and acquisition issues. As the Germans did in 1935, America now enjoys a technological superiority over friend and foe alike. At the present, there is no match for American technological know-how and application. Yet, this technology is only as good as its application. As the Germans found out, developing technology just because you can is a poor reason to carry out a government program. While the Germans had some technological innovations, such as jet engines and wind tunnels, many of their technological advances were not realized until after the Reich had vanished. Indeed, developments such as the Gotha P.60 flying wing-style fighter were not adopted until recently with the advent of the B-2 Spirit. The German programs were mismanaged from above almost from the start, including no boundaries on where technology could go. The American problem is more geared to including technology into *simple* problems, simply because it is possible. Many of the acquisition programs undertaken by the Air Force fail to consider the *low technology* or already existing technology approach, often at a large pricetag for a limited capability.

Further complicating the picture is the management of our acquisition programs. In most cases, for a new system, it can take 10-20 years from identification of the problem to fielding a system to defeat or answer the problem. Often, the items fielded are obsolete before they enter production because of changing world needs. Granted, the Department of Defense has not fallen into the pitfall that awaited the Germans; namely, changing existing programs to meet evolving needs. However, the Department of Defense tends to create a new program to handle a problem, which significantly compounds the ability to field forces capable of responding in the manner in which they are needed. Each of these programs will compete for existing, limited funds, resulting in a compromise that answers neither the existing problem nor the original problem. Additionally, the acquisition process is bureaucratically robust. Very little can overcome the inertia of the albatross (the bureaucracy) surrounding acquisition programs, and nothing gets through quickly. The Department of Defense has so many layers of management to get through that it becomes almost a self-licking ice cream cone when faced with an immediate and unforeseen threat. In certain rare circumstances, this inertia can be overcome, but these are the exceptions rather than the rule.

Finally, the American worldview is stagnant. As the Germans could not see beyond continental Europe, so the Americans cannot see below the strategic layer. The Germans could not see the forest for the trees, and America cannot see the trees for the forest. America still believes, despite the 11 September attacks, that it cannot be touched by a foe. Americans believe the way to counter potential foes is to apply a strategic, precision, lethal force. This may be true when it is a contest between nations, but in a contest between a nation and a nonstate actor, this meets limited success. Thus, America's worldview and its Armed Forces must be ready for strategic and tactical wars, both conventional and unconventional.

The real answer lies in establishing a warfighting entity that is impartial with respect to the Services' ability to handle the acquisition and technology programs for the entire Department of Defense. The logical choice is to place the integration of all military needs under the unified command tasked with determining the training and evaluation needs for Joint forces, United States Joint Forces Command. With its overarching view of all the unified commands, it is in the unique position to determine what is necessary to fight and win America's wars, both in terms of manpower and equipment. Furthermore, it should be charged with ensuring the interoperability of these programs to meet service-specific needs with minimal changes. In this time of limited resources and increasing needs, standardization is required without sacrificing individual service-unique needs. Additionally, a streamlining of the acquisition process is required to ensure timely answers to emerging needs. Without these changes, our system becomes almost as cumbersome as the World War II German system, a system that can (and in the case of World War II, Germany, did) implode if left alone long enough.

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Core values make the military what it is; without them, we cannot succeed. They are values that instill confidence, earn lasting respect, and create willing followers. They are the values that anchor resolve in the most difficult situations. They are the values that buttress mental and physical courage when we enter combat. In essence, they are the three pillars of professionalism that provide the foundation for military leadership at every level.

—Sheila E. Widnall, Secretary of the Air Force

I cannot trust a man to control others who cannot control himself.

—Gen Robert E. Lee, CSA

When the political and tactical constraints imposed on air use are extensive and pervasive—and that trend seems more rather than less likely—then gradualism may be perceived as the only option.

—Gen Joseph W. Ralston, USAF

Integrity is the fundamental premise for military service in a free society. Without integrity, the moral pillars of our military strength, public trust, and self-respect are lost.

—Gen Charles A. Gabriel, USAF

No form of transportation ever really dies out. Every new form is an addition to, and not a substitution for, an old form of transportation.

—Air Marshal Viscount Hugh M. Trenchard, RAF

Not everything that is faced can be changed. But nothing can be changed until it is faced.

—James Baldwin

Take calculated risks. That is quite different from being rash.

—Gen George S. Patton, Jr, USA

You miss 100 percent of the shots you never take.

—Wayne D. Gretzky

Your current safe boundaries were once unknown frontiers.

—Anonymous

Richard A. Hardemon

General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman

Alexander the Great

Alexander the Great is rumored to have wept upon the conclusion of his conquests because there were no longer any nations to conquer. To a large degree, it is true that at his height of power, Alexander was the ruler of the known world. The tales of his conquest take on a mythical grandeur in which he is located somewhere between a man and a god. "Alexander was in fact, a living myth, and unless we accept him as such we cannot begin to understand his history."[1]

Generalship and Military Professionalism

The almost superhuman view of Alexander is not a modern contrivance. In fact, throughout most of his life, Alexander was treated with godlike reverence.

> Led by a god they [the Macedonian Army] faced all dangers, and it was their faith in him as a supernatural world-hero, as much as his inborn genius for war, which made him not only the greatest of all the Great Captains, but which distinguishes him from all and each one of them.[2]

To a large degree, logistics concerns shaped Alexander's strategy and tactics. From the time of his initial defeat of Darius at Issus, through his campaign into Egypt, and his final defeat of Darius at Gaugamela (also known as the Battle of Arbela) Alexander displayed an acute awareness of the logistical requirements of his army.

This unparalleled allegiance to Alexander coupled with his genius for integrating logistics concerns into every facet of his military theory, doctrine, strategy, tactics, and administration enabled the support of a world-conquering army.

Alexander did not rise through the ranks but inherited his position from his father, Philip. Likewise he inherited a formidable fighting force without equal in the ancient world. Alexander's *professional education* was enviable, to say the least. He received instruction in strategy and tactics from his father and was privately tutored by Aristotle. The negative legacy of Philip and Aristotle's tutelage was their incredible hatred of the Persians, referred to by both Philip and Aristotle as the barbarians. However, Alexander seemed to rise above the hatred of his father and mentor and developed an attitude toward conquered peoples, even Persians, that was key in ensuring logistical support across the vast empire under his control.

Military Theory, Doctrine, Strategy, and Tactics

B. H. Liddell Hart characterized Alexander's logistics strategy as "direct and devoid of subtlety."[3] Moreover, to a large degree, logistics concerns shaped Alexander's strategy and tactics. From the time of his initial defeat of Darius at Issus, through his campaign into Egypt, and his final defeat of Darius at Gaugamela (also known as the Battle of Arbela) Alexander displayed an acute awareness of the logistical requirements of his army. Alexander considered the logistics implications of every aspect of the campaign, from the route he took to the allies he courted, in successfully moving the Macedonian army across the relatively barren desserts of Asia Minor.

Alexander began his move east from Macedonia, intent upon engaging the Persians at the Graeicus River. He had an estimated 10 days' worth of provisions for his army at Hellespont.[4] Ten days' provisions were ample, given Alexander's close proximity to ports along the Aegean Sea and the relative friendliness of the people of that region. Upon defeating the Persians at the Graeicus River, Alexander then marched on Sardis. It was on his march to Sardis that he encountered his first great logistics challenge. The direct route to Sardis was across mountainous terrain. However, Alexander elected to take a more circuitous route, moving back toward the coastline rather than southward to Sardis. This move was indicative of his exceptional grasp of logistics requirements and their direct influence upon the fighting capability of his army. Had he chosen the more direct route, not only would the terrain have slowed his advance, but the greater strain of covering mountainous terrain would have increased the consumption of supplies by both his men and horses. In all likelihood, his supplies would have been exhausted prior to reaching Sardis, and his army would have been located in the mountainous region vice the coastal area with its ready access to supply ships. Alexander repeated this strategy of attacking the enemy then quickly returning to the coastal region for resupply throughout his campaign against the Persians. The two exceptions to this strategy were his move on Ancrya (modern day Ankara) and his expedition into Egypt.

Alexander achieved two major logistics objectives in his capture of Sardis. Sardis was the political and economic hub of the entire region, and by bringing it under his control and raiding its treasury, Alexander further increased the resources he could draw. Second, the defeat of Sardis cleared his path southward along the coast of the Aegean. He then *liberated* Ephesus, Caria, Lycia, and Pamphylia. Alexander limited the Persian fleet's ability to move and took away their access to these ports by bringing these coastal cities under his control. A secondary effect of controlling these cities was that Alexander deprived the enemy fleet of a valued manpower resource. The Persians had been recruiting heavily from this area.[5] Alexander continued his coastal movement through Lycia and Pamphylia. While passing through this fertile region Alexander again illustrated his ability to integrate logistics requirements with the gamut of additional concerns facing the leader of a large force. Although the region was fertile and presented an excellent source of resupply for his army, he was well aware the effect mountainous terrain had on the consumption of supplies. Additionally, it was now winter. He chose to grant leave to newlywed members of his army. This act of altruism was, in fact, a brilliant means of reducing the army's consumption of stores, in addition to significantly improving morale. Though it seems unusual to grant leave in the midst of a campaign, Alexander was sensitive to the limits to which this region could support his army, and he did not intend to march on until the end of winter.[6]

Throughout his campaign, Alexander left garrisons of forces at key locations along his route. This practice had three major purposes: it ensured the allegiance of the city was secure, it allowed the city to serve as a depot for the storage of supplies, and it protected his lines of communication. In some instances, Alexander was able to send a small force ahead to secure a city's allegiance and support. His emissaries were able to secure logistics support and supplies, simply because the city's leaders desired to be in favor with Alexander.

Alexander's army remained throughout the winter and spring in the region around Pamphylia. He did not make his march to Ancyra until well into summer. The reason for the delay was purely logistical. He would be departing the coastline and heading inland. Given his doctrine of traveling light, his army would quickly exhaust its supplies and be forced to forage. Knowing that, Alexander began his march in late summer to ensure crops within the region between Pamphylia and Ancyra had an opportunity to both mature and be harvested, the latter being performed by the residents of the region, thus sparing his army that arduous task.[7]

En route to Ancyra, the Macedonian army crossed a region best described as an utter wasteland. Given the lack of potable water in this region, Alexander made frequent use of advance depots. He established the depots forward of the main army, with supplies from the rear augmented with whatever else could be secured at the advanced location.

Upon securing Ancyra, Alexander successfully consolidated his position in Asia Minor. He then marched to Issus and once again was forced to rely heavily upon the advance garrisons he had established, in addition to securing supplies from the local population en route. To his advantage, the majority of the cities between Ancyra and Issus were quite unhappy with their subjugation under Persian rule and viewed Alexander's cause favorably. Issus was a coastal city, which enabled Alexander to move forces garrisoned in the rear on the Aegean Sea forward. The army he had partitioned prior to his march on Ancyra was now back in full force at Issus. The partitioning and regrouping of his army aptly illustrates his philosophy of carrying only what was needed and could be supported. This applied to not only his supplies but also his troops.

Throughout his campaign, Alexander left garrisons of forces at key locations along his route. This practice had three major purposes: it ensured the allegiance of the city was secure, it allowed the city to serve as a depot for the storage of supplies, and it protected his lines of communication.

Upon his defeat of Darius at Issus, Alexander departed from the direct conquest of Persia. He then turned southward through Phoenicia and eastward into Egypt. Although Phoenicia and Egypt were under Persian control, Alexander did not face serious opposition until his return to Asia Minor. Additionally, his logistics philosophy was consistent with his earlier actions along the coast of the Aegean Sea. His route in Egypt followed the coast of the Mediterranean Sea. The majority of the cities, especially those in Egypt, viewed Alexander as a liberator and not a conqueror and were, therefore, generous in their support of his army.

Upon his return to Asia Minor, Alexander again remained near the coast and its valuable seaports. The cities that he passed en route from Egypt were now directly under his control and represented an asset rather than a possible threat. His departure from the coast and march on Arbela was made through the fertile Tigris-Euphrates Valley. Though meeting the logistics needs of an army is no small task regardless of location, Alexander's march through the Tigris-Euphrates Valley was not marked by any significant logistics challenges.

Alexander's defeat of Darius at the Battle of Arbela marked the end of the Persian Empire and Darius as their king. Key to his defeat of Darius was his approach to Darius' main body at an angle and the rapid encirclement of Darius' forces by Alexander's left flank. Alexander's successful use of maneuver is directly attributable to his overarching philosophy of flexibility and mobility, a philosophy integrated into and facilitated by his logistics practices.

Administration and Technology

One of Alexander's logistics strengths, one for which he cannot wholly take credit, was the organization of his army. "Alexander had as a legacy a model instrument—the army which Philip developed."[8] Key to Alexander's combat superiority and logistics prowess was his staff. In addition to the traditional second in command, called the Secretariat, Alexander had Keepers of the Diary, Keepers of the King's Plans, Surveyors and Official Historians. In addition to the more traditional staff functions, he also kept a large number of specialists and scientists on his staff. This wealth of expertise, both operational and logistical, he kept close at hand and without reservation solicited their counsel. Alexander's use of his staff of experts made his army formidable, not only in terms of its ability to execute combat operations but also in terms of its ability to plan and support combat operations.

Under Philip's direction, the Macedonian Army also underwent a significant change in the manner in which troops and provisions were transported. Philip outlawed the use of wagons in the Macedonian Army. This single act gave the Macedonian Army far greater speed and flexibility than any of their contemporaries. Philip's philosophy was expanded by Alexander, who limited the number of followers, civilians who tracked behind an army providing a gamut of services. Alexander only used horses, camels, and mules because of their greater speed and endurance over traditional pack animals such as oxen and donkeys.[9] The speed and flexibility of the Macedonian Army proved to be its greatest asset on many occasions.

One of Alexander's logistics strengths, one for which he cannot wholly take credit, was the organization of his army.

Social, Political, and Economic Factors

Philip, through his victory at Chaeronea, had secured control over Thebes and Athens. He then founded the Corinthian league and, through it, unified Greece. His next and ultimate goal was to destroy the barbarians, the Persians. His plans, however, were cut short with his assassination. Alexander was then left with the goal of conquering the Persians and, in doing so, laying claim to the known world. Despite his father's outright hatred of the Persians and the unbridled hatred of the Persians by Aristotle, his mentor, Alexander took a decidedly different view of his enemy. Alexander, too, saw the necessity of engaging and conquering the Persians. However, his purpose was well apart from the destruction of the barbarians. Under Philip, Greece had been unified, "and though he might have avenged Greece upon Persia, he [Philip] was not the man to carry the idea of *homonia* (unity in concord) into the world empire of his day ... this supremely greater task was destined for his son."[10] Alexander's philosophy was not one of revenge and destructive conquest but one of control and ownership. When brought under Alexander's control, either through defeat, or in many cases by self-capitulation, a conquered city was left with a measurable level of autonomy.

His method throughout his reign was always the same. He separated civil administration from military control. The first he handed over to the representative of the conquered people, the second he placed in the hands of one of his chosen Macedonians.[11]

Alexander's goal was not for *homonia* just among Greeks but among all men, including Persians. In addition to the obvious political benefits this policy held, it provided substantial military logistics benefits. Although not completely free to choose whether or not to lend support to Alexander, conquered peoples, on the whole, favored life under Alexander's rule to that under some other conqueror and were generally supportive. On the off chance the *carrot* of semiautonomous rule did not persuade the conquered people, Alexander still had the *stick* of garrisoned troops left behind to oversee military affairs.

Napoleon Bonaparte

Napoleon is widely regarded as one of the premier generals of all time. He brought about numerous reforms in the way in which wars are fought and the very structure and composition of the fighting forces engaged in combat. Napoleon embodied the idea of the professional military leader, not gaining his position through political or familial connections, but earning it by distinguishing himself in combat. Although the focus of this study is on the logistics aspect of Napoleon's 1812 march upon Moscow, it first seems appropriate to recognize Napoleon for what he was, one of the greatest military leaders of all time.

A major drawback to Napoleon's superior generalship and professionalism during the planning of the Russian campaign was his overpowering need to be involved in every aspect. An even greater problem than this, however, was his tendency to make decisions without consulting with his key leaders.

Generalship and Military Professionalism

A major drawback to Napoleon's superior generalship and professionalism during the planning of the Russian campaign was his overpowering need to be involved in every aspect. An even greater problem than this, however, was his tendency to make decisions without consulting with his key leaders. There is a consensus among the accounts describing Napoleon's preparation for the Russian campaign that there were severe oversights regarding the logistic requirements of his army.

Although the planning for the Russian campaign was performed over the span of 2 years and showed some aspects of logistics consideration, it is clear Napoleon did not fully understand the logistical challenges he would face.[12] His misunderstanding, coupled with his reluctance to share information, had an obvious impact upon the soundness of the logistics aspects of his plan. His reluctance to seek the counsel of others was as much a function of "delusion and irrationality clouding his powerful mind" as the lack of any competent advisor. Just prior to the invasion of Russia, "there were few men left in the imperial entourage with sufficient integrity to speak their true minds," and "for the main part, Napoleon was now surrounded by claquers and sycophants."[13] Whether acting out of ego or necessity, Napoleon planned the Russian campaign, to a large extent, entirely on his own. Operating in a vacuum led to numerous logistics problems in terms of military theory, doctrine, strategy, tactics, administration, and technology.

Military Theory, Doctrine, Strategy, and Tactics

Throughout the planning and execution of the campaign into Russia, Napoleon committed numerous errors in terms of strategic focus and tactics, which directly affected the ability of his logistics system to support sustained operations. One of his greatest oversights was his doctrinal belief he could conduct a war on two fronts. When he began the invasion of Russia in 1812, Napoleon's forces were still actively engaged in a peninsular war with the Spanish. Though it is unclear as to his exact reasoning, Napoleon chose not to regard his commitment to the war in Spain. It seems he preferred to have the British involved on the side of the enemy in Spain rather than being involved in some other less convenient sector of Europe. Regardless of Napoleon's exact reasoning, the net negative effect of the Spanish War was the loss of 50,000 French soldiers per year and the consumption of an untold amount of the materials of war that could have been used in the Russian campaign.[14]

Though Napoleon did show some consideration for logistics, he viewed these requirements in a static sense. He failed to factor in the possibility that the support he anticipated would not be available. Similarly, he did not consider the possibility that the enemy he wanted to destroy would not engage him.

Napoleon's strategy did recognize the materiel challenges to be faced by any force marching on Moscow. The date for the start of the invasion, 23 June, was largely chosen for logistics reasons.[15] Napoleon thought the crops in Russia would be sufficiently developed and provide adequate forage for the thousands of horses upon which he relied for transportation and as weapons of war. He also had the horses bear a larger-than-traditional load in an attempt to ensure an adequate supply of food for both man and beast. Unfortunately, the addition of the extra loads increased the horses' consumption of food, in essence negating or worsening the effect of the additional provisions. In very short order after crossing the Niemen River, Napoleon would see his fleet of horses cut down by a third because of an outbreak of colic, the relative lack of edible forage (on which he was counting), and incredibly hot weather. The loss of those horses had a cascading effect. Men who had been mounted were now forced to advance on foot, and horses were diverted from other details to fill vacancies in horse-drawn artillery teams. The net effect was to distribute the transportation and logistics burden over an ever-decreasing population of beasts of burden. The burden increased with the onset of heavy rains, which turned the Russian roads into impassable bogs. Throughout the campaign, the ever-dwindling supply of horses and the ever-worsening weather contributed to the complete destruction of Napoleon's ability to provide for his forces.[16]

The greatest strain on Napoleon's logistics system proved to be the Russian unwillingness to engage in battle. From the start of the campaign, the Russian forces were quite content in withdrawing and forcing Napoleon to pursue them. To compound this, they would also burn their own cities prior to abandoning them. Thus, the farther Napoleon marched into Russia, the farther he marched into a virtual wasteland. The Russians rarely left behind anything of use. Upon reaching his strategic goal of Moscow, Napoleon found it deserted and generally devoid of any useful supplies. The Russians, after fighting a pitched battle on the outskirts of the city and seeing the city would fall, simply deserted it during the night. The net effect of Napoleon's march on Moscow was that his army, some 250,000 strong when it crossed the Niemen, was reduced to 130,000 because of the lack of supplies, disease, and Russian hit-and-run attacks on Napoleon's rear. The Russian Army, which was outnumbered two to one when Napoleon crossed the Niemen, was now approximately equal in size to his army. Further, the Russian army, in spite of all its retreats, had stubbornly hung on to its artillery and enjoyed a slight numerical advantage over Napoleon's heavy guns. Upon reaching the strategic goal of Moscow, Napoleon was no closer to defeating the Russians than when he began, and he was now in the midst of a vast wasteland, several hundred miles from his stores of supplies in Warsaw.

The net effect was to distribute the transportation and logistics burden over an ever-decreasing population of beasts of burden. The burden increased with the onset of heavy rains, which turned the Russian roads into impassable bogs. Throughout the campaign, the ever-dwindling supply of horses and the ever-worsening weather contributed to the complete destruction of Napoleon's ability to provide for his forces.

In search of both victory and supplies to sustain his army, Napoleon marched on to Kaluga. It was en route to Kaluga that he obtained what he so desperately wanted—battle with the Russians. General Kutuzov made his stand at Maloyaroslavetz, a village on the road from Moscow to Kaluga. Although Napoleon was able to remove Kutzov's forces from Maloyaroslavetz, it came at the cost of 4,000 French troops. Worse yet, Kutuzov's forces still controlled the road to Kaluga. It was at this point that Napoleon began his retreat from Russia. Without losing a battle, he had lost the war.

It was now October, and 200 miles lay between Napoleon and his nearest supply depot, Smolensk. The depot at Smolensk was established on the march across Russia from Poland. Napoleon had charged the garrison commander to secure stores while the main body of Napoleon's army pressed onward to Moscow. Napoleon anticipated that upon the conclusion of the grueling 2-week march from Maloyaroslavetz to Smolensk he would be able to halt there and regroup. There were, however, three tragic flaws with this plan. The Russians were now attacking Napoleon's rear with great vigor. The garrison commander at Smolensk had precious few supplies at the onset of establishing the depot and, being surrounded by a virtual wasteland, had failed to secure any stores of adequate quantity. The weather was steadily deteriorating.

The strain on the weakened transport system was growing. All along the way, the men were discarding the bulkier and less valuable items among their loot. Rations were limited. Horseflesh began once more to be cooked at the evening campfires. Snow began to fall. And on the night of 5 November, the cold came.

No longer were the retreating troops faced with merely the unpleasant chill of frost. This was a cold that could not be held off by the upturned collars of their greatcoats. It could not be pushed aside by stamping in the snow or by holding cupped hands against ears and cheeks. This cold was so terrible that frozen feet, followed by frozen death, came upon men who had done nothing more than momentarily step into the ankle-deep water of some frozen roadside puddle on which a heavy artillery wheel, a moment before, had broken the ice.[17]

Upon his arrival at Smolensk, Napoleon realized his folly. There were no adequate stores at Smolensk, and he must keep moving, or his army would be lost. Throughout the retreat, the Russian Army dogged Napoleon's heels, at times separating the rear guard from his main body and inflicting even heavier casualties. When Napoleon finally returned from the Russian campaign, his army, once numbering 250,000, reported 8,800 men fit for duty.

Administration and Technology

The administrative weakness of Napoleon's army was directly attributable to his style of leadership. Although Napoleon's influence had garnered great success in the past, he made the tragic flaw of assuming what worked in previous situations would work again, despite the dramatic difference the Russian campaign represented from his previous conquests. Most important, Napoleon's army was larger than it had ever been, and the campaign was spread over the vast expanse of the Russian countryside.

The problems of time and distance were to prove too great for the capacity of a single mortal, even when that man was Napoleon. Napoleon's whole idea of warfare was based upon personal supervision of all parts of his army.[18]

His philosophy of direct supervision had proven difficult for him to execute over armies of smaller size that operated over a far more confined area. This philosophy proved impossible during the Russian campaign. Napoleon's inability to oversee his subordinates' preparation and execution of his planning led to significant shortfalls in readiness and synchronization of effort. The army's reliance upon guidance from the highest levels led to poor preparation and logistics support.

Technologically, Napoleon's army was the model of modern arms for the time. However, technological superiority in this case did not ensure battlefield superiority. Specifically, Napoleon's heavy guns required multiple horse teams. The horses in turn required provisions of their own. The only means of replenishing a lost horse was to obtain it from another function within the army. The net result, as mentioned earlier, was the logistics burden continually being spread over a decreasing number of pack animals. Furthermore, Napoleon's wagons were well suited for the relatively passable roads of western Europe but were woefully inadequate in the boggy mire of the Russian countryside. The combined net effect was a technologically advanced force incapable of getting to the battle in force and forced to consume itself in order to keep pursuing an enemy not committed to full engagement.

Logistics problems played the pivotal role in Napoleon's failed campaign into Russia. Inadequate transportation systems, reliance upon single sources of replenishment, and improper provisioning for extremes in climate reduced the greatest army of the time, some 250,000 men strong, to a feeble force of 8,800 survivor

Social, Political, and Economic Factors

Leading up to Napoleon's invasion of Russia, Tsar Alexander was able to make peace with Turkey, sign a treaty of alliance with Great Britain, and court the favor of Crown Prince Bernadotte of Sweden. The collective effect of this diplomatic maneuvering was that Russia "was able to clear her hands of all outstanding commitments and proved notably successful in her search for new allies."[19] Although Napoleon made similar political attempts to garner support, the vast majority of his support was obtained by force. The Russians were fighting on their own soil, which provided many logistical advantages. Their supplies had shorter distances to travel, and their personnel were well equipped to handle the severe weather. Tsar Alexander eerily predicted the results of the Moscow campaign in a conversation with Armand de Caulaincourt, then Ambassador to St Petersburg.

> If the Emperor Napoleon decides to make war, it is possible, even probable, that we shall be defeated, assuming that we fight. But that will not mean that he can dictate peace. The Spaniards have frequently been defeated; and they are not beaten, nor have they surrendered. Moreover, they are not so far away from Paris as we are, and have neither our climate nor our resources to help them. We shall take no risks. We have plenty of space; and our standing army is well organized. Your Frenchman is brave, but long sufferings and a hard climate wear down his resistance. Our climate, our winter, will fight on our side.[20]

Logistics problems played the pivotal role in Napoleon's failed campaign into Russia. Inadequate transportation systems, reliance upon single sources of replenishment, and improper provisioning for extremes in climate reduced the greatest army of the time, some 250,000 men strong, to a feeble force of 8,800 survivors. Until his retreat, Napoleon had not lost a battle, but he did lose the war.

William Tecumseh Sherman

The concept of generalship, a person's ability to be a general, cannot be viewed simply in terms of his conduct and influence upon his surroundings. His surroundings must also be evaluated. The environment in which the general commands has a great deal to do with his success and, in turn, will clearly influence the overall perception of his generalship. An analysis of William Tecumseh Sherman's environment leading up to and during the march on Atlanta provides unique insight into his generalship and military professionalism and how these threads of continuity both influenced and were influenced by his logistics practices.

Generalship and Military Professionalism

Ulysses S. Grant's appointment as Lieutenant General, Commanding the Armies of the United States in 1864, served to solidify unity, not only in terms of command but also in sense of purpose. Grant was the field general under whose leadership Sherman led the armies of the West into the heart of the Confederacy. Sherman's success can, in large part, be attributed to the autonomy with which he was allowed to operate. This autonomy was brought about as much because of Grant's trust in him as because of his geographic separation from Grant. Grant, in his written direction to Sherman, illustrates his belief in outlining what needs to be done, not how to do it. "I do not propose to lay down for you a plan of campaign, but simply to lay down the work it is desirable to have done, and leave you free to execute it in your own way."[21]

This concept of centralized control and decentralized command was especially useful given Sherman's nature as a man of action. His conduct during the preparation for and subsequent march on Atlanta is distinguished by quick and decisive action. His focus was first on the end goal, then on achieving it. In terms of logistics support, Sherman clearly identified his logistics requirements, then obtained the necessary means to meet them. Sherman was not prone to micromanagement. He simply expressed his requirements, established a completion date, and then ensured adequate motivation for completing the task. An excellent example of Sherman's leadership style, as it specifically relates to logistics, was the case in which a subordinate was not providing adequate transportation support. Sherman informed the officer that if he did not supply his army and keep it supplied "We'll eat your mules up." Sherman was far more forgiving of tactical errors than errors regarding logistics planning. He believed tactical errors often "stem from the enemy's resistance and counteractions, which are the most incalculable factors in war," but a failure to adequately prepare was intolerable. Sherman believed "by due foresight, preparation and initiative, material obstacles can always be overcome."[22]

Sherman enjoyed the benefit of the best military education available in the United States at the time. He was a graduate of the United States Military Academy. Despite not holding any cadet positions of authority while at West Point, he graduated near the top of his class, number six in the class of 1840.[23] The military education he received at West Point proved valuable because it provided a sound background upon which to build military command experience and was the same background the majority of the military leaders of the time had. Grant, Lee, Jackson, and numerous other Northern and Southern generals came from the same school of thought, West Point. The classical approach to education at West Point undoubtedly exposed Sherman to the histories of great generals and campaigns of the past. It is then not surprising that there are significant similarities between Sherman's campaign into the heart of the South and Alexander's campaign against Darius.

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Military Theory, Doctrine, Strategy, and Tactics

Sherman, in his memoirs, makes two points clear regarding his planning for the campaign on Atlanta: adequate supplies and maneuverability were key to the success. "The great question of the campaign was one of supplies."[24] Sherman was well aware of the relative length and vulnerability of his supply chain and took many creative steps to ensure he was provided adequate support.

Sherman was adamant about ensuring the highest maneuverability, while still maintaining adequate support.

> I made the strictest possible orders in relation to wagons and all species of encumbrances and impedimenta whatever. Each officer and soldier was required to carry on his horse or person food and clothing enough for five days.[25]

Sherman gave strict orders regarding the number of wagons and ambulances each regiment was allowed in addition to banning the use of tents by his army. The ultimate goal of Sherman was to strike a balance between maneuver and support. Sherman required each soldier to carry sufficient supplies for 5 days, yet he relieved units of the burden of carrying *nonessential items* such as tents, excess wagons, and ambulances. Sherman's key focus during the planning of the Atlanta campaign was to make his "troops as mobile as possible."[26]

Sherman was well aware of the possibility of not receiving adequate support despite the many actions he had taken in preparation for the Atlanta campaign—the increased buildup of supplies at the front, commandeering of the railroads, and strict limitations he placed upon his army. Sherman bluntly informed General Grant of his anticipated course of action should his supply system fail to support him.

> Georgia has a million of inhabitants. If they live, we should not starve. If the enemy interrupt our communications, I will be absolved from all obligations to subsist on our own resources and will be perfectly justified in taking whatever and wherever we can find.[27]

Sherman's strategy and tactics in terms of logistics were then clear: a highly mobile force that would rely upon significant logistics support from the rear; whenever this support was interrupted, whatever was required would be taken from the local inhabitants. The plan of taking what was required from the local population further supported Sherman's overarching doctrine of bringing the horror of war to the people of the South.[28]

From the onset of the campaign into Atlanta, Sherman's strategy emphasized maneuver and focused on logistics. Specifically, Sherman's desire was to feign an attack on the Confederate forces at Dalton while engaging in a rear action to bar the retreat of the Confederate forces farther south to Resaca. If the Confederate forces were allowed to retreat south to Resaca, Sherman not only would face the burden of being farther from his main supply depot but also be driving the Confederates closer to theirs.

Unfortunately for Sherman, his plans for a rear action were not completely carried out. Due to a lack of initiative on the part of one of his subordinate commanders, Sherman's army failed to attack the rear decisively, and Sherman's attempt to execute a rear action failed to reach complete fruition. However, Sherman's actions did have both a negative and positive result. The Confederate forces were drawn away from their fortified position in Dalton to a far less favorable position with their retreat through Resaca across the Oostenaula River.

> It was nevertheless a brilliant achievement to have maneuvered so renowned a master of defense [General Johnston, Confederate commander at Dalton] out of two strong positions against his will and his orders.[29]

The negative result of the Confederate retreat was that Sherman had missed a golden opportunity to trap Johnston's army and attack it from the rear. "Sherman had a lengthening line of communication [and supply], Johnston a shortening and less exposed one."[30]

Throughout the remainder of Sherman's march to Atlanta, he was able to effectively employ maneuver to force Johnston backward while continually supplying his troops from the rear. Essential in the resupply effort was a trailing echelon of 2,000 troops under the command of Colonel Wright, a civil engineer, whose expertise in the repair of enemy-damaged railways enabled virtually uninterrupted resupply to the forward lines beyond Resaca. "Time after time, Sherman's greater army outflanked Johnston's lesser forces, compelling their withdrawal."[31] Sherman eventually won the Battle of Atlanta and captured the city.

The Civil War arguably was the first modern war, especially when considering war in terms of the American experience.

Administration and Technology

The Civil War arguably was the first modern war, especially when considering war in terms of the American experience. The North, in particular, was a highly industrialized region capable of producing a variety of both durable and consumer goods. One key necessity of industrialization is the need for rapid, reliable transportation. In the late 1860s, the railroad developed as an indispensable mode of transportation for both military and civil concerns. Sherman, well aware of its importance, made the acquisition and maintenance of rail transportation, while denying it to the enemy, a priority.[32]

Chattanooga, the starting point for Sherman's advance on Atlanta, lay 151 miles from his supply depot at Nashville, which in turn was 185 miles from his main source of supply in Louisville. Given the significant length of Sherman's lines of supply, it was of paramount importance that he secure adequate transportation for supplies and reserves. His first step in ensuring a reliable line of supply was to acquire supreme control of the railroads. Previously, the railroads had been controlled by "the departmental commanders, with consequent friction and uneven distribution of supplies."[33] Sherman, much like Grant had done for the entire Union Army, unified his control over this critical resource. Sherman then decentralized execution while maintaining overall control. His philosophy of overarching control and decentralized execution of railroad operations resulted in two largely beneficial effects. He was able to oversee the flow of supplies to the front without directly involving himself in the *ins and outs* of rail operation, and he eliminated the bickering and supply imbalance between subordinate commands. A secondary effect of Sherman's control of the railroads was his ability to weigh in with the authority of his office should any problems arise.

He further ensured the availability and proper use of railroads by banning civil traffic. Still not satisfied, despite the fact his daily delivery of stores to the front had doubled, Sherman directed that cars and locomotives from other locations be diverted to the Chattanooga line. The decision to ban civil traffic and commandeer additional cars was not an attempt to simply bring a valuable resource directly under his control. He had a clear level of support in terms of rail shipments, 130 ten-ton car loads per day, he felt must be met, and taking control of the railroads seemed the logical way to do it.[34]

Sherman also displayed his penchant for centralized control and decentralized execution in both his mode of operation and his army's organization. An excellent illustration was the composition of his staff. His staff included functional experts in artillery, engineering, ordnance, logistics (actually called Chief Quartermaster and Commissary) and medicine. In addition to the functional representatives, Sherman's staff had three inspectors general and three aides-de-camp. Conspicuously absent from his staff was the administrative function. He advocated that clerical work in the field be kept to a minimum and used permanent clerical offices in the rear for daily correspondence. The composition of his staff facilitated the scheme of centralized control by using the staff in a controlling capacity while still leaving the execution to the lower echelons.

Social, Political, and Economic Factors

The political motives behind Sherman's campaign were clear: to bring the war and all its horror to the heartland of the South. "Sherman was eager to teach the people of the South a lesson in the horrors of war, believing that a harsh war would ensure a lasting peace."[35] Sherman further believed he was justified in his laying claim to any and all stores before him, shaking off the "old West Point notion that pillage was a capital crime."[36]

Analysis

Though it can be maintained that the two largely successful campaigns of Alexander and Sherman had many similarities among policies and practices, it cannot further be assumed that there then exists some exacting set of rules or practices shared by the two that will always guarantee success if employed. This study does not attempt to develop a listing of the key logistics principles that will guarantee success but, rather, establishes a logistics paradigm intended to be a guide or a starting point from which current and future military leaders can develop their own policies and practices. By analyzing the commonalities among successful campaigns and integrating those with the lessons learned from not-so-successful campaigns, a logistics paradigm is developed that is based upon practices proven to be valid in antiquity, which forms a starting point from which leaders can tailor their own practices to fit their specific situations. The campaigns of Alexander and Sherman illustrate the good logistics practices, while Napoleon's campaign into Russia provides the lessons learned. The framework for analyzing the commonalities and lessons learned is based upon the threads of continuity approach.

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Generalship and Military Professionalism

In terms of formal military education and background, backgrounds of Alexander and Sherman are dramatically different than that of Napoleon. The former represent the aristocratic general, while the latter represents the journeyman solider. In no way does that mean Napoleon was a lesser general. He is arguably one of the greatest generals of all time. What is meant by the distinction between aristocratic and journeyman is that both Alexander and Sherman were taught to be generals and leaders of men, while Napoleon was first taught to be a soldier and, through aptitude and hard work, rose to his position as general. Both Sherman and Alexander received superior education and military training compared to their contemporaries. Alexander's private tutor was Aristotle, and he was taught by his father, Philip, from an early age how to be a general. Sherman attended the United States Military Academy and was commissioned as a second lieutenant, with the focus of the United States Military Academy on teaching men to be leaders and, ultimately, generals. Napoleon, though a graduate of l'Ecole Militaire, did not have the formal military education of Sherman. L'Ecole Militaire during Napoleon's time was not "particularly distinguished for the attention it paid to the proper preparation of its young aspirants for commissions."[37] Similarly, given Napoleon's middle-class upbringing, he was not afforded the tutelage of a great thinker, and his father was not a great general.

Though no direct correlation can be made about the military education received by Alexander, Napoleon, and Sherman and their general logistics practices during the campaigns under study, their backgrounds provide insight into the disposition and character of these generals. It can clearly be seen that by working his way up from his middle-class beginning through the ranks as a junior artillery officer, Napoleon developed a significant sense of self-reliance and, as was the case during the planning for the invasion of Russia, a need to be involved in every aspect of the operation down to the minutiae. Conversely, both Sherman and Alexander consistently maintained supervisory oversight of their armies while leaving the precise execution of daily operations to their functional experts.

Military Theory, Doctrine, Strategy, and Tactics

Military theory, doctrine, strategy, and tactics, for the purpose of this analysis, are focused at the operational level and can be viewed in general terms as to how each general conducted the campaign. Each of the three campaigns represents dramatic differences in how the conduct of war influences or is influenced by logistics. Alexander's conduct of his campaign was greatly influenced by logistics concerns. Napoleon's logistics practices were greatly influenced by how he intended to conduct his campaign. Unfortunately for Napoleon, how he thought he was going to conduct the campaign was not how he ended up conducting it, and his logistics system proved horribly inadequate. Sherman's conduct of his campaign was influenced by logistics concerns and influenced his logistics practices.

Alexander's foremost concern was the adequate provisioning of his army, as is evident in his route through Asia Minor. Though the defeat of the Persians was the ultimate military goal of his conquest up to the Battle of Arbela, clearly that could not be accomplished without first addressing the logistics needs of his army. Throughout his campaign, Alexander employed three main techniques to ensure adequate provisioning. First, he stayed as close to the coast as possible. His proximity to the coast facilitated easy access to his fleet of supply ships while denying port access to his enemy. Second, he modified the size of his army (flexible sizing) to suit the environment he was facing. An excellent example of this was when Alexander, faced with the onset of winter after passing through the region around Pamphylia, granted leave for all newlywed members of his army. The granting of leave greatly decreased the number of troops he had to supply and undoubtedly had the additional benefit of increasing morale. Finally, when he marched inland, he took great pains to ensure advance logistics support. He sent military envoys ahead with the charter to inform local officials of his approach. The message was clear; surrender yourselves and your property or be destroyed. As was often the case, support was granted without the use of force.

The campaigns of Alexander and Sherman illustrate the good logistics practices, while Napoleon's campaign into Russia provides the lessons learned.

Napoleon's *hubris* was that he failed to fully understand the environment in which he was to conduct war and, therefore, developed a logistics system that was woefully mismatched for that environment. The most popular example was the inadequacy of Napoleon's wagons to effectively negotiate the rough Russian countryside. However, a closer examination indicates the problem was just as much about what he carried and how he carried it as what it was carried in.

Though Napoleon had planned the start of the invasion to coincide with the harvest in western Russia, the availability of crops proved inadequate to support the thousands of horses he relied upon for transportation and as weapons of war. The lack of fodder, combined with an outbreak of colic, decimated his fleet of horses and had the cascading effect of spreading the burden over an ever-decreasing number of horses, which in turn increased their consumption of supplies. Worse yet, as the number of horses decreased, horses had to be shifted from pack details to pulling artillery. The shortage of pack horses meant more was being carried by men, increasing their consumption and reducing their mobility.

Napoleon's greatest misunderstanding was how the Russians would respond to his advance. The Russian willingness to trade land for time proved to be Napoleon's undoing. As Napoleon pressed farther and farther into Russia, he traveled farther and farther away from his main supply reserves in Poland and farther into a vast wasteland. The Russians laid waste to anything of logistical value prior to retreating, leaving Napoleon with little to draw upon from the local population. The Russian *scorched earth* tactic, accompanied by constant attacks on Napoleon's lines of supply, deprived Napoleon of even the slightest relief. By the time Napoleon was able to engage the enemy face-to-face, his 2-to-1 superiority in numbers had vanished. With the onset of winter, he realized the war was lost, and in his desperate march back to Poland, he lost the bulk of his remaining troops.

Napoleon began the campaign with the anticipation of relying upon the available crops within the area to augment the provisions his army carried with them. Additionally, he intended to bring his superior numbers and firepower to bear against an enemy in an army-to-army confrontation for the control of the capital. Unfortunately, what he encountered was something far different. Had events gone as Napoleon expected, it could be argued that he well may have won in Russia. However, Napoleon's logistics plan and practices proved woefully inadequate in the end.

Sherman's logistics policies and practices influenced and were influenced by how he conducted his campaign. Sherman was well aware of the logistics strain and the vulnerability of his lines of supply as he advanced toward Atlanta. He took unusual measures to bolster his lines of supply. From the planning stages through the execution of the campaign, he maintained control of the railways. He diverted locomotives from other locations and aggressively repaired battle-damaged rail lines. His route southward followed the main rail line from Chattanooga to Atlanta. Clearly, in this instance, his conduct of war was influenced by logistics.

Sherman is noted for the destruction that he brought to the heart of the South. The destruction he inflicted was neither solely the result of pillaging for supplies nor the result of pure malice and wanton destruction but a combination of both. Sherman was clear from the onset of the campaign that one of his motives was to bring the war to the people of the South. He also considered himself completely justified in obtaining whatever he required from the local population. He believed if the Confederate forces impeded the flow of supplies to the front he was then perfectly justified in acquiring the supplies he needed from the local population. Whether it be the case that the Confederate forces significantly affected Sherman's supply lines or that he simply needed more supplies than he could provide for himself, before the onset of the campaign, he clearly established his intention to take what was needed from the local population. Sherman allowed his desire to bring the horror of the war to the people of the South, a key element in how he was to conduct this campaign, to influence his logistics practices.

Sherman and Alexander shared one key factor in their conduct of war: the logistics requirements they placed upon individuals during the planning stages of their respective campaigns. Both gave specific instructions aimed at lightening the load of individuals and individual units under their commands. Interestingly, both Alexander and Sherman prohibited the use of tents. Alexander built upon Philip's requirements and minimized followers, while Sherman limited the number of wagons available to individual units. The ultimate end goal was to increase individual and unit mobility by limiting to the bare essentials what was carried. This is not to say that Napoleon did not take measures to increase mobility and in turn increase the army's ability to maneuver, but in the case of Alexander and Sherman, maneuver proved to be the deciding factor in the defeat of their enemy. Sherman was able to outflank Johnston's forces, and Alexander was able to attack Darius' forces at an angle and encircle them. Both victories resulted from the successful use of maneuver, which was directly attributable to their armies' ability to move quickly, a concept integrated into and facilitated by their logistics policies.

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Administration and Technology

A key attribute shared by both Alexander's and Sherman's success, which proved to be a contributing factor to Napoleon's failure, was the use of their staffs. Both Alexander and Sherman had experienced and trusted military advisors to advise them on a multitude of functional areas. Though Napoleon also had a staff, his, to a large degree, was made up of *claquers and sycophants*.[38] It is unclear if the lack of sound advisors resulted in Napoleon's tendency to micromanage or if his management style made a staff position an overly unattractive billet for anyone except a sycophant. Regardless of the cause for his less than competent staff, its lack of competence left Napoleon with little choice but to rely upon his personal involvement in all aspects of the operation of his army.

As discussed earlier, both Sherman and Alexander, to a large degree, dictated what was to be done but not how to do it. Such a philosophy is an excellent indicator of a high level of trust and respect for one's subordinates and indicates a capable and competent staff.

Each of the three armies represented the most technologically advanced fighting forces of their time. They differ, however, in how they adapted their technology to fit the situation at hand. Napoleon had state-of-the-art weaponry, especially artillery, yet he was unable to use it effectively because he could not transport it effectively. The wagons carrying his artillery were well suited for the well-maintained roads of Western Europe but were woefully inadequate in the impassable bogs of the Russian countryside. Alexander, on the other hand, purposefully did not use traditional pack animals, such as oxen and donkeys, but opted for animals with better endurance and speed, such as horses and camels. Alexander adapted his transportation technology to suit the situation. Sherman took complete control of the railways and ensured he had a viable repair activity prior to the start of the Atlanta campaign. He exploited available technology to his advantage while denying the enemy access to it.

Similarly, Alexander made great use of naval resupply and, in doing so, denied the enemy similar access since he controlled the ports. Alexander's and Sherman's ability to adapt and apply logistics technology, specifically transportation technology, rather than their absolute technological superiority, proved valuable in the success of their campaigns.

Social, Political, and Economic Factors

To analyze the effect of social, political, and economic factors, this study examines the interaction between the campaign forces and the indigenous peoples and local environment. Although each of the three campaigning forces interacted differently with local inhabitants, there is one common aspect that defined the interaction. In the case of the successful campaigns, the commander understood the environment he was to operate in, to include not only the tangible factors such as terrain but also the intangible factors such as the resolve and attitude of the people he intended to conquer.

As discussed previously, Napoleon's failure to comprehend Russian resolve and willingness to sacrifice land for time was key in his defeat. In his statement to Armand de Caulaincourt, Tsar Alexander was quite clear about the Russian willingness to use the vastness of their frontier and the severity of their climate as key aspects in their defense. Apparently Napoleon failed to regard these comments or simply thought that even if the Russians did employ these tactics they would be of little impact. Napoleon was also willing to begin his offensive against Russia while still engaged in a war with Spain. He neglected to realize that a fundamental building block to alliances is a common enemy. Unfortunately for Napoleon, the fact that France was engaged in two wars made France far less attractive to any new prospective allies than Russia, who had settled all her other disputes. The net result was Russia was able to form alliances with Great Britain and Sweden and make peace with Turkey. Napoleon failed not only to comprehend the impact of the physical environment upon his logistics plan but also to recognize the political environment's effect upon his logistics plan. Russia had gained new allies and made peace with former enemies, which allowed her to focus on the entire military logistics capability toward a single foe. Unlike his Russian enemy, Napoleon was now actively engaged in fighting a war on two fronts, with the bulk of his allies being former conquered peoples whose support was tenuous at best.

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Sherman understood well the environment he was to encounter during his campaign. One of his specific goals was to change the environment of the enemy citizens he encountered. Atlanta and the surrounding region represented a wealthy and pristine area of the South, particularly in terms of its exposure to the destruction of the Civil War. Sherman conducted his campaign "aimed at defeating the South psychologically as well as militarily."[39] He was dramatically successful in both aspects. Sherman not only successfully completed his campaign to capture Atlanta but also left a lasting mark on the consciousness of the enemy population he encountered. Sherman clearly understood his environment and made affecting that environment a key factor in his campaign.

Alexander, too, was well aware of the environment he was to encounter. He, however, took a decidedly different approach than Sherman. Alexander allowed the conquered people to retain some measure of autonomy with regard to their own civil affairs. Additionally, the people he encountered often surrendered to Alexander without a fight and in some instances viewed him as a liberator from the oppressive rule of the Persians. The conquered peoples' view of Alexander is in stark contrast to how Napoleon and Sherman were viewed during their respective campaigns. Alexander's goal, too, was different from that of Napoleon or Sherman. Where Sherman explicitly wanted to make war on the people of the South and Napoleon wanted to conquer the people of Russia, Alexander, to a large extent, wanted to unify, under his rule, the people he conquered. This distinction between conquering and unification on the surface may seem subtle, but examination of how conquered people were treated by the two generals illustrates the dramatic difference between the two concepts. Alexander retained military control but, to a large extent, left the civilian population to continue their lives as they had done before. Napoleon, in contrast, retained control through the establishment of some puppet civil and military leadership. The net result was those under Alexander's rule, to a large extent, were unaffected by the shift in power, whereas former enemies under Napoleon's control were much the worse for the shift in power. Clearly, Alexander realized that if he was to accomplish his goal of *homonia* he would have to ensure the eventual and lasting support of the people. *Homonia* could not effectively be accomplished at the point of a spear. By understanding and integrating the political and social environment of the people he conquered, Alexander obtained their support, a factor that played a major role in his logistics practices during the campaign to defeat Darius.

Conclusions

The conclusions set forth in this article result from an examination of the events surrounding the campaigns examined and an analysis of the commonalties among successful campaigns and lessons learned from the not-so-successful one. The logistics paradigm resulting from this analysis has four key principles. Each principle of logistics put forth by the analysis relies upon the use of demonstration by "revealing a necessary connection between the defining properties of the object being compared."[40] Key to the validity of the logistics principles, and in turn the entire paradigm, is the underlying assumptions specifically outlined with the explanation of the principles. The assumptions form the framework in which the application of the principles apply as per the demonstration.[41]

It can easily be seen the four principles of logistics offered by this article are not entirely new to anyone familiar with the study of war. In fact, in some form or another, each of these principles appears in several prominent historians' statements of principles of war and logistics. However, the method with which these principles can be applied distinguishes them from previous theory. The difference between the principles put forth in this article and other theories will be discussed, but the principles themselves must first be described.

Centralized Control, Decentralized Execution

As described earlier, both Alexander and Sherman made extensive use of staffs of functional experts. Conversely, Napoleon, though possessing a staff of his own, tended to be involved down to the lowest operational levels. The logistics challenges Napoleon faced would prove too great for any one man to handle, even if that man was Napoleon.[42] Sherman and Alexander allowed their functional experts to manage the daily operations of their specific area of responsibility, and both generals weighed in with the authority of their office only when needed. Their management philosophies allowed them to focus on the overall management of their armies, while still staying close to the daily operations managed by their staffs.

Although these campaigns involved large armies and the necessity for centralized command and decentralized execution seems well founded, there is just as much applicability of this concept for smaller sized, more modern military units. Given the assumption that logistics concerns are a function of the complexity of the operation at hand, which is, in turn, a function of the people, equipment, and supplies being used, then the challenge of meeting basic logistics requirements has increased in proportion to the complexity of the fighting force. Though the size of the army or military unit may be quite different from that of Alexander, Napoleon, or Sherman in modern times, it is still quite complex. Complexity then implies the need for exacting expertise in numerous, specific fields integrated to support an overarching end goal or mission. In much the same manner that even a general as brilliant as Napoleon could not manage the wide gamut of logistics and nonlogistics issues he faced during the campaign into Russia, neither can a modern military leader expect to have adequate knowledge in the gamut of functional areas of responsibility. Though an extensive staff may be neither practical nor attainable, a leader should be willing and endeavor to consult the functional experts.

The conquered peoples' view of Alexander is in stark contrast to how Napoleon and Sherman were viewed during their respective campaigns.

Key to the validity of centralized control-decentralized execution and its implied reliance upon functional experts is that such experts exist and are available. This assumption seems negligible, but the availability of a competent staff or group of advisors is quite rare in small military units. Of even greater concern is the lack of true functional experts. Though career broadening and the blurring of the lines between logistics specialties in the modern military does provide an increased pool of *trained* personnel from which to draw upon to fill logistics billets, it necessarily results in the reduction of true functional experts who have spent the bulk of their career learning their specialty and honing their skills to a superior level. The greatest challenge to the concept of centralized control and decentralized execution is the loss of true functional experts.

Flexibility

The need for flexibility seems to be an item of consensus among students of military history. Flexibility is analyzed in this article as the degree to which forces can adapt to their environment, specifically, how logistics policies and practices enable forces to quickly adapt to their environment. Both Alexander and Sherman made advance orders to their armies specifically outlining what they could and could not bring with them, the ultimate goal being the most mobile force they could possibly have. Alexander and Sherman used maneuver as a key tactic in the defeat of their enemies. What is not so well documented, but equally important, is how their ability to move rapidly between battles further enhanced the capability of their armies. Napoleon, on the other hand, was unable to maneuver with any success and was forced to plod along the Russian countryside, enabling the enemy before him to retreat and lay waste to anything of value prior to his arrival. The flexibility to move and maneuver was clearly key in the success of Alexander and Sherman and was integrated into all aspects of their armies, to include their logistics planning and practices.

Additionally, this article examines flexibility not only in terms of an army's ability to respond to the physical aspects of the environment but also in the more intangible aspects of the environment. Napoleon very well may have been able to overcome the hardships he faced crossing the Russian countryside if he had an enemy to fight directly in battle. Ironically, it was the lack of an enemy that led to his eventual defeat. In taking Moscow, Napoleon fully expected the war to be won. When Napoleon marched into the capital largely unopposed, he was no closer to defeating the Russians than when he began his campaign. The Russians simply abandoned Moscow and, after Napoleon's arrival, set parts of the city ablaze. The intangible factor of Russian willingness to trade land for time proved to be the downfall of Napoleon's logistics plan. Though it cannot be said if his logistics plan would have adequately supported his troops had he been able to conduct the war as he had planned, it can be said that his logistics plan based upon the invasion of Russia and the ultimate capture of Moscow was not capable of sustaining his army in the protracted conflict into which he was lured.

It can easily be seen the four principles of logistics offered by this article are not entirely new to anyone familiar with the study of war. In fact, in some form or another, each of these principles appears in several prominent historians' statements of principles of war and/or logistics. However, the method with which these principles can be applied distinguishes them from previous theory.

Flexibility is the key to the success of any organized unit, military or otherwise. If an organization cannot adapt to changes in the physical and intangible factors which encompass its environment, then it will become extinct. The challenge in developing, obtaining, or maintaining flexibility is that it, in some sense, presumes clairvoyance. Clearly, it is easy to identify factors that at present must be adapted to or overcome. It is an entirely a different matter to plan for factors—or contingencies— before they manifest themselves, the mark of true flexibility. The measure to which a unit can respond to unforeseen contingencies is the true measure of the unit's flexibility. Therefore, the principle of flexibility implies the assumption that measurable flexibility is the result of planning for immeasurable and unforeseeable contingencies. Additionally, every contingency that is planned for and not encountered is needlessly planned for. The paradox is there is no way to know with any surety which contingencies will arise and which will not. The lack of a spare tire is only problematic when a flat tire is encountered. Otherwise, the omission of a spare tire represents additional cargo space and possibly better gas mileage. Flexibility then is more an aspect of the art of logistics than the science of logistics. It is both logistically and economically not feasible to plan for every possible contingency, but to the largest degree possible, logistics plans should be adaptable to the gamut of most likely contingencies. Quality planning and experienced logistics leadership can go a long way in the development of viable contingency plans. The major factor in ensuring flexibility, however, is not to attempt to analyze every possible contingency and then plan for it. In fact, this will result in excessive waste, and as pointed out earlier, those contingencies not encountered are needlessly planned for. The key is to develop a logistics plan that at its core is highly adaptive, meaning it requires the minimum possible support from external agencies. By having a highly adaptive logistics plan, the unit's reliance on its environment is minimized, allowing it to function unencumbered in a wide variety of environments, thus enhancing flexibility.

Proper Application of Technology

Both Alexander and Sherman not only properly applied the technology available to them but also integrated this technology into their logistics support practices. Alexander made use of nontraditional pack animals because they better fit the environment in which his army was operating. Additionally, Alexander made use of sealift whenever available. The capture of enemy ports and the coastal route Alexander followed illustrate how he integrated transportation technology into his overall strategy. His route and the ports he captured enabled him to exploit available shipping while preventing his enemy from doing the same. Similarly, the use of shipping enabled better and more rapid resupply, further enhancing his capability to execute his strategy. Sherman, prior to the march on Atlanta, was well aware of the critical role railroads would play in his preparation and execution of the campaign. He took the unprecedented step of bringing this critical asset under his control to ensure its proper use and application in support of his efforts. Furthermore, Sherman had the foresight to form and utilize a rail repair force of some 2,000 troops. The rail repair force enabled the quick repair of any damaged rail lines and resulted in the preservation of this valuable transportation technology.

It cannot be said, however, that technologic superiority necessarily equates to victory. Napoleon's force at the onset of the Moscow campaign represented the most technologically advanced force of its time. Additionally, it enjoyed numeric superiority over the Russian forces by whom it was ultimately defeated. The key in Napoleon's case was that he was unable to exploit his technological advantage, or in other words, he failed to properly apply the technology available to him. There are numerous instances throughout recent history in which a technologically superior force was defeated by a technologically inferior enemy, but those conflicts are not the focus of this article. In a broad sense, technology can be seen as a single tool. No matter how advanced the tool, if it is used improperly or if it is the wrong tool, it simply will not work.

For modern military leaders, the challenge to the proper use of technology is that in most instances leaders do not have the leeway to determine the technology they employ. This is most true in terms of the actual weapons a unit employs. The critical assumption regarding the proper application of technology is that there is some choice regarding the technology that can be used. The greatest leeway, in terms of technologic choice, is in how the weapons of war, to include troops, are provided. It is true in this case the most technologically advanced method may not always be the best method. Though airlift in its own right might be the fastest mode of shipment, attempting to airlift an entire support package may result in a bottleneck and lengthy delays awaiting available air transport. The ultimate result may be the support package, had sealift been used, would have arrived earlier than by air due to sealift's ability to handle a larger capacity of freight. Similarly, the best way to provide potable water is to employ portable water purification units. However, this application of advanced technology is only of use if some source of water exists. This may not always be the case in extremely arid regions. The examples are numerous and further illustrate that superior technology is only of use if it is applied properly or can even be applied at all.

Understand the Environment

A major function of logistics is the neutralization of the effects of the environment. Clearly, it follows that to neutralize the effects of the environment the environment must be understood first. The paradox is the ability to completely understand the environment is beyond the capacity of any individual or group of individuals. This problem is further compounded by the fact that the environment can be defined in varied terms or at varied levels of precision. For example, the United States can be defined as the 50 states and all territories. An equally valid description is that the United States consists of all those individuals who consider themselves American. Furthermore, the United States can be defined in terms of longitude and latitude. The course of action offered by this article is that, given the environment is at best vaguely defined, the key to understanding the environment is to define as much as can be defined and then integrate control, flexibility, and technology in such a manner as to minimize the effect of any unforeseen factors in the environment. Therefore, the fourth logistics principle offered in this article is as much the integration of the previous three as it is an individual concept in its own right.

A major function of logistics is the neutralization of the effects of the environment.

The environment, though definable in multiple terms, does have basic characteristics of interest to military leaders. Though the physical aspects of the environment, terrain, size of the enemy force, and supply requirements, to name a few, tend to garner the bulk of a military leader's attention and accordingly are addressed by his strategy, tactics, and logistics plans, the intangible aspects of the environment are just as important. Napoleon had a fairly good grasp of the tangible environmental factors that he would encounter during his invasion into Russia. What he failed to consider was the intangible factors that dramatically altered the effect of the physical factors of the environment. The Russian willingness to trade land for time resulted in Napoleon's advancing farther into the interior of Russia without garnering a victory. The Russian willingness to surrender their capital without a major conflict resulted in Napoleon's having to press even farther into Russia in search of an enemy to defeat. These two intangible factors resulted in Napoleon's having to completely change his concept of how he was going to defeat the enemy. Furthermore, Napoleon's logistics plan was not developed to support a seek-and-destroy mission across the vastness of the barren Russian countryside. Had Napoleon understood Russian resolve—that is to say, understood the intangible aspects of the environment of a war with Russia and integrated proper control, flexibility, and technology into his logistics plans—the outcome of the Moscow campaign could have been dramatically different.

Alexander was attuned to the environment he encountered during his campaign against Darius. His goal of *homonia* for all people had no hope of being achieved unless he could bring the conquered peoples under his control. Alexander knew that he would not maintain lasting control if he relied upon military force alone to keep his newly acquired territories in line. He, therefore, allowed them a large measure of autonomy with regards to their own civil affairs. Interestingly, Alexander was viewed as a liberator in some of the areas that he conquered since life under Alexander was viewed as better than life under the rule of Darius. Alexander was able to exploit his understanding of the environment to gain support from the local population. He successfully integrated his control policies, flexibility, and technology into a plan that exploited the support of the local environment and could be adapted to any adverse factors that arose from the environment. Alexander would gladly accept support from the local population, but should they choose not to support him, he was more than capable of adapting and taking whatever he needed by force.

Sherman, too, was well attuned to the environment. In fact, one of his overarching goals was to affect the environment of the people he encountered. Sherman, from the planning stages of the Atlanta campaign, was clear in expressing his willingness to acquire whatever was needed from the local population if the need should arise. This would serve the twofold purpose of meeting his logistics requirements while further supporting his goal of bringing the war to the people of the South. Sherman, by understanding his environment, was able to integrate control polices, flexibility, and technology into his logistics plan, which not only limited the effect of adverse environmental factors but also promoted one of his ultimate goals.

The paradigm consisting of the four principles of logistics is intended to guide thought, not specify actions. It facilitates creativity while offering a bounded framework for the development of executable logistics plans.

Modern military leaders face an environment that is extremely complex and consistently changing. Major political events in recent history have significantly changed the political, social, and economic landscape of the world. The potential theaters of operations are now, more than any other time in history, more diverse and geographically separated. Given that, it is impossible to understand every possible environmental factor, both tangible and intangible, that may present a logistics challenge. However, by knowing as much as possible about the people, geography, and culture of many areas and developing logistics plans and practices that integrate proper control, flexibility, and technology, the effect of unforeseen and adverse environmental factors can be minimized.

Other Views on Logistics Principles

The four logistics principles put forth by this article—Centralized Control/Decentralized Execution, Flexibility, Proper Application of Technology, and Understanding the Environment—can be found in some form or another in other research. However, it is how this article applies these principles that is quite different from previous research. These principles are not simply a listing of specific *dos* and *don'ts*, they are intended to form a paradigm or framework of thought from which military leaders can draw to develop their own policies and practices. The biggest failing of a list of *dos* and *don'ts* is that it cannot hope to fit every possible situation and, in fact, may be the worst possible course of action for a given environment or situation. The paradigm consisting of the four principles of logistics is intended to guide thought, not specify actions. It facilitates creativity while offering a bounded framework for the development of executable logistics plans. A comparison of Huston's and Thompson's principles of logistics with the four principles of logistics outlined in this article serves to further illustrate the applicability and adaptability of these principles.

In *The Sinews of War: Army Logistics 1775-1953*, Huston outlines 14 principles of logistics: "First with the Most, Equivalence, Materiel Precedence, Economy, Dispersion, Flexibility, Feasibility, Civilian Responsibility, Continuity, Timing, Unity of Command, Forward Impetus, Information, Relativity."[43] It is clear that Huston's principles are intended to be a list of things to do vice a description of how to approach logistics challenges, the latter being the focus of this article's principles. Similarly, Thompson makes use of the *British Principles of Administration* as a reference for general logistics principles in his book *The Lifeblood of War: Logistics in Armed Conflict*. Thompson's principles—foresight, economy, flexibility, simplicity, cooperation—are fewer and broader in scope than Huston's but still, to a large extent, focus on what to do rather than how to think.[44] If viewed on a continuum with the right being the pragmatic *how to* and the left being the thought-provoking paradigm, Huston's principles would be on the far right, Thompson's somewhere between the middle and the right, and this article's principles would be past the middle and more toward the far left. There is no particular spot on the continuum that is particularly better than the other. However, as one moves from the right to the left, the focus becomes more broad, but the principles' applicability also increases to a larger number of situations. Admittedly, moving to the extreme left of the continuum is of little use because the principles would be so broad that, although they would surely apply to any situation, they would be of little use. The resultant guidance would be broad, with useless principles like *employ sound logistics principles* at all times and *ensure your logistics requirements are met*. Generally, an extreme point on a continuum is of little use. The principles put forth in this article, though less pragmatic than the traditional listing of *dos* and *don'ts*, are still specific enough to provide guidance while enhancing applicability by focusing on outlining a way to think instead of listing specific actions to complete.

Application of the Logistics Paradigm

Operational level commanders should, at the onset, endeavor to understand as much about their theater of operations as possible. Studying history, combined with genuine intellectual curiosity, will go a long way in gaining an understanding of a diverse and often multicultural theater of operations. As the perception of the operational environment becomes more clear, commanders, with the aid of their functional experts, can begin to modify their existing command structure, protocols, and organization to facilitate the proper balance between centralized control and decentralized execution. Certain tangible and intangible environmental factors will lend themselves to either a more centralized control structure or a more decentralized one. For example, a geographically vast theater of operations with diverse climates and terrain lends itself to a decentralized control structure. Therefore, the logistics policies and practices within that theater of operations should support a high level of autonomy between distinct, geographically separate units.

Much in the same manner that the logistics command and control structure should be tailored to the specific theater of operations, so should the application of technology. Advanced technology should not be forced into use in an environment in which it is not well suited. Advanced technology should not be the *square peg* forced into an inappropriate situation's *round hole*. Commanders should use the most advanced technology available that is suited for the theater of operations. For example, no matter how advanced the available motorized transportation is, if the only means of transport through a mountainous area of operations is by donkey, then donkeys should be used. It would be of greater benefit to ensure the best donkeys and donkey drivers are used than to force the use of motorized vehicles in an unsuitable environment.

Much in the same manner that the logistics command and control structure should be tailored to the specific theater of operations, so should the application of technology.

The fine tuning of control practices and technology to best mesh with the environment within the theater of operations is an iterative process. As more information is obtained about both the tangible and intangible factors of the environment, adaptations to existing policies and practices will need to be made. As stated earlier, a major role of logistics is the neutralization of adverse environmental factors and the exploitation of favorable ones. As a better understanding of the environment is gained, policies and practices must be modified to best take advantage of new opportunities or defend against previously unknown adverse conditions. The discovery of a previously unknown water source could result in a change of logistics policy by allowing the practice of drinking locally acquired, fresh water. Similarly, the discovery that a local water source is no longer potable may result in changing logistics policy and banning of the use of any water found in the local area.

An excellent measure of the soundness of existing logistics policies or practices is the speed with which they can be adapted to meet changes in the environment. The speed of change is a direct function of the flexibility of the existing logistics system. It is, therefore, of paramount concern that flexibility be a core characteristic of any logistics plan, policy, or practice. Reliance upon single sources of supply, the belief there is only one way to do something, and resistance to new ideas are key indicators of a lack of flexibility. Without flexibility, the ability to adapt slows, which, in turn, can result in an excellent logistics plan evolving into a dated, useless way of doing things. The highest degree of flexibility should be maintained in all aspects of an operation. By maintaining the highest level of flexibility, the unit's logistics policies and practices will be able to rapidly adapt to a constantly changing environment.

The previous description of how the logistics paradigm should be applied illustrates the pronounced difference between its application and the use of more traditional, list-type logistics principles. Fundamental to the logistics paradigm is its iterative and adaptive nature. It is meant to guide thought instead of specifying specific actions to take. The shortfall of any list of *to dos* is that there will always be some instance where they do not fit, are inadequate, or are the wrong thing to do. The logistics paradigm focuses on integrating logistics policies and practices with the environment in order to ensure adequate support, exploitation of opportunities, protection against threats, and the ability to adapt to change, all key abilities demonstrated during Alexander's and Sherman's campaigns and woefully lacking in Napoleon's.

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How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

Introduction

The night of 19 February 1944 found England shrouded under a heavy cloud cover, but the weather over Germany was breaking. While the murk might complicate getting away and possibly landing, General Spaatz had made his decision—"Let 'em go."[2] What was to be called the Big Week (20-25 February 1944) had begun. The next day, 20 February, saw the largest force of aircraft up to that time take off and head for targets in Germany. England literally shook under the roar of engines—some 1,004 bomber aircraft plus their fighter escorts.[3]

The primary objective of Big Week was to direct a strategic bombing campaign against the Luftwaffe that would destroy its means to continue the war and, as a result, gain air superiority before Operation Overlord.[4] Bomber operations were conducted principally by the Eighth Air Force, with support from both the Fifteenth Air Force and the Royal Air Force (RAF). In-theater logistics support, the key element that allowed the Eighth Air Force to kick off Big Week, came from the VIII Air Force Service Command (AFSC). An order of magnitude measure of this logistics effort is seen in the number of bomber aircraft generated—VIII AFSC made 1,292 bombers available, an unprecedented number. However, many other facets of logistics support, often on a scale never seen before, were also necessary for Big Week. These include preparation—industrial mobilization, unit buildup and beddown, stateside logistics support, facility expansion and modernization, training and equipping of personnel, and organization of air logistics activities. As is often the case, much of the planning, preparation, and execution of the Eighth's bombing operations was subject to uncertainties that made logistics support difficult and required improvisation on the part of both logistics organizations and logistics leadership.[5]

The Industrial Mobilization Plan of 1924 called for instantaneous industrial mobilization upon declaration of war (M-day), based on the assumption that civilian leadership would not accept gradual mobilization prior to a declaration of war, and for military control of the economy. The plan was revised in 1934.

The Foundations of Eighth Air Force Logistics

> *Armies do not go out and have a fight and one guy wins and the other loses and the winner takes all. Throughout history victorious commanders have been those that knew logistics when they saw it. Before any plans can be made to provide an army, logistics must be provided first. History has changed a lot, but logistics has been the crux of every one of these changes, the nail that was missing, which lead to the loss of a country lead to a lot of those decisions.*[6]
>
> **—Major General Hugh J. Knerr, USAAF**

Industrial Mobilization Planning

Organizations and planning that focused on industrial mobilization were primarily the result of the *National Defense Act of 1920* and the *Industrial Mobilization Plan of 1924*. The Defense Act established the War Department Planning Branch, Army and Navy Munitions Board, and Army Industrial College. It also directed the Assistant Secretary of War to prepare mobilizations plans. The Industrial Mobilization Plan of 1924 called for instantaneous industrial mobilization upon declaration of war (M-day), based on the assumption that civilian leadership would not accept gradual mobilization prior to a declaration of war, and for military control of the economy. The plan was revised in 1934. A variety of flaws plagued mobilization planning efforts and the 1934 plan itself. These include incorrect assumptions (no civilian support for gradual mobilization), not addressing the needs of the civilian populace or potential allies, and military control of the civilian economy. Further, the operations staff that prepared the plan failed to seek input from either civilian leadership or industry and did not consult with relevant military logistics planning or support activities. Industrial mobilization planning in the post-1920 period was superficial at best and, therefore, "The muddling that had accompanied World War I mobilization was being repeated."[7] Even as late as 1940, when President Roosevelt wanted some 50,000 aircraft produced per year, there was no guidance as to what types should be produced.[8]

Army/Army Air Forces Logistics Planning

In September 1941, faculty from the Air Corps Tactical School drafted *Air War Plans Division Plan No. 1* (AWPD-1) to address what would be needed should the United States go to war.[9] In August 1942, AWPD-1 was rewritten to address the requirements for conducting an air offensive against Germany, and this resulted in a new plan known as AWPD-42.[10] In the fall of 1942, the US Army Air Force (USAAF) staff made aircraft utilization projections by aircraft type—which included allocations for attrition, transit, reserves, training, and modification—for November 1942 through December 1944, totaling in excess of 65,000 aircraft.[11] However, neither AWPD-1 nor AWPD-42 addressed the needs of the RAF, logistical requirements beyond personnel end-strength, or anything more than a generic total of munitions required. Operational planning took precedence over logistical planning, which resulted in war plans that were incomplete at best. "The organization and proper position of the logistical arm had long been a subject of debate in the Army and the Army Air Force (AAF)."[12] Recommendations by the commanding general, Army Service Forces (ASF) for standardizing organizations and procedures to improve efficiency and effectiveness were misunderstood and rejected by the War Department. Lack of doctrine resulted in each theater commander establishing complex, unique logistics organizations. Further, the Army's lack of emphasis on logistics training prior to the war—due to outright neglect—resulted in too few personnel with an extensive knowledge of logistics and its functions. Ultimately, during World War II, "Large headquarters with ill-defined and duplicating functions were the rule and achieved only partial success in coordinating supply...."[13]

In the summer of 1943, the Bradley-Knerr committee made an extensive study of air force installations in Europe and published the Bradley Plan, which became part of the Air Force Buildup Plan. The plan, largely written by Major General Hugh Knerr, prescribed the manning and organization of air units and installations.

In the summer of 1943, the Bradley-Knerr committee made an extensive study of air force installations in Europe and published the *Bradley Plan*, which became part of the *Air Force Buildup Plan*. The plan, largely written by Major General Hugh Knerr, prescribed the manning and organization of air units and installations. A key feature of the plan was the requirement to establish third echelon maintenance activities (subdepots or service groups) manned by Air Service Command (ASC) personnel at each operational base. Third echelon maintenance would be augmented as necessary by depot field teams dispatched from fourth echelon (depot) maintenance organizations (base area depots and advance depots) to take care of abnormal battle damage repair loads. The *Air Force Buildup Plan* provided for coordinated buildup of combat units, increased flow of materiel, expansion of maintenance and supply installations, and increased stateside Air Service Command personnel. Shortly after the *Bradley plan* was adopted, Knerr was selected to command the VIII AFSC in the United Kingdom (UK), where it became his task to put the plan into operation.[14]

Industrial Mobilization

At the onset of and continuing well into World War II, industrial mobilization was hampered by a proliferation of organizations and procedures.

In 1940, President Roosevelt created an advisory commission to address industrial mobilization. Roosevelt appointed William S. Knudsen, a General Motors executive, as the commission's advisor for industrial production, and the commission reported directly to the President. The commission, however, was largely ineffective.[15] Military efforts to control the mobilization effort and the Army and Navy Munitions Board's autonomy contributed to the commission's difficulties and led to Roosevelt's disenchantment with it.[16] While every effort to gain control of the economy would be thwarted by the President, there can be no doubt this activity behind the scenes created more problems than it solved and negatively influenced civil-military relations. The one bright spot in the commission's performance was giving industry the incentive to build munitions factories by allowing them to amortize all construction costs over a 5-year period. This was the brainchild of Donald M. Nelson, the chief merchandizing executive at Sears and an advisor to the committee.

The President replaced the advisory commission with the Office of Production Management (OPM) on 7 January 1941 and appointed Knudsen as its director general, undoubtedly contributing to the OPM's ineffectiveness, as he was not considered a strong leader. The OPM lacked authority and was plagued by organizational design defects resulting in duplication of effort, so it could not dictate to industry, which still preferred to cater to the civilian population. Even Roosevelt's declaration of national emergency on 27 May 1941 did not enhance the OPM's clout. However, despite all its problems, the OPM accomplished a great deal. It surveyed industry to determine output by examining the potential to standardize production processes. In March 1941, it prioritized raw material usage and production of nondefense items. At the same time, the Army and Navy Munitions Board prioritized production of specific defense products. Considering the long lead times required for procuring and manufacturing machine tools, the OPM's identification of a shortage in this area early in the mobilization effort is clearly significant.[17] The OPM also initiated retraining programs to increase the pool of skilled labor and encouraged industry to hire women.

In April 1941, the President created the Office of Price Administration and Civilian Supply. However, when the organization's leader decided to end automobile and major appliance production for the civilian population, a decision with which the President disagreed, Roosevelt moved the civilian supply function to the OPM by creating the Supply Priorities Allocations Board. Donald M. Nelson, appointed to head the board, still worked for Knudsen as part of the OPM but possessed particular authority his boss did not—the authority to set priorities. The board set out to first establish an allocation process and then set priorities within the allocations. In late 1941, industrial production rates were stagnating because of prioritization problems with both raw materials and the mix of consumer-to-defense goods produced as a result of the OPM's general lack of authority. Nelson, in his role as head of the Supply Priorities Allocation Board, cut back on production of automobiles, appliances, and raw material for civil sector use. While the reorganization that created the Supply Priorities Allocations Board did prove to be essential to satisfying the defense requirements for the Victory Plan, the board was often rendered ineffective by government officials who sought assistance from department secretaries or the President whenever things did not go their way.[18] In addition, the board was challenged with coordinating with the Services—who still retained their procurement authority—the Joint Chiefs of Staff, and other powerful organizations.

In January 1942, Roosevelt created the War Production Board (WPB) and appointed Nelson as its chairman. The War Production Board absorbed the OPM, Supply Priorities Allocation Board, and National Defense Advisory Committee. However, these organizations continued to perform a role under the WPB umbrella. During the war, the advisory committee grew to more than 20,000, with many of these people located at defense manufacturing facilities across the country. Throughout the war, Nelson and his staff were occupied by three problems as they tried to increase production.

- Supplying raw materials from which war materiel and essential civilian products were made
- Providing the plants and equipment in the factories to manufacture the *tools of war*
- Staffing the plants with enough people who had the right skills

Unfortunately, the WPB, like its predecessors, suffered from the lack of real authority to make decisions affecting the civilian populace. Its authority was further diluted when the President created the Office of War Mobilization. It did, however, have "the power to compel acceptance of war orders by any producer in the country and could requisition any property needed for the war effort."[19]

Unfortunately, the WPB, like its predecessors, suffered from the lack of real authority to make decisions affecting the civilian populace. Its authority was further diluted when the President created the Office of War Mobilization.

A key example of the effect the proliferation of industrial mobilization organizations and procedures would have on operational logistics is seen in munitions production. Beginning in early 1942, General George C. Marshall headed the Combined Chiefs of Staff, with authority over the munitions allocation process; however, Prime Minister Churchill and President Roosevelt retained the authority to resolve disagreements.[20] The Army and

Navy Munitions Board determined military munitions requirements, and the Munitions Assignment Board controlled the assignment of all military hardware. The President and his various civilian organizations controlled resource allocation and the means of production. Clearly, with no fewer than four large organizations involved in munitions planning, the beginnings of major difficulties were created that would hinder the effectiveness of Allied bombing from late 1943 onward.

In spite of many difficulties, the industrial output of the US grew almost geometrically into 1944. However, demand consistently exceeded production because of "overestimation of capacity by those responsible for producing materiel."[21]

In sum, while the military put much effort into planning, plans were often incomplete because they were formulated in a vacuum. Military leadership did not seek advice from industry leaders or consult with elected officials. The proliferation of civilian, civil-military, and military organizations—often with overlapping functions and lacking authority—resulted in duplication of effort, confusion, and frustration. Further, the military attempted to gain control of the economy, contrary to the desires of the President, adding to the problems. Clearly, all of this was counterproductive and retarded the efforts to build and sustain the logistics support necessary to conduct large air operations like Big Week. Major General O. R. Cook, Deputy Director of Service, Supply and Procurement, summed it up well:

> It is, therefore, imperative that advance plans provide for more effective civilian war agencies. Most serious duplications, wasteful methods, and complex procedures existed during World War II, when the organization of these agencies was largely improvised. Their very multiplicity impeded the accomplishment of essential activities.[22]

The USAAF's Air Service Command provided stateside depot, technical, research and development, and acquisition support to the Eighth, while the ASF Service of Supply provided the Eighth with items common to the Army and the USAAF.

The Pillars of Support

Several military organizations provided logistical support to the Eighth Air Force and VIII Air Force Service Command in the United Kingdom. The USAAF's Air Service Command provided stateside depot, technical, research and development, and acquisition support to the Eighth, while the ASF Service of Supply (SOS) provided the Eighth with items common to the Army and the USAAF. Although the Eighth and VIII AFSC together had a very large logistics capability and capacity, they depended on the ASC and the ASF for supplies and support and could not have succeeded without their assistance.

On 17 October 1941, the Air Service Command was activated and made responsible for acquisition of weapon systems and provision of fourth echelon (depot level) maintenance support to the warfighting commands.[23] Headquarters USAAF established maintenance policies and procedures, while the Air Service Command issued technical instructions.[24] However, there is evidence that field commanders occasionally issued guidance without ASC coordination.[25] In early 1942, the Air Service Command also became responsible for providing airbases with third echelon (subdepot or intermediate-level) maintenance support.[26] By June 1943, ASC's work force of 50,000 worked day and night to support the war effort.[27] The expansion of ASC's depots and acquisition effort was vital to the Eighth's ability to generate and sustain Big Week raids.

The aviation industry in America had focused on research and development during the interwar years. This focus tended to result in the production of aircraft in small lots, so the ASC acquisition function faced the challenge of trying to convert the industry to a mass production ethos.

> In 1940, when President Roosevelt set a goal of producing 50,000 aircraft per year and funds were appropriated in large amounts, severe acquisition problems developed. Many of the carefully developed procedures relating to advertising and competition had to be set aside simply because of a shortage of time.[28]

Additionally, on 9 April 1942, Congress simplified accounting and contracting by appropriating funds for war materiel directly to the Service departments.[29]

"World War II demonstrated the importance of scientific research in a spectacular manner. Never in the history of warfare were there more rapid and far-reaching scientific and technological developments in weapons."[30] Some of the most significant technological developments were the identification of suitable material and process substitutions to satisfy military requirements. Synthetic rubber is a good example of a substitution that was made in

World War II. Much time and effort was required to research and develop suitable substitutes, but they played an important part in providing the logistical support necessary to sustain combat operations. In hindsight, Cook observed, "A most important logistic lesson is that our safety depends on the continuation of this close collaboration in the development of new instruments of war."[31]

Improvements in supportability were also gained through the combination of engineering expertise and quality maintenance. "By strict adherence to the best standards of inspection and routine maintenance, it was possible to lengthen the time interval between overhauls and thus to increase the force available for operation."[32] As early as July 1941, greatly reduced maintenance and supply demand resulted from lengthening aircraft inspection intervals by 25 percent.[33] The official history maintained:

> During the earlier years of the war ... the desperate need for aircraft in most theaters argued so strongly for repair of the crippled or damaged plane that air depot and service groups were strained to provide the special skills, equipment, and materials to meet the demand.[34]

The spare parts shortages that existed through the end of 1942 made this problem more acute, and the difficulty was not overcome until late in the war.[35]

Between 1931 and 1939, the Air Corps had fewer than 2,000 aircraft, and the depots' small capacity was adequate as they overhauled an average of 166 planes and 500 engines annually.[36] USAAF expansion after the summer of 1940 was so rapid the Air Service Command found it almost impossible to meet the steadily growing maintenance demands. The USAAF did not initiate depot expansion plans until late 1940; therefore, by 1941, the depots were wholly inadequate. From January 1942 through January 1944, depot modernization and expansion, along with the addition of eight depots and many subdepots, meant that capacity outstripped the availability of qualified technicians.[37]

There were just not enough skilled technicians to meet demands, and there was no time to properly train unskilled laborers. The Air Service Command found itself in competition with the more attractive war industry employers in recruiting civilian laborers and generally suffered from a lower priority for civil service personnel fills. A training program for military personnel, which graduated hundreds of thousands of technicians, and special technical training programs for civilian employees recruited to work in stateside depots only partially alleviated the personnel shortage.[38]

The Air Service Command also turned to the private sector for solutions, increasing depot capacity by contracting for training and transport aircraft maintenance and adopting mass production methods to improve productivity.[39] Production line techniques alleviated some problems associated with integrating unskilled labor into depot and flight-line maintenance functions worldwide. A task performed by one mechanic was broken down into several simple steps to quickly make new employees productive. Conveyor belt systems were used to support engine overhaul, repair of parts and accessories, and even some phases of aircraft inspection and repair.[40] Depot management statistically measured and monitored production to identify areas for improved productivity and often adopted the innovative ideas of technicians for improving tools, equipment, and processes. The combination of special civilian training programs, use of military personnel in depots and contractors to augment depot capacity, and process improvements remedied the depot personnel shortage and improved quality and productivity.[41]

The Eighth's performance directly reflected that of the Army Service Forces. General Marshall's reorganization of the War Department as America entered the war had created three separate but equal commands under the Chief of Staff.

ASC acquisition, engineering, research and development, and depot maintenance activities were beneficial to the Eighth Air Force operations. The improvements made within the Air Service Command improved the Eighth's and VIII AFSC logistical support capabilities to some extent. Whether in the form of a new aircraft, a repaired part, an aircraft modification, or a technical directive to maintainers, ASC performance directly impacted the Eighth's performance.

Similarly, the Eighth's performance directly reflected that of the Army Service Forces. General Marshall's reorganization of the War Department as America entered the war had created three separate but equal commands under the Chief of Staff. The new commands were the Army Ground Forces, USAAF, and the Army Service Forces. In the theater, the SOS commander supported the operational USAAF commanders. However, many commanders felt the Services of Supply infringed upon their responsibilities, and many misunderstandings occurred.

The Army Service Forces established command in the UK in 1943, with headquarters functions split between London and Cheltenham, resulting in inefficiency. "This split in

SOS HQ was brought about by the desirability of having SOS planning staffs near the various other planning agencies in London and by the inability of facilities in London to accommodate the entire staff."[42] Communications support was inadequate and travel was time consuming, so the geographical separation caused acute problems.[43]

> ...SOS was the "rear area" organization of the theater. Under field service regulations, the rear areas of a theater were organized as a "communications zone," an autonomous theater-within-a-theater. The communications zone commander was responsible to the theater commander for moving supplies and troops from the zone of the interior forward to the combat zone. In this regard, he relieved the theater commander from ... rear area activities.... In the European Theater of Operations (ETO), however, there was as yet not a combat zone—the entire theater was essentially a rear area. This geographic coincidence... exacerbated the ambiguities over ... logistical roles.[44]

The USAAF maintained its own supply system for things unique to its mission. Therefore, split USAAF supply support responsibilities existed as supply support of common items was provided by the ASF Services of Supply. This split was a source of great contention.[45]

Knerr, commanding general of the VIII Air Force Service Command and later the United States Strategic Air Force (USSTAF) Deputy for Administration, was responsible for all USAAF logistics in the United Kingdom. He hotly contested the Army's tables of organization and tables of equipment that placed artificial limits on authorized manpower and equipment. Knerr wrote in 1945, "The tables of organization and tables of equipment are a convenient and simple means for a staff agency in the United States to do its job easily, but they place the people in the theater of war in a straight jacket."[46] He provided many examples of the impact strict adherence to these tables had on the war. Problems included shortages of vehicles to move ammunition, vehicle maintenance and ordnance equipment, and high-explosive bombs due to increased usage during late 1943. These problems made the execution of Big Week more challenging for the Eighth's logisticians. More important, the latter problem meant that not every bomb dropped would produce the desired effect, increasing requirements to revisit targets.[47] Knerr believed the Army should reinvent its manpower and equipment authorization policies. He wanted the Army to use authorization tables more flexibly, like the USAAF supply tables, treated more as guidelines than strict policy.[48] Although Knerr tried to resolve many of these problems before February 1944, the Army did not adopt his suggestions.

ASC and ASF Services of Supply support was critical to the Eighth and VIII AFSC, but the theater logistics organization evolved throughout the war and was characterized by functional overlaps and power struggles.

ASC and ASF Services of Supply support was critical to the Eighth and VIII AFSC, but the theater logistics organization evolved throughout the war and was characterized by functional overlaps and power struggles. Even after the VIII AFSC shouldered the responsibility for supply distribution, the Army Service Forces provided it some supply support.

Eighth Air Force Logistics

> *Let us, the next time, have our logistics prepared before we plan to operate. We managed to skin by, in this last war, particularly in training personnel, on the logistic side by pulling ourselves out by our bootstraps.... Here 273 groups were set up but not a Depot Group was thought of. That meant that the very late start that was made had to be taken care of in the theater, and in the European theater our logistic establishment in the Burgenwood (sic) area was simultaneously a training school and the support for the operating pilot. But that is a bad situation to be in.*[49]
>
> **—Major General Hugh J. Knerr, USAAF**

An enormous effort was required to receive, support, and sustain the US bomber units, and British support was the key to success in massing strategic bombardment forces within striking distance of Germany. The British provided the materials for and constructed 91 of the 138 airfields required for American flying operations, allowing the forward deployment of USAAF units.

> The buildup of American air and ground forces in Britain (Operation Bolero) was determined by the logistics constraints the British-American coalition faced before the Normandy invasion. During the first year or so of its operational status from August 1942, Eighth Air Force's buildup was greatly helped by Britain's industrialization and the RAF's maturity.[50]

However, logistical sustainment of the deployed units was also critical in order to increase pressure on Germany and step up those efforts during Big Week. These efforts could only be made if flyable airframes and the right munitions were available. Unfortunately, the emphasis at home on aircraft acquisition overshadowed problems of supply and maintenance, which received inadequate attention from USAAF senior leadership until they became acute.[51]

As evidenced by the data in Table 1, the in-theater logisticians found a way to conquer obstacles and get the kind of results necessary to support an effort with the magnitude of Big Week. Although some of the success is attributable to the improvements made stateside, most of the credit goes to the American and British logisticians in the UK and those braving the Atlantic sea lines of communications. Dramatic improvements across the spectrum of logistics were made in less than 1 year, enabling the Eighth to sustain crippling bombing missions against Nazi Germany from Big Week onward.

Leadership and Organizational Evolution

The USAAF established the VIII AFSC to provide the Eighth's combat units with supply, intermediate- and depot-level maintenance, and transportation support. However, in many respects, the AFSC concept was in direct conflict with the ASF Services of Supply.[53]

Air service groups provided intermediate-level maintenance support for two combat groups, possibly with the squadrons dispersed. One air depot group supported two air service groups. However, in Europe, an entire combat group, sometimes two groups, usually operated at a single airfield, complicating intermediate-level maintenance operations.[54]

VIII AFSC established two depots in England and one at Langford Lodge, Ireland.[55] A government contracting oversight gave Lockheed control of all personnel working at the depot in Ireland, which further complicated operations.[56]

General Knerr spearheaded the logistics efforts within the Eighth up to and beyond Big Week. His past experiences in corporate America, combined with those gained while part of the Bradley-Knerr Committee, did much to influence the logistics organizations and processes supporting the Eighth flying operations. Knerr arrived in Britain in July 1943 as the deputy commander, VIII AFSC.[57] AFSC was separate from the Eighth and subordinated to the numbered air force A-4 (logistics) staff, resulting in conflicts between staff office and operating agency. Knerr pressed for a reorganization of the Eighth, consistent with the recommendation he made to the Bradley Committee, elevating AFSC to a status equivalent to other staff functions. He also sought to consolidate A-4 and AFSC headquarters and reorganize Headquarters Eighth Air Force around two deputies—one for operations and one for logistics. Knerr believed a commander in constant contact with his two deputies could eliminate the need for much staff work and get results by being able to make major decisions quickly. Knerr took control of the Eighth A-4 staff on 11 October 1943, while still acting as deputy commander of VIII AFSC. Shortly after that, he took command of the AFSC. Knerr, by December 1943, "absorbed the personnel and functions of A-4 to become, in effect, the sole logistical agency entitled to act in the name of the commanding general, Eighth Air Force."[58]

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Unfortunately, the Eighth took staff and other resources from VIII AFSC, without warning, to stand up the Twelfth Air Force in October 1943. This unforeseen loss of resources degraded VIII AFSC capabilities for some time.[59] VIII AFSC anticipated the activation of IX AFSC, so when this occurred, it did not affect VIII AFSC as the need to support the Twelfth had.[60]

Reestablishment of the Ninth Air Force in Britain prompted further organizational changes. In late December 1943, General Carl Spaatz, commander of the newly created US Strategic Air Force, established a two-deputate structure, administration and operations. The deputy for administration would direct the logistics efforts of the Eighth and Ninth, while the deputy for operations would direct the strategic operation of both the Eighth and

Activity	Dec 42	Nov 43
Aircraft Assembled	12	463
Engines Overhauled	35	714
Aircraft Modified	5	619
Tons of Bombs Delivered	2,329	18,000
Propellers Repaired	65	375
Supply Tonnage Received	4,000	20,600
Truck Tonnage Hauled	2,700	22,194

Table 1. VIII Air Force Service Command Production Comparison[52]

the Fifteenth.[61] With the birth of the USSTAF organization, Knerr became the deputy for administration. Knerr stated, "We had a good demonstration of the smooth operation of that partnership thesis during this war in Europe, and we should never forget that lesson because it produced results."[62] Under this new command structure, Knerr made the final preparations and executed support of the Eighth bombing operations during Big Week.

Workloads resulting from initial combat operations, however, were greater than anticipated. In April 1943, VIII AFSC modeled itself after the Air Service Command by establishing three operating divisions—supply, maintenance, and personnel. This organizational change replaced the traditional general staff structure and produced a more effective operation. AFSC also decentralized operations in conjunction with this reorganization, allowing headquarters to focus on management and process improvement. In 1943, logistics organizations and processes were specialized and optimized, and the reduced threat of bombardment in the UK allowed for more efficient centrally located functions. However, VIII AFSC sustainment of the Eighth's combat operations became a major problem, and the "anxious examination of the factors affecting the rate of bombing operation in the fall of 1943 had emphasized anew the basic importance of its varied functions."[63] VIII AFSC had not addressed all the organizational overlaps, inefficiencies, and difficulties. Despite great organizational improvement, its effectiveness suffered.

Although the number of USAAF personnel in Britain increased by 300 percent in 1943, buildup of AFSC personnel lagged behind that of combat forces and handicapped logistics.

Infrastructure, Personnel, and Training

"Britain contained a core of civilian workers with maintenance and supply management skills" but "logistics met with an immediate shortage of British labor at ports and construction sites."[64] Although the number of USAAF personnel in Britain increased by 300 percent in 1943, buildup of AFSC personnel lagged behind that of combat forces and handicapped logistics.[65] Despite the fact that 1,000 Eighth Air Force personnel completed technical schools each month in 1943, Knerr noted the biggest problem he faced in 1943 was a shortage of personnel, and those he did have required training. He solved the problem, at least for the maintenance function, by cycling personnel through the air depot groups for formal training. Once trained, they were reassigned to air service groups, and "maintenance was no longer a problem."[66]

In late 1943 and early 1944, thousands of unskilled and untrained workers were shipped to the UK to help man rapidly expanding depots. In order to use new personnel quickly, production-line methods were instituted. Although this approach was not efficient, there was no other way to productively employ these people more rapidly.[67]

In June 1941, a factory representative section was established in London, and when the VIII AFSC was activated, it became responsible for the section. The factory representatives assisted the RAF and the USAAF with technical problems in the field and at depot. By May, it had 222 civilians representing 34 different American manufacturing companies. Then, as now, the factory representatives were invaluable in sustaining operations.[68]

Supply

"The decision in 1939 ... to put almost all of the funds made available to the Air Corps into complete aircraft explains in large part the critical shortage of spare parts which persisted through 1942."[69] Throughout 1942, aircraft grounded for lack of parts was a concern throughout the USAAF.[70] To make matters even more stressful for VIII AFSC, on 1 December 1942, the unanticipated withdrawal of supplies and essential personnel to support the Twelfth created much chaos.[71]

Through most of 1943, the Eighth's logistics system suffered shortages because of shipping losses and the support it provided to the Twelfth. "Shortages of spare parts for such items as superchargers, bombsights, and trucks (which themselves were in short supply) were frequent."[72] However, by the beginning of 1944, more than 190,000 supply items were cataloged, spares were at satisfactory levels, and "no aircraft was long on the ground for lack of spare parts."[73] The improvement is attributable to the synergistic effects of:

- Decreases in shipping losses
- Redeployment of Ninth Air Force to Britain
- Local purchase and manufacture
- Improved transportation, maintenance, and supply distribution processes

- The learning curve
- ASC service life extension and economic repair policies

US forces in the UK relied on merchant shipping that was subject to German U-boat attacks. U-boats caused the loss of 6.3 million tons of cargo in 1942, but losses steadily declined in 1943 and afterwards. Cargo reaching the UK increased from some 50,000 tons in May 1943 to about 1 million tons in December 1943, while monthly losses decreased from more than 700,000 tons in November 1942 to approximately 100,000 tons in June 1943.[74]

Although cargo losses subsided, problems with manifests and cargo markings often delayed deliveries to units. In 1942, ships commonly arrived in the UK without the SOS having received a copy of the manifest or loading information. Even when documentation was received in a timely manner, it was often too general, making planning almost impossible.[75] Actions were taken to standardize markings and documentation, and dramatic improvement was realized.

> As late as the first quarter of 1943, only 46 percent of the manifests and Bills of Lading were being received five or more days before the arrival of the ships, and 24 percent were not received at all. However, during the month of April 1943, 80 percent were received five or more days ahead of ships, and in May 90 percent. Thereafter, delays in receiving documentation ceased to be a serious problem.[76]

SOS unfamiliarity with USAAF markings and procedures delayed distribution of supplies and prompted VIII AFSC to establish intransit depots at sea and aerial ports. Further improvements in distribution were realized by dividing the British Isles into two geographic zones. Northern Ireland was later established as a third zone. Intransit depot zoning was based on the capacity of the geographic area to receive supplies, and ships in the United States were then loaded with supplies based on zones, reducing the amount of intratheater transportation required within the UK.[77]

Consequently, VIII AFSC distributed all USAAF supplies received in the UK. With respect to the Eighth, the Services of Supply provided wholesale supply support, and VIII AFSC provided retail supply support.[78] On 14 December 1943, VIII AFSC reported that intransit depots could deliver bulk supplies from the port to a depot or base within 72 hours. They also reported that 88.5 percent of requisitions were satisfied immediately and requisitions for items not on hand were being filled in less than 24 hours. These process improvements may seem simple, but they did wonders to make the flow of USAAF supplies to and within the UK more efficient and reliable.[79]

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It took the USAAF nearly 2 years to develop an effective supply statistics system to aid in spare parts requirement forecasting. As early as 1942, supply planning was accomplished using automatic supply tables based on peacetime consumption rates for 30-, 60-, 90-, and 180-day stock levels in 20-, 40-, and 80-aircraft units. The tables were developed and implemented to help reduce pipeline times for high demand parts with low availability—some were, in fact, taking up to 2 months to obtain from the United States.[80] Supply conferences were held in April and November 1943 to fine tune the tables.[81]

In September 1943, the Air Service Command discontinued automatic resupply shipments for all but new aircraft types. An agreement to ship 50 percent of the 6-month requirement as soon as possible and the remainder 60 days later resolved the problem. Further process refinement averted both shortages and overstocks, and depots were authorized 90-day stock levels of specialized aircraft parts. Subdepots were authorized 6-month levels of common supply items. The prepositioned pipeline stocks were used to fill supply demands at all echelons of maintenance.[82]

In October 1943, the VIII AFSC began to use 3-month forecasts to account for the effects of sortie rates, enemy opposition, repair facilities, and other factors that were not accounted for by the automatic supply tables. Supply transactions were recorded manually, and by late 1943, the aircraft fleet size made it evident that automation was necessary. However, automation did not occur until after 1944. As a result, Big Week did not enjoy the speed and efficiency of an automated supply demand forecasting process.[83]

The amount of equipment being shipped to support the Twelfth caused acute equipment shortages in the Eighth, hampering beddown and support of new units arriving in theater.

During the early part of 1943, the movement of air echelons to the United Kingdom prior to the movement of ground echelons, service units, and their equipment, contributed to low serviceability. A new unit, for example, seldom reached a serviceability rate higher than 50 percent during the first month of operations.[84]

To alleviate theater shortages, the USAAF began to require units deploying to the UK to ship their own equipment 1 month before deployment.[85] Given the lead times associated with the manufacture of peculiar support equipment items, this policy maximized the number of combat ready aircraft during Big Week.

Before February 1943, all requisitions were passed through HQ VIII AFSC, slowing the process and making it inefficient. After February 1943, the supply channels for Air Force-unique supply items were decentralized. Only those needs that could not be satisfied by military supply within the theater were passed to HQ VIII AFSC and filled, preferably by stateside ASC depots. If ASC could not satisfy the demand, local purchase was used as a last resort.[86] Supply stocks after the winter of 1943-1944 were adequate, and overages were shipped back to the United States.[87] Reinvention of supply demand processing procedures, beginning in February 1943, improved supply support.

By May 1942, it was apparent that operational requirements would not permit the delays associated with waiting for parts from the United States, so local procurement was begun.

In a fine example of cooperation and teamwork, the "British dispensed all the petroleum, oil, and lubricants (POL) in Britain, even though most of it came from the United States under lend-lease."[88] Further, British POL manpower brought some relief to VIII AFSC personnel shortages.

By May 1942, it was apparent that operational requirements would not permit the delays associated with waiting for parts from the United States, so local procurement was begun. The Army SOS established the General Purchasing Board in May 1942 for the purpose of locally procuring goods and services.[89] Shortly thereafter, the SOS commander granted VIII AFSC limited procurement authority.[90] This decentralized procurement tool gave logisticians powers similar to today's International Merchant and Procurement Authorization Card program.[91] Also, by early 1943, local manufacture of some spare parts by European theater of operations depots aided in partially alleviating shortages.[92]

A mutual aid agreement establishing reverse lend-lease with the British was signed 23 February 1942. In the first 2 years of the war, approximately 422,721 tons of supplies were procured from the British.[93] "From June 1942 to July 1943, the British provided US forces in the UK half or more of their quartermaster, engineer, Air Corps, medical, and chemical warfare service supplies."[94] During the war, the United States received more than $6.7B worth of goods and services from the British through reverse lend-lease.[95]

The supply support received from the British was significant as the United States suffered losses of 100,000 to 700,000 tons of shipping per month from late 1942 to mid-1943. Logistics personnel made good use of local purchase, local manufacture, reverse lend-lease, and pooled common supplies. These resources brought relief to weary maintainers by reducing the number of aircraft part cannibalization actions required to satisfy supply shortfalls while maximizing the mission capable rate. The RAF's extensive use of US-built aircraft allowed the RAF and USAAF to create a large pool of common supplies in early 1943. VIII AFSC eventually took over procurement responsibility for the common supply pool, and many items were obtained from UK sources, reducing pipeline time and transport burdens.[96] It would not have been possible to execute Big Week in February 1944 if it had not been for the materials the United States received from the British through local purchase and reverse lend-lease, coupled with the synergistic effect of pooling common aircraft supplies and local manufacture capabilities.

Maintenance and Munitions

During 1943-1944, the average life of an Eighth Air Force heavy bomber was 215 days, during which it flew missions on 47 days and was undergoing maintenance, repair, or modification on 49 days.

The quality of maintenance was often the margin of difference between the life or death of an aircrew or the success or failure of a mission. The greatly increased rate of operations, the high incidence of battle damage, and the growing complexity of military planes during World War II made maintenance one of the most vital functions in waging of air war.[97]

Maintenance system operations were flexible, and the amount of maintenance was determined by the availability of equipment, supplies, and manpower.[98] Prior to mid-1944, heavy bomber maintenance organizations were constantly challenged by having to expend labor and parts to keep war-weary aircraft flying, since replacement aircraft were not available in sufficient quantities to stabilize aircraft availability with respect to losses.[99] Fighter and medium bomber serviceability was higher than that of heavy bombers "primarily because of a much lower percent of battle damage and less extensive modification requirements."[100] Large theater depots also put increased flexibility into theater maintenance, relieving VIII AFSC organizations on the airbases of a wide variety of labor intensive tasks.[101] In late 1943, General Knerr established subdepots at various operational bases to enhance field maintenance capability. He also implemented a mobile aircraft repair team concept to support onsite repair of aircraft too badly damaged to fly to the depot. In existence between 1943 and 1945, mobile repair teams comprised of supply and repair trucks and specially trained personnel were very important to base maintenance activities. Because the mobile repair teams repaired damaged aircraft that landed off station and aircraft damaged beyond the bases' maintenance capabilities, base maintainers could concentrate on minor repairs and aircraft regeneration.[102]

Further, Knerr reorganized the VIII AFSC and instituted a system to monitor and control aircraft production. He established "statistical reporting and control procedures at all bases" so commanders knew what the situation and requirements were.[103] This included, beginning in September 1943, collecting 3-month sortie forecasts from the combat commands to forecast and adjust depot workloads in order to reduce backlogs.[104] Late in 1942, the British agreed to let Americans replace British workers at the Burtonwood depot, and "under American leadership and production methods the production of engines and instruments increased at a rapid rate."[105] Depot capacity was also increased when Warton Air Depot was activated in September 1943. Several smaller subdepots, known as advance depots, were activated at selected operational airbases to further enhance field capabilities.[106] Knerr's reallocation of repair and modification work in December 1943 took advantage of the efficiency of specialization by spreading backlogs and making the depot in Ireland responsible for aircraft modification kits.[107] The necessity of modifying all incoming aircraft frequently reduced theater aircraft serviceability rates as much as 16 percent.[108] "Following this reorganization, the volume of work accomplished was vastly increased."[109]

Lockheed Corporation, under US contract, manned the Irish depot. Lockheed's depot support was considered advantageous because it provided in-theater specialized engineering work, modifications, development of special tools, design changes, and kit manufacture for all types of USAAF equipment.[110] Finally, "Between 12 and 20 February 1944 no bombing missions had been flown; hence the backlog of aircraft in repair had been diminished, and an unprecedented number of bombers were available."[111] This period of inactivity was the result of poor weather conditions that restricted flying operations. Maintainers took advantage of the situation to generate the 1,292 aircraft that were available entering Big Week.[112]

The Eighth had a sufficient tonnage of munitions and quantities of ammunition available to support Big Week. However, disagreement centered on the types of munitions available and the types the flying units needed to destroy the targets assigned. Knerr believed the disagreement was due to improper communication of field requirements to munitions production plants in the states. The shortage of desired bomb types began in December 1943 and was not corrected by 1 April 1945. The lack of proper bomb types to support Big Week, given the bombing accuracy of the B-17 and B-24, degraded mission effectiveness.[113]

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Transportation

Knerr attempted to address airlift problems, which he had foreseen, by trying to secure the dedicated airlift he had apparently been promised. In the summer of 1943, he wrote, "Not more than 3 percent of the required airlift has ever been forthcoming in the United States from that promised service."[114] With the exception of inter- and intra-island air service, the Eighth was relieved of airlift functions. These functions had been placed under the Air Transport Command sometime in the summer of 1943. Knerr later wrote in his lessons learned, dated 10 May 1945, that air cargo had been delivered to places where it was "extremely difficult to assemble and process" and that units and equipment were separated from each other, delaying unit mission execution in the theater.[115] A military airline was formed by the Eighth for moving troops and supplies throughout the UK and proved its merit by moving an average of 300 tons of cargo and 2,500 personnel per month in 1943.[116]

The Army Service Forces controlled what was shipped via sea to the UK. Knerr felt the Army Service Forces mismanaged sea shipments, and although it never happened, he believed the Air Force should have been allocated dedicated sealift.[117]

Knerr addressed many key logistical problems in 1943. Not the least of his efforts included resisting the return of the Truck Transport Service to the Service of Supply because "until the Air Forces took over segregation and distribution of their own supplies from shipside (sic) to consuming unit, they starved."[118] A shortage of vehicles added to interservice squabbles over control of the ground transport function. "A truck shortage adversely affected distribution, although it was mitigated by Britain's fine transportation system."[119] In addition, the Eighth's trucks were pooled into a single organization and were effective and efficient in moving supplies from port to base and laterally between bases.[120]

Concerning transportation, the Eighth made the best of a bad situation. It operated an intratheater airlift service but depended on Air Transport Command for intertheater airlift. This combination of intertheater and intratheater support apparently satisfied the Eighth's airlift needs despite its dependence on another command. Despite the sealift problems Knerr believed the ASF created, he never was able to secure dedicated sealift.

Eighth Air Force Logistics—The Bottom Line

World War II, as exemplified by the Eighth's tremendous efforts up to and through Big Week, "dramatized as never before the importance of the essentially undramatic functions of transportation, supply, and maintenance and lent new strength to calls for centralization of responsibility."[121] From 1942 right on through Big Week, improvements were constantly sought in all logistical functions to make them more responsive and effective. Many of the accomplishments were achieved because of Knerr's leadership. Although logistics organizations and process deficiencies still existed in late February 1944, many problems had already been addressed and yielded the logistics capability to initiate and sustain operations the size of Big Week. The improvements made within all the logistical functions, combined with continuous process improvements, put the *big* into Big Week.

Perhaps the most significant lesson of World War II is that the military potential of a nation is directly proportional to the nation's logistic potential.

Success Reaped the Hard Way

> *Perhaps the most significant lesson of World War II is that the military potential of a nation is directly proportional to the nation's logistic potential. The first hard fact to be faced in applying that lesson is that our resources are limited. The next is that the slightest delay or inefficiency in harnessing our logistic resources may cost us victory.*[122]
>
> —**Major General O. R. Cook, USA**

Logistics indeed made Big Week *big* with respect to the Eighth's bombing operations. The Eighth generated 3,880 bomber sorties that delivered 8,231 tons of bombs to targets throughout the Third Reich. The number of operational bombers declined to about 900. However, within 5 days after Big Week ended, maintainers had returned about 150 of the approximately 200 bombers with battle damage back to a combat ready condition.[123] Big Week was *big* because, although Allied air superiority was not won until later, as General Spaatz noted, it did spell the beginning of the end for the Luftwaffe daylight fighter force.[124]

Leadership greatly influenced the logistics capability and support the USAAF was able to establish in the UK. On the negative side, it took a long time for the civil-military organization to evolve into an effective one, and it appears the military spent more time trying to take charge of the economy than to work within the President's system.

General Cook remarked:

> Time is the most precious element in logistics preparation for military security. Measures must be prepared in advance for the all-out, logistic mobilization that must be completed between the time when the danger threatens and the time that war actually strikes.[125]

Indeed, the military did not adequately plan for industrial mobilization, which contributed to the myriad of problems encountered.

Congress' streamlining of acquisition procedures and granting of obligating authority to the armed services greatly reduced lead times associated with the major procurements necessary to prepare for and prosecute the war. However, military management of acquisitions was not perfect. In 1942, there was an imbalance between the number of whole aircraft procured and the spare parts required, resulting in a parts shortage. Fortunately, the spare parts situation improved by 1943, and maintainers had the spares needed to support Big Week.

ASC research and development activities enabled technologies to be exploited and, thus, improved combat capability through a controlled aircraft modification program. Technology insertion was a positive influence on logistics.

Functional overlaps, process inefficiencies, and what could be labeled *intraservice rivalry* between the VIII AFSC and AFS Services of Supply caused many of the processes critical to providing and sustaining aircraft maintenance to break down. VIII AFSC addressed most of the problems during 1942 and 1943, but Knerr, because of his overall dissatisfaction with ASF support, made every effort to make the Eighth as logistically independent from the Army as he could, and he got results.[126]

VIII AFSC suffered personnel and training shortages. The leadership's adoption of production-line maintenance processes was not the most efficient use of personnel, but it did allow for speedy incorporation of unskilled workers into the depots and service groups.

"Host nation support, or whatever resources happen to be in the place one fights, can contribute greatly to a logistics system's capability."[127] British airfield construction allowed the United States to mass bomber units on the island. Interservice supply support was critical to the Eighth's maintenance. Finally, British dispensing of POL made efficient use of manpower, which was important to the undermanned VIII AFSC.

Civilians also provided critical support to the logistics team. Civilians in ASC worked acquisition programs and provided supply and repair support. The Lockheed employees at Langford Lodge depot provided in-theater support in a much more timely manner than would have been possible had they been located in the United States. Factory representatives further enhanced theater maintenance capabilities. In-theater depots, subdepots, and intermediate-level maintenance organizations provided in-depth aircraft repair service independent of stateside organizations. In addition, they developed and provided limited but valuable local manufacture capability, alleviating parts shortages. By the time Big Week arrived, these organizations had evolved and could provide effective logistical support to the combat units, thus enabling sustained bombing raids of 1,000-plus bombers.

Knerr was the single greatest influence on the capabilities and effectiveness of the Eighth's logistics. From the time he served on the Bradley-Knerr Committee to plan the organization and buildup of forces through his tenure as the US Strategic Air Force Deputy of Administration, he constantly improved all logistical functions. His institutionalization of statistical monitoring and requirements forecasting was used effectively to minimize depot backlogs. His implementation of mobile repair teams for battle-damaged aircraft helped sustain the bomber fleet. Finally, he championed making the logistics and operations functions equal at the headquarters level, giving logistics the clout needed to ensure their logistics considerations were taken into account and that logistics and operations were synchronized. "Responsiveness and flexible logistics support requires a management system that consciously links operations and logistics."[128] A good example of Knerr's effort to synchronize operations and logistics was his ability to get 3-month sortie forecasts that were used to plan logistical support.

Knerr was the single greatest influence on the capabilities and effectiveness of the Eighth's logistics.

The processes of producing or allocating munitions, or both, were broken because units did not always have the types and quantities of munitions needed to destroy the assigned targets. Big Week was *big*, but it did not pack the punch it had the potential to because of the many munitions substitutions.[129]

Ship escorts, establishment of distribution zones, ship loading based on destination of goods, improved documentation and communication, establishment of intransit depots, VIII AFSC's pooling of trucks for supply distribution, and theater controlled intratheater airlift were very positive influences on operations.

Eighth Air Force logistics prior to Big Week was the story of *brute force* logistics. Knerr's effort to synchronize logistics and operations and provide responsive, effective, and efficient logistics serves as the benchmark for all airmen. At the end of the day, the logisticians conquered many challenges through innovation and adaptation that yielded improved productivity and paved the way for Big Week. Indeed, Big Week would not have been *big* were it not for the dedicated efforts of the logisticians for months and years prior to 20 February 1944.

Notes

1. Maj Gen O. R. Cook, "Lessons of World War II," Lecture to Air War College USAF HRA, K239.7162241-22, 10 Dec 1947, 4.
2. Edward Jablonski, *Airwar*, Garden City, New York, NY: Doubleday and Company, Inc, 1971, 52-53.

3. USSTAF, "Materiel Behind the 'Big Week'," *USAF HRA, 519.04-1*, 20-25 Feb 1944, 4. On 20 February 1944, Eighth Air Force had fighter escort support from both Eighth and Ninth Air Force units, totaling 902 sorties.
4. Stephen L. McFarland and Wesley Phillips Newton, *To Command the Sky*, Washington, DC: Smithsonian Institution Press, 1991, 168-169.
5. Jacob A. Stockfisch, *Linking Logistics and Operations: A Case Study of World War II Air Power*, Santa Monica, CA: RAND, 1991, v.
6. Maj Gen Hugh J. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," Lecture to Air War College,USAF HRA, K239.716246-18, 19 Oct 1946, 3.
7. Alan L. Gropman, ed, *The Big "L": American Logistics in World War II*, Washington, DC: National Defense University Press, 1997, 10-15, 94, 98-100. The War Industries Board, established in 1917, was the focal point for the nation's resource and acquisition management. The Board, short-lived, was abolished in the wake of post-World War I acquisition reform that replaced streamlined procedures with peacetime bureaucracy.
8. Gropman, 21.

9. Maj H. Dwight Griffin, et al., *Air Corps Tactical School: The Untold Story*, Washington, DC: US Government Printing Office, 1995, 45.
10. Haywood S. Hansell, Jr. *The Strategic Air War Against Germany and Japan, A Memoir*, Washington, DC: Office of Air Force History, 1986, 62-63. AWPD-1 called for 61,799 aircraft, of which 4,328 were to be based in Britain, and required 2,118,625 Army Air Forces personnel. AWPD-42 included munitions requirements and called for a total of 8,214 aircraft, including a 50 percent reserve, to be based in Britain.
11. "AC/AS Plans: 1942-1945," *USAF HRA, 145.92-18*, 1943.
12. USASF, *Logistics in World War II: Final Report of the Army Service Forces*, Washington, DC: US Government Printing Office, 1947, 247-250.
13. *Ibid.*
14. "Materiel Behind the 'Big Week'," 1-2.
15. Gropman, 9-31.
16. *Ibid.*
17. Gropman, 23-25.
18. Gropman, 25-31.
19. Gropman, 31-35, 38, 55.
20. Gropman, 265-283.
21. Gropman, 31-35, 38, 55.
22. Cook, 7.
23. Lois E. Walker and Shelby E. Wickam, *From Huffman Prairie to the Moon*, Washington, DC: Office of History, 2750th Air Base Wing, Wright-Patterson Air Force Base, Ohio, 1986, 146-147.
24. AAF Historical Office, *"Army Air Forces Historical Studies No. 51: The Maintenance of Army Aircraft in the United States 1939-1945," USAF HRA, 101-51* (1945), 133. In February 1942, improvements in engine construction enabled overhaul schedules to be changed. Only when inspection revealed it was necessary were aircraft reconditioned. In 1943, the *obsoletion* policy requiring the retirement of combat aircraft after 6 to 8 years of service was changed and replacement was not required until "whenever superior equipment was available."
25. Maj Gen Hugh J. Knerr, "Knerr Correspondence," USAF HRA, 519.1613, October, November, December 1943. Although the commanders who did this probably felt operational necessity justified their actions, they increased the complexity of logistics support by creating nonstandard configurations. Their actions negated the advantages of interchangeable parts and lengthened the time it took for VIII Air Force Service Command intermediate and depot maintenance activities to return affected aircraft to service.
26. Wesley Frank Craven and James Lea Cate (ed), *The Army Air Forces in World War II, Vol 6, Men and Planes*, Chicago, IL: The University Press of Chicago, 1955, 391.
27. Walker and Wickam, 145.
28. Gropman, 123.
29. Gropman, 122, 282.
30. Cook, 18.
31 *Ibid.*
32. Craven and Cate, *Vol 6, Men and Planes*, 389-392. "The basic data from which policies and instructions were derived came from reports which flowed in from the depots and stations and from various inspection activities.... Although jurisdiction of ASC did not extend overseas, it was responsible for providing service units, equipment, and supplies for all AAF commands."
33. *Army Air Forces Historical Studies No. 51*, 134-135. The suggested overhaul time for the B-17 increased from 4,000 flying hours or 30 to 60 months of service in 1940 to 8,000 flying hours or 84 months of service in 1944.
34. Craven and Cate, *Vol 6, Men and Planes*, 393.
35. *Ibid.* By 1944, aircraft production allowed replacement of heavily damaged planes by new ones, and battle damage repair became less critical. ASC was then able to establish criteria for determining whether or not it was more cost effective to repair or replace badly damaged aircraft, and the job of the depots "became mainly one of modification and overhaul."
36. Craven and Cate, *Vol 6, Men and Planes*, 389.
37. *Army Air Forces Historical Studies No. 51*, 121, 124, 136-139.
38. Craven and Cate, *Vol 6, Men and Planes*, 395. In 1941, there was an urgent need for more and better maintenance, and the quality of maintenance continued to be low during the early months of the war due to a lack of adequately trained engineering officers and civilian mechanics to man the depots. In part, this was caused both by the increased production pressure associated with the parts shortage that existed through 1942 and the fact that ASC was the lowest priority command for personnel fills.
39. Craven and Cate, *Vol 6, Men and Planes*, 391, 395.
40. Craven and Cate, *Vol 6, Men and Planes*, 396.
41. *Army Air Forces Historical Studies No. 51*, 118-122, 127-128, 135. During the period Jan 1942 through Jan 1944, stateside depot maintenance facilities returned approximately 25,000 aircraft and 90,000 engines to service. In 1943 alone, 236,622 aircraft visited the 200-plus subdepots for repair and other work. Finally, an Air Inspector survey conducted in the summer of 1943 attested to the fact that the Eighth Air Force was satisfied with the third and fourth echelon maintenance support it was receiving from ASC.
42. General Board United States Forces, European Theater, *"Logistical Build-Up in the British Isles," USAF HRA, 502.101-128, 9 Jun 1953*, 4.

43. *Ibid.*
44. Gropman, 345.
45. *Logistics in World War II*, 248, 341. Within the ASF, "there was an unnecessary overspecialization in types of service troops, thereby making it difficult to secure maximum flexibility in the utilization of service personnel." Although it was believed units comprised of both USAAF and Army personnel would improve the situation and some experimenting with this type of organization was done, the idea "was not pushed vigorously."
46. Maj Gen Hugh J. Knerr, "Air Force Logistics," *USAF HRA, 519.8086-1*, 10 May 1945, 2.
47. "Air Force Logistics," 6-7
48. "Air Force Logistics," 2.
49. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," 4-5.
50. Stockfisch, 18.
51. Craven and Cate, *Vol 6, Men and Planes*, 390.
52. USSTAF, "*Notes for Supply and Maintenance Chapter,*" USAF HRA, 519.057-4, 1942-1945, 10.
53. *Ibid.*
54. Stockfisch, 19. Further complicating an already complicated task, commanders of combat units wanted command of Air Force Service Command intermediate-level maintenance (air service group) activities on their bases. This quickly became the practice, diluting the authority but not the responsibility of the VIII Air Force Service Command commander.
55. Knerr, "Knerr Correspondence."
56. "Notes for Supply and Maintenance Chapter," 6.
57. *Biographical Data, Personnel Index, USAF HRA, 519.293-1*, 1945. Knerr, a graduate of the US Naval Academy, became an Army artillery officer in 1911. He joined the Air Corps near its birth and retired from active duty in 1939 only to be recalled in 1942, having spent the interim years at the Sperry Gyroscope Company "in work that ... proved invaluable both to him and to the Military Service."
58. Craven and Cate, *Vol 2, Europe: Torch to Pointblank—August 1942 to December 1943*, 742-743. As a member of the Bradley Committee, in the spring of 1943, Knerr had prepared a special report on air service in Africa. In the report, he advocated the elimination of the problems caused by the logistics function being subservient to the staff and operations functions by the simple expedient of elevating the agency to the staff level of command.
59. Stockfisch, 18-19.
60. Notes for Supply and Maintenance Chapter, 6-11.
61. Notes for Supply and Maintenance Chapter, 752.
62. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," 5.
63. Craven and Cate, *Vol 2, Europe: Torch to Pointblank—August 1942 to December 1943*, 742.
64. Stockfisch, 18, and Gropman, 346.
65. Gropman, 364.
66. USAF Historical Research Agency, "Notes on an Interview with Maj Gen Hugh J. Knerr," USAF HRA, *168.2-12*, 24 Nov 1947, 1-2.
67. Craven and Cate, *Vol 6, Men and Planes*, 395-396.
68. "Civilian Technicians and Representatives," *USAF HRA, 519.8023*, 1941-1945.
69. Craven and Cate, *Vol 6, Men and Planes*, 390.
70. Craven and Cate, *Vol 6, Men and Planes*, 394.
71. Notes for Supply and Maintenance Chapter, 2.
72. Stockfisch, 19. "During early 1943 spare parts for 50-caliber aircraft machine guns became so scarce that the total supply was pooled in a single depot with telephone requests being doled out by special truck delivery."
73. "Materiel Behind the 'Big Week'," 3.
74. Gropman, 347-348, 359, 361-363, and Maj Gen William E. Kepner, "Supply (Congressional Committee)" Kepner Collection, USAF *HRA, 168.6005-84*, 3 Jun 1945, 2.
75. "Logistical Build-Up in the British Isles," USAF HRA, *502.101-128*, 9 Jun 1953, 25-26. "Entries on the manifest such as '1000 boxes of Quartermaster Class I supplies' were not uncommon."
76. *Ibid.*
77. Notes for Supply and Maintenance Chapter 3, 128.
78. Notes for Supply and Maintenance Chapter 3, 3.
79. Knerr, "Knerr Correspondence."
80. Notes for Supply and Maintenance Chapter, 3.
81. "Stock Control in the ETO," USAF HRA, *519.8024-1*, 1945, 1, 8-9.
82. "Stock Control in the ETO," 25, 31.
83. "Stock Control in the ETO," 3-5, 10.
84. Notes for Supply and Maintenance Chapter, 5.
85. Notes for Supply and Maintenance Chapter, 4.
86. "Stock Control in the ETO," 15-16, 19-23, 36-37. Combat group demands not met were first sent to the air service group, then the depot. If neither organization could satisfy the demand, it was then sent to headquarters VIII Air Force Service Command. A three-tier supply priority system was established, in which priority was based on urgency of need. Aircraft grounded for lack of parts were given highest priority, and those requirements were sent via teletype to the air service group. If the air service group could not fill the request, a teletype was sent to the air base depot, and if it still could not be satisfied, a cable was sent to the responsible stateside depot.

87. Notes for Supply and Maintenance Chapter, 5. AOG rates fell from 5 percent in Dec 1942 to 2.3 percent in Nov 1943.
88. Stockfisch, 19.
89. General Board United States Forces, European Theater, *Logistical Build-Up in the British Isles*, 15.
90. "Stock Control in the ETO," 22-23. Local purchases were limited to 25 pounds sterling ($100), required written approval of the station commander, and could only be done when urgency of need did not permit procurement through the British Equipment Liaison Officers. Station purchase (for example, contracting) officers had standing authority to make purchases not exceeding 5 pounds sterling.
91. Deputy Assistant Secretary of the Air Force (Contracting). *Contracting Toolkit: IMPAC*, 5 Jan 2000 [Online] Available: http://www.safaq.hq.af.mil/contracting/toolkit/impac/.
92. Notes for Supply and Maintenance Chapter, 2.
93. "Stock Control in the ETO," 19. Reverse lend-lease arrangements were used to make routine purchases exceeding 25 pounds sterling and were processed through the commanding general, VIII Air Force Service Command and the RAF Equipment Liaison Officers.
94. Stockfisch, 18.
95. Gropman, 273, 277.
96. Notes for Supply and Maintenance Chapter, 4.
97. Craven and Cate, *Vol 6, Men and Planes*, 388, 394.
98. Craven and Cate, *Vol 6, Men and Planes*, 389.
99. Stockfisch, 43-44.
100. Notes for Supply and Maintenance Chapter, 4. For example, medium bomber serviceability went from 29 percent in July 1943 to 92 percent in Nov 1943.
101. Craven and Cate, *Vol 6, Men and Planes*, 391.
102. "Notes for Supply and Maintenance Chapter, 6, 11. Transport of aircraft via truck to depot in the UK was infeasible due to the physical constraints associated with humpback bridges, narrow winding roads with reverse camber, and bridge clearances.
103. "Materiel Behind the 'Big Week'," 2-3.
104. Knerr, "Knerr Correspondence."
105. Notes for Supply and Maintenance Chapter, 6. Although it is not clear from the historical account if VIII Air Force Service Command sought to replace British personnel at Burtonwood depot with Americans because the British were not productive or if the decline in British employee productivity was caused by the agreement, it is clearly documented that productivity increased.
106. *Ibid.*
107. "Materiel Behind the 'Big Week'," 3-4.
108. Notes for Supply and Maintenance Chapter, 5. The shortage of station overhead personnel also necessitated the use of skilled service personnel for overhead functions.
109. "Materiel Behind the 'Big Week'," 4.
110. "Materiel Behind the 'Big Week'," 6. Despite initial USAAF reservations regarding Lockheed's control of depot personnel at Langford Lodge, which occurred due to an error made by the government in writing the contract, it appears the contractor managed the personnel satisfactorily.
111. "Materiel Behind the 'Big Week'," 4.
112. *Ibid.*
113. Maj Gen Hugh J. Knerr, "Letter from USSTAF in Europe Deputy Commanding General, Administration to Commanding General," USAF, HRA 519.8671-3, 1 Apr 1945.
114. Knerr, "Knerr Correspondence."
115. Knerr, "Air Force Logistics," 7.
116. "Notes for Supply and Maintenance Chapter," 12.
117. Knerr, "Air Force Logistics," 7.
118. Knerr, "Knerr Correspondence."
119. Stockfisch, 19.
120. Notes for Supply and Maintenance Chapter, 12.
121. Craven and Cate, *Vol 2, Europe: Torch to Pointblank—August 1942 to December 1943*, 742.
122. Cook, 6.
123. "Materiel Behind the 'Big Week'," 4.
124. Richard G. Davis, *Carl A. Spaatz and the Air War in Europe*, Washington, DC: US Government Printing Office, 1993, 327.
125. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," 7.
126. Knerr, "Air Force Logistics," 1.
127. Stockfisch, 52.
128. *Ibid.*
129. Knerr, "Air Force Logistics," 6-7.

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Colonel Logan "Jay" Bennett, USAF, Retired

Murphy's Law

Colonel Crawford O. Murphy was my boss for 1 very remarkable year in the late 1970s. I was in a very comfortable assignment at the Military Personnel Center, Randolph AFB, Texas, but chose to go to Osan AB, Korea, for my second remote assignment in 15 years. About a month before departing, I received my first correspondence from the unit's deputy commander for maintenance (DCM), Colonel Murphy. It was a handwritten note stating, "Don't bring your golf clubs; we don't have time for it here." I'd heard all sorts of stories about this intrepid character (most recently from a friend, Major Luke Gill, who had arrived at Osan AB months earlier), so my anxiety was heightened with this caustic note. In the next 12 months, I was to receive many of these notes.

TIt always began at 0430 (except for Sunday) with a phone call to my quarters. I was usually in the shower at that time and kept a close ear for the ring. It was Colonel Murphy. "Good morning, are you the commander of the Animal Gathering Society (sometimes it was the All Girl Squadron)?" This was followed by a long pause. "Major, why aren't your crew chiefs getting their paychecks on time?" Or, "Why do your crew chiefs need haircuts?" Or, "When are you going to insist on clean forms on your airplanes?"

My assignment, on paper, was to command the component repair squadron (CRS). However, when I arrived, the departure of several field grade officers meant the maintenance control officer, CRS commander, aircraft generation squadron (AGS) commander, and quality control (QC) jobs were all up for grabs. Murphy wanted time to evaluate the possible replacements before selecting them. He insisted that departing incumbents remain in place until the very end of the month they were eligible to return from overseas. (All incoming field grade officers arrived at the beginning of the month. A year later, they left Osan at the end of the month, making this nearly a 13-month tour of duty, a Murphy policy.)

Colonel Murphy interviewed all senior noncommissioned officers (NCO) and officers one-on-one within days of their arrival. This interview was strictly a one-way conversation. Here's the nature of my interview, as I've kept my notes over the years and used them myself.

- Be happy and aggressive.
- Know the -6.
- The squadron maintenance supervisor runs maintenance.
- Production belongs to the senior NCOs, not the officers.
- Identify weak people and press them to become stronger.
- Don't accept anything short of perfection.
- No battles, period.
- Quality assurance (QA) reports are to be answered with what we're doing to correct the problem.
- Know at what level decisions should be made and hold those people responsible.

In about 2 weeks, Murphy made his decision on assignments, and I was extremely fortunate to be selected to command the AGS, replacing the extremely popular and very competent Major Dick Rose.

In those days, Osan (51st Composite Wing) had 24 F-4Es, 16 OV-10s, and a full-time detachment of 6 RF-4Cs. The maintenance organization was an early production-oriented maintenance organization (POMO), with a DCM—Colonel Murphy, also known as *Alpha One*. While the tour of duty was nearly 13 months for most of us, certain key staff members served longer tours (Murphy served for 3 years).

My memory is very clear about those events 22 years ago, serving as AGS commander under Alpha One, and I would like to share some of those experiences with you.

Permit me to describe a standard day. It always began at 0430 (except for Sunday) with a phone call to my quarters. I was usually in the shower at that time and kept a close ear for the ring. It was Colonel Murphy. "Good morning, are you the commander of the *Animal Gathering Society* (sometimes it was the *All Girl Squadron*)?" This was followed by a long pause. "Major, why aren't your crew chiefs getting their paychecks on time?" Or, "Why do your crew chiefs need haircuts?" Or, "When are you going to insist on clean forms on your airplanes?" Then, before I could answer, he would hang up. After a few of these calls, I became very annoyed, with him and with my inability to anticipate his daily questions. It soon became apparent that Alpha One cruised the flight line every morning from 0300 on, searching out *his people*, my crew chiefs. After several weeks of this, I eventually got used to it and followed up during the day, unless it was an airplane problem, which I investigated before I left my quarters in the morning.

I always stopped by job control before starting my rounds. Murphy's job control was unique, as were his expectations. Every decision that could be moved from job control to the flight line was, letting the AGS expediter work the problem through the specialist supervisors on the line and work out a course of action. Job control was to let that course of action stand unless they could prove it impacted future schedules—or other priorities to the on-scene bosses—to prepare aircraft to fly. Job control should keep reminding the flight line of considerations, and they should obtain the help on-scene bosses needed. Colonel Murphy considered the AGS expediter the orchestrator of the ongoing maintenance effort. He spent lots of time needling the specialist dispatchers for failing to keep the workforce occupied when there was something productive they could be doing, such as dispatching avionics specialists to clear delayed discrepancies. He never let the shop chiefs forget they were the ones who should be bugging job control for an airframe or to do what needed to be done.

After establishing how the schedule was being met for the day, I usually visited each shelter that housed an aircraft on the day's flying schedule. Over time, you could tell just by looking at the activity (or listening to the radio) whether the bird was coming together or not. It was especially nice to have fewer than 50 airplanes—knowing tail numbers, locations, names of the crew chiefs, and the aircrafts' history wasn't difficult.

Colonel Murphy's reputation, integrity, and work ethic centered on scheduling. With 27 F-4Es authorized and 24 or so on station (2 or 3 were often at programmed depot maintenance), his ironclad policy was to keep half of them on the ground for scheduled, unscheduled, and delayed maintenance; time compliance technical orders; washes; paint; weapons load training; and so forth. He forbade any tail number *swapping*, with the policy concurrence of the deputy commander for operations and the wing commander. In short, if aircraft 421 was scheduled to fly on Monday, Tuesday, and Thursday, it damn well flew on those days. No one substituted one airplane for another, or they would have been fired. Case closed. If the wing commander took aircraft 551 to Kunsan for a conference on Monday and returned that evening with it out of commission, it was not substituted if it wasn't able to fly as scheduled on Tuesday. That's what spares were for. On a typical day, using 11 jets, the schedule called for 9 + 3; that is, 8 + 3 spares on the first go. The turn was a diminishing rate, 8 + 4, then 7 + 5, and so on. I recall, quite early one morning when driving down B-ramp, seeing two crew chiefs scuffling in front of a shelter. I broke it up and asked why they were fighting. Colonel Murphy had been by that morning and said the crew chief of the aircraft flying the most sorties that day would get something special from him (probably a six-pack if memory serves me.) The scuffle broke out because one crew chief's airplane was a spare that day and he was being teased by the other guy because the spare would never be flown and was thus ineligible for the Alpha One *special*.

Colonel Murphy's reputation, integrity, and work ethic centered on scheduling. With 27 F-4Es authorized and 24 or so on station (2 or 3 were often at programmed depot maintenance), his ironclad policy was to keep half of them on the ground for scheduled, unscheduled, and delayed maintenance; time compliance technical orders; washes; paint; weapons load training; and so forth.

Combat turnarounds occurred almost every day. A special location was set up where returning jets were *combat turned*, engines running, weapons loading, refueling (engines were shut down), and overall servicing, including the through-flight inspection. We often *turned* aircraft in less than 30 minutes. Given the scheduling scenario of a diminishing number of follow-on sorties with each turn, there were always plenty of airplanes available, mainly because of the discipline Murphy had established for scheduled maintenance on nonfly days. That was the key to his extraordinary success. (From July 1978 to July 1979, the wing had an astonishing 1.02 sortie rate for the F-4E.) I cannot emphasize enough the discipline that made this system work. No one changed the weekly schedule, where tail number assignments were published. It was common at the end of the flying day to have airplanes fully mission capable and no pilots to fly them. There were no exceptions to the *no change* policy unless we had an operational readiness evaluation or operational readiness inspection (ORI), and obviously, the wing then had to generate *all* aircraft.

Perhaps now would be an appropriate time to share an event that occurred on 9 November 1978 during an ORI. At about 1700, following an especially tough flying day (one F-4 needed an engine change, and one had a serious fuel leak), the Pacific Air Forces (PACAF) ORI team landed after holding on final for an F-4 to be removed from the barrier. The senior maintenance inspector, Lieutenant Colonel Harry Blue, went directly to job control where the commanders and maintenance supervisors were assembled. Harry walked in, checked the status, got the *brief* from the maintenance control officer, and commented to me when he walked out, "You'll never make it." We had 24 F4-Es and about 15 OV-10s, and no one knew how many RF-4Cs Kadena would send us. Of the F-4s, five were in very serious shape, including one in phase and one in phase prep, besides the two with major problems mentioned above. We needed to generate all 24 F-4s in 12 hours, or by 0500 the next morning, to get the top rating. We returned to our squadrons, established the shifts, and subconsciously fretted over how in the *Sam Hill* we would get it done. Murphy always went to the officers club for dinner at about 1800. Always. There was a special maintenance table at the club in those days that sat about a dozen people. The head seat was Alpha One's. No one else sat in that seat, unless it was a tourist (upon which Murphy would exit the club and go to his quarters). That infamous night, Murphy went to the club as usual, ate alone (the rest of us were sweating bricks on the flight line), and then went to his quarters on the hill. All night, we watched the activity on the line, and one by one, the jets came together. Murphy showed up at about 0400, just in time to watch the last of the engine changes—the engine run and the preflight completed about 5 minutes before the 12-hour generation expired. All 24 F-4s, OV-10s, and RF-4Cs were in-commission and preflighted. The ORI report read in part:

> The professionalism displayed throughout the maintenance complex was the best observed in PACAF.... "Excellent" rating for the DCM complex ... and, "highly commendable" on the unit's miraculous recovery from severely degraded maintenance following an especially tough flying period.

Months later, during a rare post-dinner exchange with Alpha One, I asked him about that evening. "Colonel, during the most important period of time during our assignment here at Osan, you were in your quarters. I don't understand." His comment was enlightening, "Jay, I spent months preparing you and the other members of my team to go to war. My goal was to put you all in a position to lead the effort, and you did. I wasn't needed, and my presence would have had a negative impact on your efforts." That was classic Crawford Murphy.

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Aside from the normal, day-to-day activities of a flying unit, our role as commanders was to deal with our people and their problems, with an unrelenting eye (and ear) on generating airplanes. Not that we had to have the job control net in our office (we didn't), but our maintenance supervisors were always keeping us informed. Murphy made it very clear to all of us that *production* meant senior NCOs and *management* meant officers. The real power belonged to the E-6/E-7 line chiefs and our superintendents. The officers provided the wherewithal for them to do their job.

Which brings me to the subject of meetings under Alpha One. He believed big meetings with lots of people invited decisions to be made at too high a level. He felt that hardly ever in a meeting atmosphere does the DCM make a decision that couldn't be made better by someone below him. He also said that because the boss in those circumstances seldom had enough information to make the right decision the decisions made were "usually unmade by sundown." He believed the DCM should do only those things that only he could do. For example, he thought it was most absurd to have people call him to get approval for cannibalizations. Most of the decisions traditionally reserved for DCMs were, in his view, inappropriate because they were decisions dealing with the minutiae of executing plans, programs, or schedules. Murphy decided, with advice, how many sorties to fly in a period and what patterns to use in scheduling. He would set the policy on what types of things to cann or what types of missions to support. That would allow others to make the right decisions on each occasion. So what about his meetings? There was only one, the *Seventeen-ten* (1710). The meeting was called by the noncommissioned officer in charge (NCOIC), Deficiency Analysis (an E-7) whenever there was a deviation from the day's flying schedule (air abort, ground abort, maintenance nondelivery). It didn't matter if it was triggered by a deviation at 1700 that day or 0730, and if there wasn't a deviation, there was no 1710. Each commander; maintenance supervisor; complex superintendent (a chief); QC officer; maintenance control officer; job control officer; and NCOIC, Deficiency Analysis showed up in Murphy's small office. There weren't enough seats, so one person stood (usually Captain "Bubba" Parker, my maintenance supervisor). The meeting began promptly at 1710. Murphy wanted the entire wing complex, most of whom had gone to their quarters by then, to know that the

DCM complex was on *point*. The NCOIC, Deficiency Analysis opened the meeting by saying something like, "Aircraft 330 had a ground abort for a leaking brake," upon which Murphy would look right at me with hawklike eyes and ask why. Bubba would tell him the brakes had been changed in phase the day before, and Murphy would look at Luke and ask why. Captain Steve Smitherman, the Equipment Maintenance Squadron maintenance supervisor, would say, "Sir, the brake stack was installed backwards and Airman so-and-so was unsupervised, and Staff Sergeant Smith or Jones failed to do an IPI." Murphy would then look to the QC manager (Major Rich Romer) and ask why QC didn't catch it. Sometimes this dialog would last half an hour on each deviation until he was satisfied the root causes were discovered. Days with more than one deviation often had the 1710 go way past 1830. After deviations were discussed, every repeat and recurring writeup written since the last 1710 meeting was discussed. Sometimes, we hashed over scores of these with the same dissecting inquiry used on the deviations. At least we had time to prepare for these. I recall never going more than a couple of days without a 1710 that year with mixed emotions, because if we had, it would have allowed a lot of repeat or recurring writeups to pile up.

After the 1710, most of us returned to our offices to wrap up the day and make sure the swing shift course was set. Then off to dinner at the officers club, where we would probably find Alpha One finishing his meal and others in various stages of dinner. The dinner period was enjoyable—not a lot of shoptalk—rather, poking fun at each other and once in awhile taking a fun shot at Colonel Murphy.

Dirty airplanes were not acceptable, and had Murphy found one to be unacceptable, I would catch hell. That included faded paint or greasy fingerprints on access panels. The crew chiefs knew it, too, as they were pampered by Alpha One almost to the point of fraternization. He knew them all by name, often their backgrounds and individual personalities.

Once during our tour, each officer was invited to Murphy's quarters for homemade soup. That was a very special occasion, and surely, all of us have special memories of that event. The setting was a little awkward given the circumstances—a bachelor colonel's quarters—with classical music. The soup was superb. The evening lasted about 90 minutes, and then it was time to go. No shoptalk, just listening to him read some favorite poems or inquiries about our family and life.

Saturdays were like every other day for the most part, occasionally with only half a day flying. We never flew on Sunday. I used Sundays to spend quiet time with each airplane, without any company, to review the forms and evaluate the overall condition of the airplane. Dirty airplanes were not acceptable, and had Murphy found one to be unacceptable, I would catch hell. That included faded paint or greasy fingerprints on access panels. The crew chiefs knew it, too, as they were pampered by Alpha One almost to the point of fraternization. He knew them all by name, often their backgrounds and individual personalities. I recall the image of a crew chief leaning in the open window of Murphy's pickup truck at 0500 or 1000 or 1430, joking with their big boss. He loved those crew chiefs. He often had lunch with them in the flight-line cafeteria, a facility that he insisted on having near the troops.

I saw Colonel Murphy cry one time, and I hope he forgives me for bringing it up, but it shows the compassionate side of this special person. One of his favorite crew chiefs was a staff sergeant who was on his third year at Osan. He was married to a Korean national and was also one of the most respected mechanics in the complex. This sergeant was indicted for black marketing activities (he sold a washing machine to a Korean). When Colonel Murphy learned of this, he cried like a baby. He was devastated. Murphy spoke on his behalf at the court martial in emotionally muted tones you could barely hear in the courtroom.

There are, of course, far too many memories to capture in this narrative about Alpha One. Each one of us was pushed to our full potential, and in my case, I carried his intensity and focus on to greater challenges in subsequent assignments. It became natural in the years following Osan, when faced with problems and decisions, to find the clear and correct course of action using the foundation provided by him. He was outspoken and light-years ahead of his time, but his focus was always the same. In my later active duty and Boeing years, some of my decisions were challenged and criticized, often by government agencies with a different agenda, but my bottom line was always a clear conscience with the knowledge that I had done the right thing. I owe that to Crawford O. Murphy.

Some of us stayed in touch with our old boss over the years. He retired in the early 1980s and returned to his birthplace and home in Cambridge, Maryland. There he was affectionately known as Neal. I visited him twice and found him to be very happy and comfortable. He remained a bit curt and always the disciplinarian but very modest and full of life. He passed away in the early 1990s.

Crawford Murphy should have been promoted again. He made colonel in less than 15 years, as a nonrated maintenance officer. His downside, I am told, was his impatience with higher headquarters and the reorganization of aircraft maintenance that was occurring in the Air Force. His attitude on that was unacceptable to his superiors, but he, nevertheless, voiced his objections at every opportunity. His messages were infamous. One I will never forget was known as the *Shah of Iran* message. It started out in a message to Third Air Force and PACAF. "I feel quite certain that the Shah of Iran thought the only obstacles to his program were some older supervisors who were resisting change." He then went on to outline two major logistics initiatives (POMO and centralized intermediate repair facility [CIRF]) in PACAF that he felt were detrimental to "flying plenty of safe and effective sorties," his motto. He believed the idea of a self-sufficient aircraft maintenance unit (AMU), the heart of POMO, was an appealing idea. However, he also felt it took far more fully qualified and experienced technicians than we could afford, working in a more stable environment than we could provide. Additionally, he felt that the specialists, under POMO, were fragmented and that led to instability. Constantly moving and borrowing specialists between shops and other AMUs turned out to be an unsupervised nightmare and led to poor quality work. He also believed the quality of troubleshooting was reduced under POMO because complete malfunction histories were not readily available to supervisors. Finally, he believed qualified supervision was seriously reduced, primarily because the system would not provide the smaller work centers with the higher NCO grades previously authorized in the larger organizations.

Crawford Murphy worked with CIRF for 3 years. He didn't believe it enhanced our combat capability in Korea; he felt CIRF degraded it. Remember, he was managing F-4 and OV-10 aircraft with considerable intermediate-level maintenance requirements. The loss of a reparable asset out of the base-level maintenance system was unacceptable. He also felt that airlift, absolutely critical to a functioning CIRF, made the whole process extremely vulnerable in wartime. The loss of the base-level pipeline, from shop to flight line to supply, was simply unacceptable. His arguments continued with challenges to the economics of the system, the increased damages to avionics line replaceable units, and loss of the capability to rapidly fix bad boxes during wartime.

In his end-of-tour report, he credited the "unparalleled cooperation of the aircrews and their bosses ... who willingly did the mission in a fashion that provided us the best chance of success regardless of their personal druthers."

Some Murphyisms:[1]

Crawford Murphy should have been promoted again. He made colonel in less than 15 years, as a nonrated maintenance officer. His downside, I am told, was his impatience with higher headquarters and the reorganization of aircraft maintenance that was occurring in the Air Force.

- Commanders are supposed to command—maintenance control officers are supposed to stay in maintenance control and not bother anybody.
- Maintenance control officers are not supposed to be out on the flight line—that is squadron business, not maintenance control business.
- First of all, it's [maintenance] going to have one boss—me. I will not ask and do not expect either my assistant, my maintenance control officer, or my squadron commanders to set maintenance policy. I want one clear source of policy—me. However, I want my commanders to command. I do not want my staff to interfere in that command.
- The single most important thing controllable at wing level that will advance the sortie-production goal is to follow the weekly flying schedule. Once it has been decided which aircraft will fly on which days, do not change it. If you think just a few changes will be acceptable, you are wrong. When your people realize they can count on the schedule about as well as a sunrise, you can be sure they will fight to fly that schedule.
- I hear officers shy away from field assignments because the risks are high, exposure low, and the work hard and less forgiving. Base-level jobs were, in my opinion, the most difficult—and for me the most rewarding—and they were the ones where the rubber meets the road and the flying and fighting are done.
- Probably the most frustrating job is being my maintenance control officer. Most maintenance control officers think they control maintenance. I don't want that. I want him to coordinate all operations staff and supply matters and coordinate maintenance schedules. The NCOs on the flight line do a marvelous job controlling maintenance and do not need lots of direction. There is no need for directions from job control, just information and outside support.
- I expect being my assistant DCM must be a frustrating affair. I always instruct my assistant to not give any instructions or directions to maintenance people about the job of maintaining aircraft. I never ask him to catch the overflow and do things that I don't

have time to do. The assistant is responsible for civil engineering programming, manpower changes, communications, budget, programs and plans, and training. He is in charge of ORI procedures and maintenance manning in the command post during exercises and preparing nominations for unit and individual awards. Two areas that make me the most money are his actions in manpower and civil engineering matters. No one is usually working those areas daily to get results; he does and gets results.

- I think all squadron commanders who work for me would agree there really are only a few things that I insist be done my way. They have more decisionmaking power than any maintenance squadron commander I know. One of my favorite answers to a question is, "I don't plan to answer that—you do what you want to do." If I think they made a dumb decision, I tell them, but I don't pull the decision up to my desk when they make a dumb one.
- I ask commanders to tell me why we have holes in the schedule and what they are doing to prevent it from happening again. It is useless to discuss preventive action unless you know who did what wrong. Only then can you find out why it is done wrong, identify the cause, and develop a good corrective action.
- Insist that your people be aggressive supervisors. Ask them to do the maximum, not the minimum acceptable. If they are the type person who will do only those things that, if left undone, you could prove they should have done, then they are meeting the standard. To be outstanding, they must do the things their bosses wouldn't even know they had the opportunity to do until they saw it done.
- I warn incoming supervisors they have two tasks anytime they receive a QA report: one, identify deficiencies and, two, do not debate the validity of the report. Once the report is written, the owner of the deficiency needs to fix the problem and prevent it from recurring as best he can. Reporting deficiencies is not a happy business. I want a ranking officer in QA. Only my assistant and I outrank him. Each morning before 0700, I have my QA officer bring me the results of the on-aircraft inspections of the last 24 hours. I want to be in a position to mention success and failure to those responsible as I visit them during the day. I see all QA reports when they have been completed to show cause and corrective action and preventive action. Most failures of QC control inspections are directly attributable to first-line supervisors; either they did not teach the failed technician how to do the job, or they did not insist that the technician do the job he was trained and directed to do.

Notes

1. Taken in part from "Compendium of Things," authored by Colonel Murphy, and sent to me in 1979.

One machine can do the work of 50 ordinary men. No machine can do the work of one extraordinary man.

—Elbert G. Hubbard

Our military culture must reward new thinking, innovation and experimentation.... Every dollar of defense spending must meet a single test—it must help us build the decisive power we will need to win the wars of the future.

—George H. W. Bush

Let it be admitted that the modern technological revolution has confronted us with military problems of unprecedented complexity, problems made all the more difficult because of the social and political turbulence of the age in which we live. But precisely because of these revolutionary developments, let me suggest that you had better study military history, indeed all history, as no generation of military men have studied it before.

—Frank Craven

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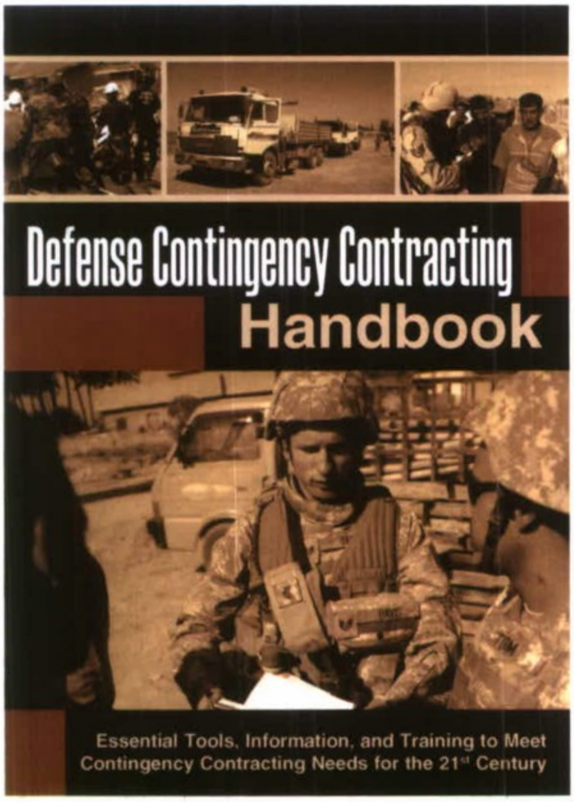
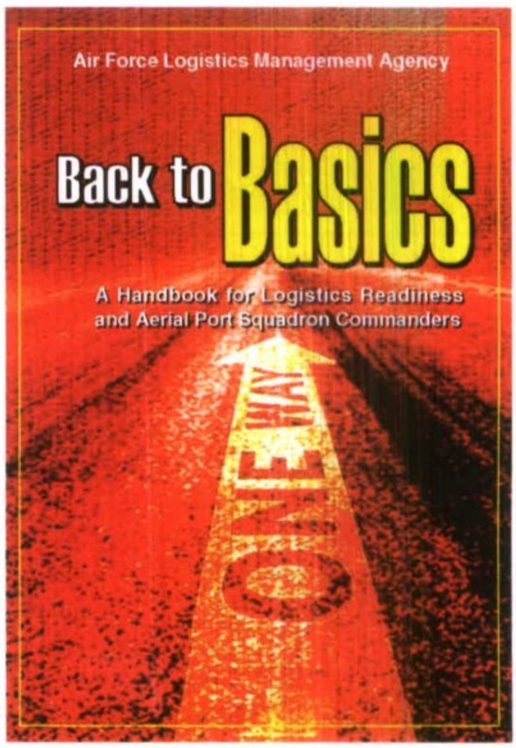


contingency contracting

Contingency contracting support has evolved from purchases under the simplified acquisition threshold to major defense procurement and interagency support of commodities, services, and construction for military operations and other emergency relief. Today, this support includes unprecedented reliance on support contractors in both traditional and new roles. Keeping up with these dramatic changes, while fighting the Global War on Terror, is an ongoing challenge. This pocket-sized handbook and its accompanying DVD provide the essential information, tools, and training for contracting officers to meet the challenges they will face, regardless of the mission or environment.

back to basics

This handbook is designed to serve as a quick reference functional guide. It is broken down by process, similar to the current logistics readiness squadron and proposed aerial port squadron structures. The areas covered include deployment and distribution, fuels management, materiel management, vehicle management, traffic management, and aerial port. The handbook also contains quick facts on high-profile logistics areas such as nuclear weapons-related materiel and the Air Force Global Logistics Support Center.



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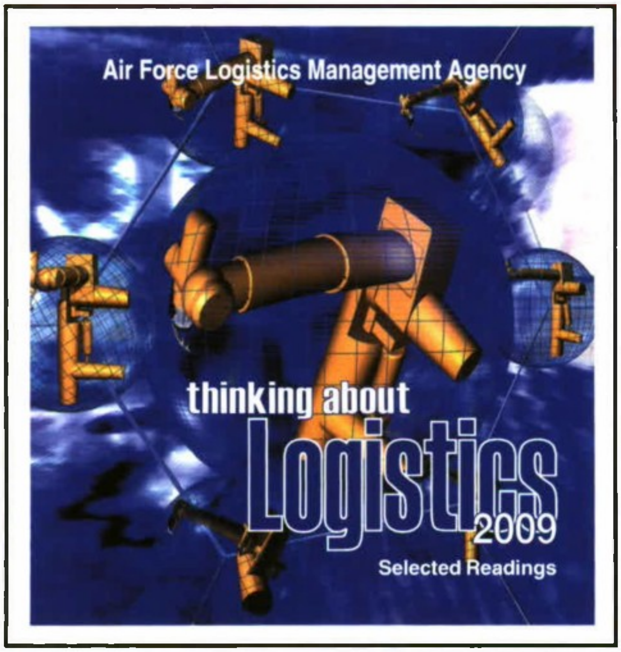
Newest Products with Style and Impact

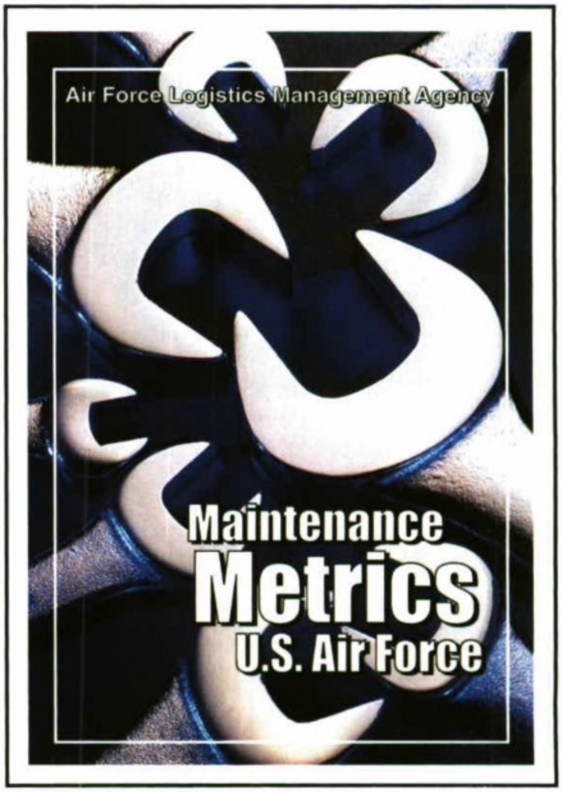
maintenance metrics

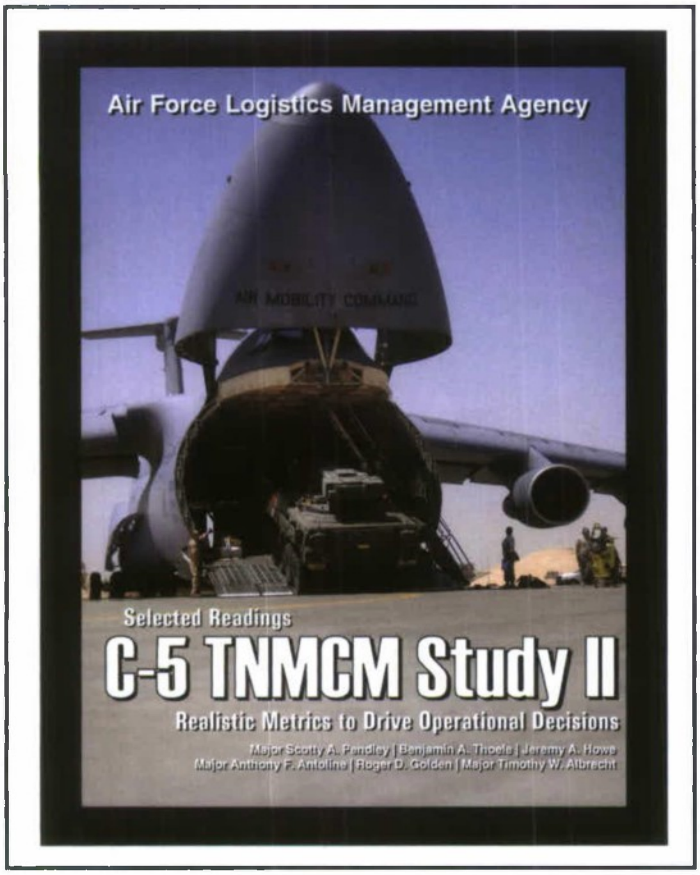
This handbook is an encyclopedia of metrics and includes an overview to metrics, a brief description of things to consider when analyzing fleet statistics, an explanation of data that can be used to perform analysis, a detailed description of each metric, a formula to calculate the metric, and an explanation of the metric's importance and relationship to other metrics. The handbook also identifies which metrics are leading indicators (predictive) and which are lagging indicators (historical). It is also a guide for data investigation. Limited quantities. New version in development.



thinking about logistics 2009

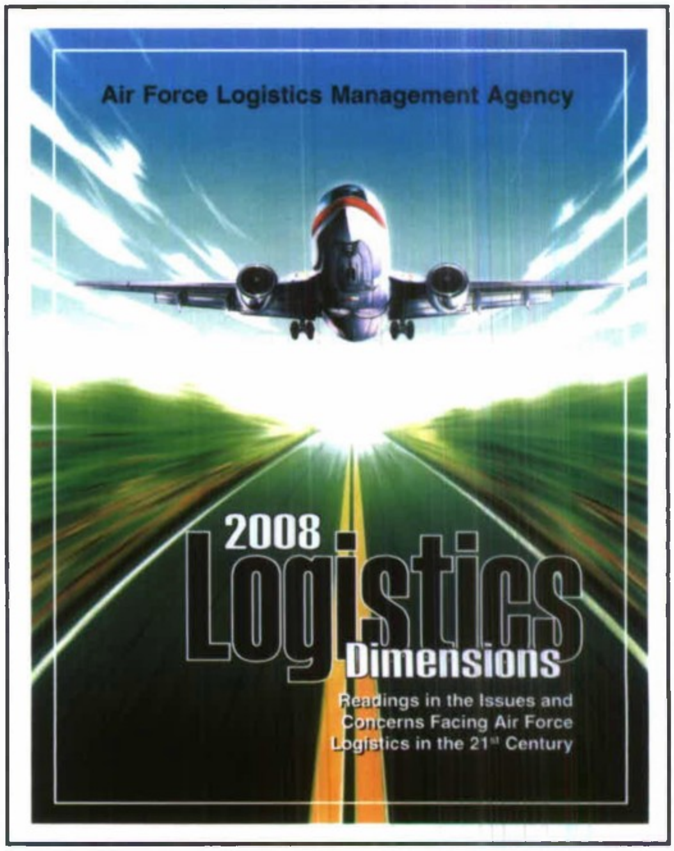
Thinking About Logistics 2009 is a collection of 37 essays and articles—in three sections: Historical Perspective, Contemporary Thought and Issues, and Studies and Analyses—that lets the reader look broadly a variety of logistics areas. Included in the volume is the work of many authors with diverse interests and approaches. The content of *Thinking About Logistics 2009*, ranging across approximately 10 years, was selected for two basic reasons—to represent the diversity of the ideas and to stimulate thinking.





C-5 TNMCM study II

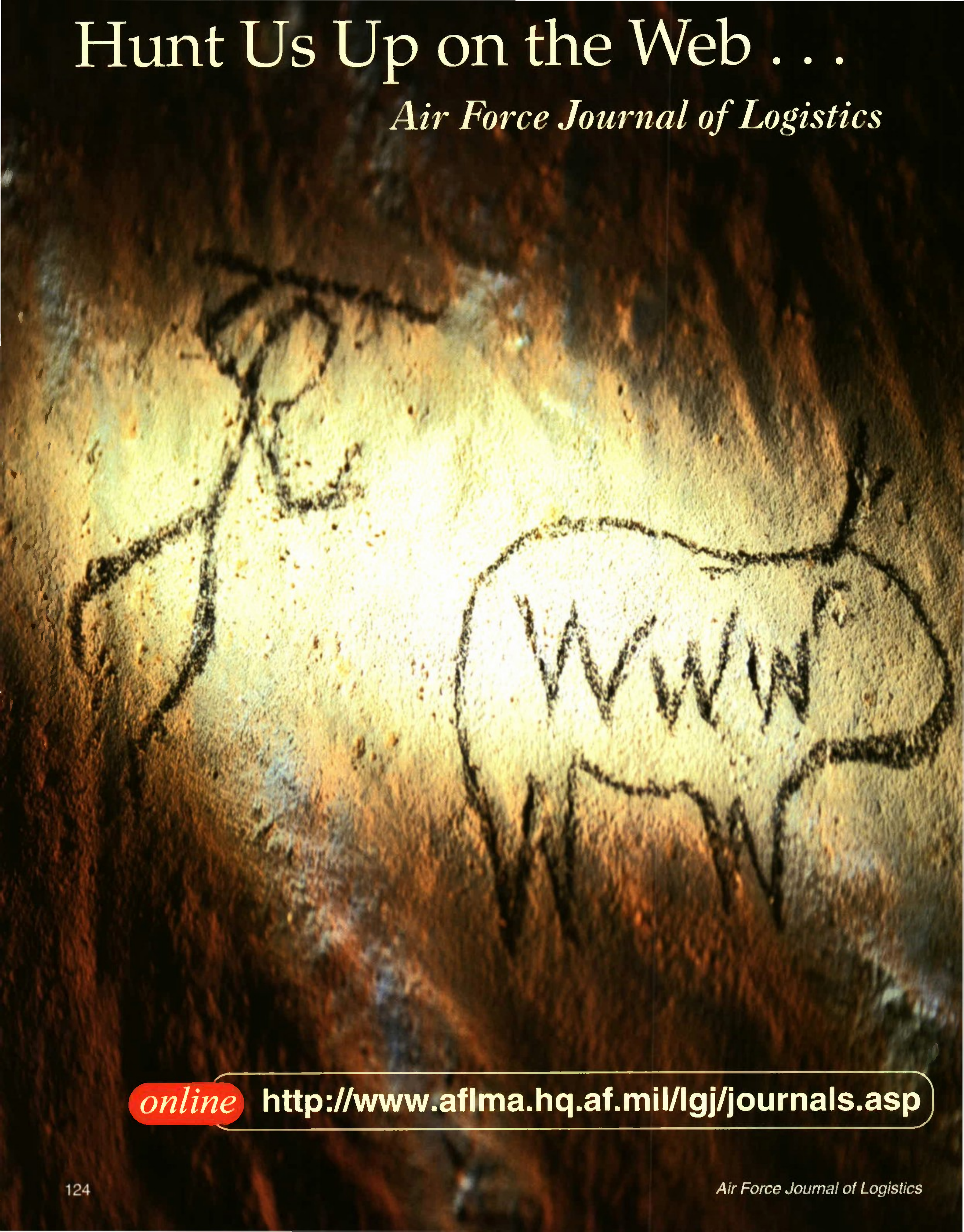
The *C-5 TNMCM Study II* proved to be a stern test of AFLMA's abilities and perseverance. The research addressed areas of concern including maintaining a historically challenged aircraft, fleet restructuring, shrinking resources, and the need for accurate and useful metrics to drive desired enterprise results. The study team applied fresh perspectives, ideas and transformational thinking. They developed a new detailed methodology to attack similar research problems, formulated a new personnel capacity equation that goes beyond the traditional authorized versus assigned method, and analyzed the overall process of setting maintenance metric standards. A series of articles was produced that describes various portions of the research and accompanying results. Those articles are consolidated in this book.



logistics dimensions 2008

***Logistics Dimensions 2008* is a collection of 19 essays, articles, and vignettes that lets the reader look broadly at a variety of logistics concepts, ideas, and subjects. Included in the volume is the work of many authors with diverse interests and approaches. The content was selected for two basic reasons—to represent the diversity of the ideas and to stimulate thinking. That's what we hope you do as you read the material—think about the dimensions of logistics.**

Have you noticed there seems to be a void when it comes to books or monographs that address current Air Force logistics thought, lessons from history, doctrine, and concerns? We did, and we're filling that void. Our staff produces and publishes selections of essays or articles—in monograph format—on a quarterly basis. Each has a theme that's particularly relevant to today's Air Force logistics. Informative, insightful, and in many cases, entertaining, they provide the Air Force logistics community the kind of information long taken for granted in other parts of the Air Force.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EXPLORING THE HEART OF LOGISTICS

Using Leadership to Increase Commitment for Civil Servants and Air Force Personnel in Times of Conflict

Donald S. Metscher, Lieutenant Colonel, USAF Ret, Embry-Riddle Aeronautical University
William A. Lowe, Jacksonville State University (AL)
F. Barry Barnes, Nova Southeastern University
Leanne Lai, Nova Southeastern University

Introduction

Over the past two decades, recruiting and retention has become an enormous concern for the all-volunteer military service. The commitment level required of Air Force employees and government employees continues to be an important issue as well. Following the terrorist events on 11 September 2001, an increase in patriotism coupled with a declining economy allowed recruiting and retention goals to be met. Individuals seemed to be more willing to commit to a career in the military. However, as the war on terrorism continues, retention rates are expected to decline.[1] General D. L. Peterson, the Air Force Deputy Chief of Staff for Personnel, testified to the United States (US) Senate Subcommittee on Personnel that, "Although we will continue to have a challenging recruiting and retention environment, the Air Force is committed to developing the right programs to recruit and retain America's best and brightest."[2] More recently "service officials point to the hard work by recruiters as the key to the success, but they also say increased patriotism as a result of the war on terror and a bleak economic picture in many areas also play a role in attracting young people into the military."[3] Retention rates of military members are still up but officials are concerned about how long it will last.

This study examines the influence of leadership practices on active duty (military) Air Force personnel and government civil service (civilian) employees concerning their organizational commitment using a model developed by Steers[4] and refined by Mowday, Steers, and Porter[5] as the theoretical foundation. This research seeks to measure the different elements of organizational commitment of Air Force employees and how those levels are related to employees' perceptions of their supervisors' leadership styles.

Background of the Problem

The nature of the jobs associated with the US military requires a higher level of commitment than most other civilian jobs since the American people look to their men and women in uniform as symbols of America's strength, power, and determination.[6] Men and women in the US Air Force are trained to expect dangerous assignments requiring a higher level of commitment than most other employees in the private sector. Government civil service employees may not experience the dangers associated with military service or time separations away from home that their active duty counterparts do, but they do require increased dedication to support the active force. General Peterson says, "We recognize the increasingly important role of civilians to our Armed Forces. They are our leaders, scientists, engineers and support force that provides reachback for deployed and forward-based forces."[7] Civilians play an important role in support jobs within the US, allowing deployed forces to reachback for needed logistical support from the forward areas. Civilians can be found at all levels within the Department of Defense (DoD) and within military units.

The United States Air Force and DoD continue to examine the recruiting and retention statistics of Air Force employees and to make program changes as necessary.[8] Although deployments continue to remain high, recruiting and retention statistics for the active and reserve components remain high.[9] "People don't come here to make money…there is something else that motivates people to serve. Retention is not driven purely by when the economy is hot and when it is not."[10] Although climate assessment surveys look at many factors affecting commitment, no studies were found which have directly examined the relationship between leadership and organizational commitment of Air Force employees.

Commitment is now considered a central concept in military motivation. This is in contrast to an earlier emphasis on compliance through obedience.[11] Commitment to the military organization, which could involve combat operations, creates an unlimited liability clause for members of the military.[12]

Leaders can have a significant impact on people, communities, and organizations. For a leader to make a difference, he or she should invest in becoming the very best leader possible.[13] Getting others committed and keeping them that way is important to leaders because commitment to one behavior has implications for several other behaviors. Providing people with choices, making choices visible, and making choices hard to back out of will help ensure that the future matches the leader's vision.[14]

The single most important element of success in war is leadership. Leaders can inspire their subordinates to go *above and beyond*, and the expectations of the leader and subordinate play key roles in the development of leadership. Just as important are the leader's vision, the working environment, and the example the leader sets to his or her followers.[15]

As the number of military engagements of US Armed Forces around the world continues to increase (without an increase in the total number of military personnel), it is critical for military leaders to understand the specific leadership practices that will result in high levels of employee commitment and attainment of organizational goals. The purpose of this study is to examine the specific leader behaviors as perceived by Air Force personnel and civilian employees, and its effects on their organizational commitment.

Organizational Commitment

According to Gal, commitment is a powerful motivator, greater than a paycheck, especially when military service activities involve high risk, extreme demands, and severe stress.[16,17] Commitment is the backbone of the military profession. Belonging to the Armed Forces is not merely a question of a place to work, a job, or an occupation. It is a way of life and often a lifetime commitment. The nation's Armed Forces have a long and proud history of serving our country in peace and war. Each of these times in our history has different levels of involvement and different levels of commitment. In times of peace it may involve time away from home and family during training. In war, it may involve increased danger. Our government and military leaders must seek to understand what will affect their subordinates' commitment during times of peace and war, in good times and difficult ones.

Over the last 40 years, the interest in organizational commitment has grown in both the public and private sector. Within the subject of organizational commitment, job satisfaction and job involvement are among the more popular and widely studied employee attitudes.[18] According to Lowe, the consequences of the research are the establishment of linkages among numerous personal values, role states, and work environment aspects ranging from job characteristics to organizational structure dimensions.[19]

The Volcker Commission suggested that organizational commitment is a key to increasing public service motivation and recommended more empirical studies of employee commitment.[20] Previous studies have helped us to understand the motivational base of public service and government service employees at all levels.[21, 22]

Article Acronyms

ANOVA–Analysis of Variance
CPA–Certified Public Accountant
DoD–Department of Defense
LPI-O–Leadership Practices Inventory: Observer
OCQ–Organizational Commitment Questionnaire
US–United States

Military Perspective on Organizational Commitment

Sarkesian suggests there are three types of commitment in the military: organization, career, and moral. Organizational commitment aligns with the organization's goals, purposes, and norms.[23] Career commitment results in one's own success, and moral commitment is related to the moral codes that each person believes in and for which one will sacrifice. Gal also suggests commitment derives from one's own sense of duty, responsibility, and conviction.[24] Finally, Bass proposes that all three types of commitment need to be in alignment for military professionals to be in harmony with their organization.[25]

For military commanders and many others in leadership positions, there is commitment to one's personnel, the unit, and the task.[26] Bass believes that transformational leadership can develop, maintain, and enhance this alignment. When the leaders' commitment to their personnel, unit, and the task are not aligned, leaders may fall back on demanding obedience, serve their most important commitment, or rationalize their actions as matters of obedience and professional loyalties.[27] "Transformational leaders ask their followers to transcend their own self-interests for the good of the group, organization, or society."[28] Kouzes and Posner do this by having leaders exemplify the leadership practices described in their book, *The Leadership Challenge*. "Transformational leaders closely resemble the leaders we describe in this book, inspiring others to excel, giving individual considerations to others, and stimulating people to think in new ways."[29]

The nature of the jobs associated with the military requires a higher level of organizational commitment than most civilian jobs. Jobs associated with the military first require taking the enlisted or officer oath. The *Air Force Promotion and Fitness Study Guide*, says the oath is a solemn promise to do one's duty and meet one's responsibilities. Implied in that oath is the responsibility to lead others in the exercise of one's duty.[30]

In addition, men and women in the Air Force are trained to expect dangerous assignments requiring a higher level of commitment than most employees in the private sector. Each active duty member is expected to memorize and abide by the *Code of Conduct for the Armed Forces of the United States*.[31] The code contains six articles, which require the highest commitment anyone can be expected to give to their country. The first two articles require the highest sacrifice. Article I states that the member will "serve in the forces which guard my country and our way of life. I am prepared to give my life in their defense." Article II states that the member will never surrender of "my own free will. If in command I will never surrender my men while they still have the means to resist." Finally, the code demands dedication to the principles that "made my country free."[32] The Code of Conduct clarifies the commitment level required of all Service members in different situations they may encounter. It includes basic information useful to US prisoners of war in their efforts to survive honorably while resisting their captor's efforts to exploit them to the advantage of the enemy's cause and their own disadvantage.[33]

Mowday, Steers, and Porter: Organizational Commitment Core Theory

In 1982 Mowday, Steers, and Porter suggested the following integrated definition of organizational commitment.

The relative strength of an individual's identification with and involvement in a particular organization. Conceptually, it can be characterized by at least three factors: (a) a strong belief in and acceptance of the organization's goals and values; (b) a willingness to exert considerable effort on behalf of the organization; and (c) a strong desire to maintain membership in the organization.[34]

The central theme of this definition is the identification with the organization. For the Air Force, it is being part of the team. The strong belief in, and acceptance of, the goals and values means accepting the higher level of commitment which includes taking the oath, signing a contract, and abiding by the Code of Conduct. Exerting considerable effort on behalf of the organization means accepting the fact that Air Force employees must work long hours and spend time away from home on temporary duty. Finally, career Air Force employees have a strong desire to maintain membership in the organization.[35, 36]

Commitment is the linkage between the employee and the organization. This linkage helps identify the outcomes or consequences of organizational commitment: absenteeism, job performance, tardiness, and turnover.[37] All of these are important to organizations, especially the Air Force concerning both its active duty and civil service employees. The linkage is also the bond and involvement the employee has with the organization.

Mowday, Steers, and Porter include three stages or time elements of organizational commitment.[38] The first is pre-entry, which can be compared to the recruitment stage of employment. It represents anticipation and job choice influence on commitment. The second is the early employment stage. This is similar to the training stage and first few years or first term of enlistment for Air Force employees. It represents initiation or the development of commitment during the first few months of employment. Last is the middle or late career stage. This stage is similar to the career Airman or employee who plans on staying in the organization until reaching retirement eligibility. In this stage, there is continuing development and maintenance of commitment. Mowday, Porter and Steers' research indicates that different factors will influence commitment in the different stages.

Kouzes and Posner's Leadership Practices Inventory Model

The Air Force has recently adopted Kouzes and Posner's five leadership practices for leadership training at Wright-Patterson Air Force Base, Ohio.[39] According to Patton, Kouzes and Posner's five dimensions of leadership provide a better explanation of successful leadership behavior than alternative theoretical frameworks with fewer dimensions.[40, 41]

Kouzes and Posner first introduced the leadership practices theory in their book *The Leadership Challenge* in 1988.[42] Their research determined what extraordinary leaders did when they were at their "personal best" in leading others rather than managing. In the second edition of that book (1997) they concluded that leadership is a set of behaviors that can be learned and applied by supervisors and managers, at all levels of leadership, and regardless of seniority, experience, and education.[43]

As a result of the personal-best cases, Kouzes and Posner developed a model of leadership identifying five key practices, each having strategies or commitments.[44] The five key leadership practices, which are most important for effective leaders, are as follows.

- Challenge the process
- Inspire a shared vision
- Enable others to act
- Model the way
- Encourage the heart

People who use these practices create higher performance teams, inspire loyalty and commitment, reduce absenteeism and turnover, and demonstrate a high degree of credibility. Kouzes and Posner also created a quantitative instrument called the *Leadership Practices Inventory* to measure leadership behaviors pertaining to their model.

The first key leadership practice for the model is to challenge the process.[45] This means encouraging people to search for opportunities to change the status quo, experiment, take risks, and learn from mistakes. The two required commitments are: (a) search out challenging opportunities to change; and (b) experiment, take risks, and learn from the resulting mistakes.

The second key leadership practice is to inspire a shared vision.[46] Leaders who inspire a shared vision convey a clear image of the future and develop a general understanding of the vision to members of the organization. The two commitments are: (a) creating a vision by envisioning an uplifting and ennobling future, and (b) enlisting others in a common vision by appealing to their values, interests, hopes, and dreams.

The third practice for leaders is to enable others to act.[47] "Without trust, you cannot lead."[48] The first required commitment is to foster collaboration by promoting cooperative goals and building trust. The second is to strengthen people by giving power away, providing choice, developing competence, assigning critical tasks, and offering visible support.

The fourth key leadership practice is for leaders to model the way by demonstrating high standards and establish clear expectations for individual performance.[49] A leader who models the way demonstrates the commitments of: (a) setting the example by behaving in ways that are consistent with shared values, and (b) achieving small wins that promote consistent progress and build commitment. "People become the leaders they observe."[50]

The final practice is for leaders to encourage the heart.[51] The two commitments are: (a) recognize individual contributions to the success of every project, and (b) celebrate team accomplishments regularly. This is done by setting high expectations, recognizing individuals for their progress and contributions, providing rewards for exceptional performance, and celebrating the accomplishments of the work group.

Research Questions

This study addressed the following questions.

- What is the influence of leadership practices on employee organizational commitment of active duty Air Force and government civil service employees working for the Air Force? This research question was directed at identifying the specific leadership behaviors that will aid in developing a strategy for increasing the organizational commitment of Air Force employees.

- Is there a relationship between certain personal characteristics (rank, time in service, age, education level, and gender) and organizational commitment of Air Force members? The answers can help identify specific leadership behaviors that are most likely to result in an increase in organizational commitment among Air Force members. They also could help to develop a strategy to increase military and civilian motivation, as well as job effectiveness and efficiency.
- Is there any difference between active duty military and government civil service Air Force employees' perceptions on the leadership practice of their leaders?

The three research questions led to 35 hypotheses for testing the relationship between the five perceived leadership practices, the elements of organizational commitment, and the demographic characteristics.

Research Design

This study surveyed 430 civil service and active duty employees working for the US Air Force. The objective was to examine the relationship between the perceived leadership practices and organizational commitment of Air Force employees. All respondents were students, faculty, and staff of the Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, and students on-site at Ogden, Utah and Warner-Robins, Georgia. The courses taught at these locations were for logistics personnel. Most civilian respondents work at one of the three Air Force air logistics centers performing maintenance or supervising major maintenance and aircraft overhaul. All respondents volunteered to participate in the survey with anonymity being assured.[52]

Survey Instruments

The survey instrument for this research contains the following three components: (1) the Organizational Commitment Questionnaire (OCQ) developed by Mowday, Steers, and Porter;[53] (2) the Leadership Practices Inventory: Observer (LPI-O) published by Kouzes and Posner;[54] (3) a Personal Characteristics/ Demographic Questionnaire.

The Organizational Commitment Questionnaire

The Organizational Commitment Questionnaire (OCQ) developed by Mowday, Steers, and Porter (1979) consists of 15 questions.[55] This previously validated organizational commitment instrument has been selected to ensure data reliability and validity, as well as consistency with previous research. Mowday et al., originally used a sample population of 2,563 employees working in nine different organizations, including both public and private organizations, for the OCQ's validation.[56] The OCQ was selected to measure organizational commitment because of its high levels of internal consistency, test-retest reliability, convergent validity, discriminate validity, and predictive validity. Past studies that demonstrate reliability and validity of the OCQ include research by Lowe,[57] Stonestreet,[58] Sturges, Guest, Conway, and Mackenzie-Davey,[59] Parnell and Crandall,[60] and Peterson and Puia.[61]

Leadership Practices Inventory-Observer Questionnaire

The Leadership Practices Inventory: Observer (LPI-O) instrument was developed by Jim Kouzes and Barry Posner and provides 30 descriptive statements for the respondents to rate the extent their leader engages in specific leadership practices or behaviors.[62] The LPI-O was selected because extensive research confirms the Leadership Practices Inventory model's reliability and validity ratings and extensive use in related research.[63, 64, 65]

Personal Characteristics Questionnaire

The demographic characteristics of the respondents were determined by answers to Part III of the survey instrument. This data was requested to establish the characteristics of the sample population including position in the Air Force or civil service, years of service, gender, age group, and highest education completed.

Results

Questionnaires were distributed to 430 students and faculty. The respondents consisted of both active duty (military) and government civil service (civilian) Air Force employees. Of 430 surveys distributed, 328 were returned providing an acceptable response rate of 76.3 percent. Total active duty (military) Air Force respondents were 215 (65.5 percent of total respondents) and government civil service (civilian) Air Force employees were 113 (34.5 percent of total respondents).

Results of Hypothesis Testing

The statistical methods used in this study included both descriptive analysis and inferential statistics. Descriptive univariate analysis was performed to check the frequency distribution, means, and standard deviation. The inferential statistics include analyzing data obtained from Independent t-test, ANOVA (Analysis of Variance), Pearson Correlation, and Post Hoc test with a .05 alpha significance level.[66] The study included reviewing the demographic profiles of the respondents' position in the Air Force (civilian service or active military), years of service (tenure), gender, age, and education level. Furthermore, the data analysis for the OCQ analysis and the LPI-O was completed and discussed.

The research questions suggested 35 hypotheses that were tested. The results in Table 1 indicate there is a relationship between all Air Force employees, the combined and individual leadership practices (of challenging the process, inspiring a shared vision, enabling others to act, modeling the way, or encouraging the heart) in employees' self-reported commitment to the organization.

In addition, the results supported separately, the relationship for active duty Air Force (military) and government civil service employees (civilian), and the combined sum of the individual leadership practices and individual leadership practices in employees' self-reported commitment to the organization (see Tables 2 and 3). However, active duty Air Force employees reported higher levels of commitment when compared to government civil service employees.

In a test of the perceived leadership practices of supervisors of the active duty (military) employees, government civil service (civilian) employees, and the combined and individual leadership practices, only the individual leadership practice of modeling the way was found significant (see Table 4). In this test the military group reported a higher mean than the civilian group. The leadership dimension of modeling the way shows a significant difference ($p = .025$) and the military group mean (43.38) is greater than the civilian group (39.89).

All the other respondents' demographic characteristics were tested using the ANOVA with only the respondents' employee position supporting a statistically significant relationship in commitment to the organization (see Tables 5 and 6).

As a result of the ANOVA for the sum of organizational commitment in Table 5 indicating a significant difference among positions in the Air Force, a Post Hoc test was conducted. This is shown in Table 6, indicating personnel in senior positions, colonels and above, and GS-15 and above, as the top two groups having the highest levels of organizational commitment. The other active duty personnel fell below them in rank order with E-1 through E-3 at the bottom. Of note was that the three remaining civilian groups comprising GS-5 through 14 fell just above the bottom in reverse rank order with the GS-13 through GS-14 group being the lowest. It is recommended that additional research be conducted in just the civilian ranks to determine if this remains valid and what reasons can be surmised for the GS 5-9 group showing higher commitment level than the GS 13-14 group. None of the other demographic characteristics were found significant.

Pearson Correlations							
Statistic	Sum OCQ	Sum LPI-O	Challenge	Vision	Enable	Model	Heart
Sum OCQ	1.000	0.398*	0.376*	0.374*	0.408*	0.406*	0.336*
Sum LPI-O		1.000	0.952*	0.960*	0.932*	0.967*	0.947*
Challenge			1.000	0.837*	0.911*	0.876*	
Vision				1.000	0.837*	0.911*	0.876*
Enable					1.000	0.899*	0,873*
Model						1.000	0.889*
Heart							1.000
Pearson Probabilities							
Statistic	Sum OCQ	Sum LPI-O	Challenge	Vision	Enable	Model	Heart
Sum OCQ	0.000	0.963	0.890	0.978	0.713	0.874	0.895
Sum LPI-O		0.000	0.000	0.000	0.000	0.000	0.000
Challenge			0.000	0.000	0.000	0.000	0.000
Vision				0.000	0.000	0.000	0.000
Enable					0.000	0.000	0.000
Model						0.000	0.000
Heart							0.000

Sig. (2-tailed)
* indicates significant ($p < 0.05$)

Table 1. Pearson Correlations and Probabilities. Compares the five leadership dimensions With the Organizational Commitment Summary

Pearson Correlations							
Statistic	Sum OCQ	Sum LPI-O	Challenge	Vision	Enable	Model	Heart
Sum OCQ	1.000	0.419*	0.406*	0.373*	0.453*	0.398*	0.362*
Sum LPI-O		1.000	0.951*	0.960*	0.919*	0.966*	0.943*
Challenge			1.000	0.934*	0.810*	0.906*	0.853*
Vision				1.000	0.826*	0.908*	0.875*
Enable					1.000	0.883*	0.849*
Model						1.000	0.884*
Heart							1.000
Pearson Probabilities							
Statistic	Sum OCQ	Sum LPI-O	Challenge	Vision	Enable	Model	Heart
Sum OCQ	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum LPI-O		0.000	0.000	0.000	0.000	0.000	0.000
Challenge			0.000	0.000	0.000	0.000	0.000
Vision				0.000	0.000	0.000	0.000
Enable						0.000	0.000
Model						0.000	0.000
Heart							0.000

Sig. (2-tailed)
* indicates significant ($p < 0.05$)

Table 2. Pearson Correlations and Probabilities for Active Duty (Military) Air Force Employees

Summary of Findings

Leadership Practices and Organizational Commitment Relationship

The findings show a positive relationship between pairs of all five dimensions of leadership practices (challenging the process, inspiring a shared vision, enabling others to act, modeling the way, and encouraging the heart) and organizational commitment for Air Force active duty and civilian personnel using surveys developed by Kouzes and Posner,[67] and Mowday, Steers and Porter.[68] In addition, a positive relationship was found between the combined sum of Kouzes and Posner's five leadership practices and organizational commitment. The study results showed that the leadership practice of *enabling others to act* had the strongest positive relationship to the respondents' self-reported levels of organizational commitment. We conclude this is a reflection of the Air Force's continued efforts to empower their military employees and allow them a great deal of responsibility. Many recruiting posters and commercials show young active duty members responsible for highly technical and expensive equipment.

The study also found the weakest positive relationship of the respondents' self-reported levels of organizational commitment corresponded to the leadership practice of encouraging the heart. When divided between military and civilian, the results were similar except that the civilians showed inspiring a shared vision

Pearson Correlations							
Statistic	Sum OCQ	Sum LPI-O	Challenge	Vision	Enable	Model	Heart
Sum OCQ	1.000	0.337*	0.302*	0.352*	0.312*	0.384*	0.266*
Sum LPI-O		1.000	0.955*	0.959*	0.951*	0.969*	0.953*
Challenge			1.000	0.947*	0.862*	0.901*	0.867*
Vision				1.000	0.854*	0.916*	0.876*
Enable					1.000	0.926*	0.911*
Model						1.000	0.896*
Heart							1.000
Pearson Probabilities							
Statistic	Sum OCQ	Sum LPI-O	Challenge	Vision	Enable	Model	Heart
Sum OCQ	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sum LPI-O		0.000	0.000	0.000	0.000	0.000	0.000
Challenge			0.000	0.000	0.000	0.000	0.000
Vision				0.000	0.000	0.000	0.000
Enable					0.000	0.000	0.000
Model						0.000	0.000
Heart							0.000

Sig. (2-tailed)
* indicates significant ($p < 0.05$)

Table 3. Pearson Correlations and Probabilities for Government Civil Service (Civilian) Employees

LPI-O Five Dimensions of Leadership	Military Group (n = 215) Mean (Std Dev)	Civilian Group (n = 113) Mean (Std Dev)	Sig (2-tailed) P-value
1.Challenge the Process	39.09 (13.651)	36.89 (13.539)	.165
2. Inspiring a shared vision	38.87 (14.157)	36.24 (14.496)	.113
3. Enabling others to act	44.20 (12.826)	41.82 (13.975)	.123
4. Modeling the way	43.38 (13.109)	39.89 (13.843)	0.25
5. Encouraging the heart	41.30 (14.362)	38.68 (15.343)	.126
Total	206.85 (64.562)	193.52 (68.148)	.082

Sig. (2-tailed) equal variances assumed
* indicates significant ($p < 0.05$)

Table 4. Leadership Practice Inventory, Survey Part II, T-Test of Military versus Civilian

as the strongest positive relationship rather than enabling others to act.

Military versus Civilian Organizational Commitment Relationship

This study compared the relationship between active duty (military) and government civil service (civilian) Air Force employees in commitment to the organization (Table 7). Of the 15 OCQ questions, 8 showed a statistically significant difference in p-value where $p < .05$, including the totals between the military and civilian group where the military group showed consistently higher levels of the mean. The total mean for military (89.07) was found to be higher than the total civilian mean (85.95) and p-value ($.031 < 0.05$) shows a significant difference, indicating a higher level of commitment among military employees. This is likely due to the nature of the jobs associated with the military requiring a higher level of organizational commitment than most civilian jobs.

Jobs associated with the military first require taking the enlisted or officer oath of office. In addition, military abide by a set of core values that stem from the higher level of commitment required and directly relate to the oath of office that all military people take prior to entry on active duty. The Air Force core values for active duty military are Integrity First, Service Before Self, and Excellence In All We Do. These core values set the common standard of conduct across the Air Force and inspire the trust, which provides the unbreakable bond that unifies the force.[69]

The results from the individual demographic questions indicate that military employees are more willing to talk up the Air Force to their friends as a great organization for which to work; feel more loyalty to the Air Force; find that their values and the Air Force values are very similar; are more proud to tell others that they are part of the Air Force; would not work for a different organization even if the type of work was similar; are extremely glad that they chose the Air Force over other organizations; agree with Air Force policies on important matters relating to its employees; and they do not regret their decision to work for the Air Force. Finally, military personnel reported higher levels of commitment than civilian employees.

Military versus Civilian Leadership Practices Relationship

The study sought to compare the relationship between active duty (military) and government civil service (civilian) Air Force perceptions of the leadership practices of their leaders. The leadership practice of *modeling the way* was the only practice found significantly different, with the results showing the military group had a higher mean than the civilian group. The resulting degree of commitment from modeling the way indicates that the military personnel have a stronger belief in setting the example by behaving in ways that are consistent with shared values and achieving small wins that promote consistent progress and build commitment.[70] Leaders motivate their people by more than just words. Setting the example is just as important as what a leader says and how well the leader manages the work.[71] Since government civil service employees are found at all levels of the DoD and within military units, it is not unusual for a military member to work for or lead a civilian and vice versa.

Demographic Characteristics and Organizational Commitment Relationship

The findings of this research found no significant relationship between the demographic characteristics of years of service (tenure), gender, age, education, and organizational commitment.

The findings do show a significant difference in employees' position or rank and their organizational commitment, however. A Post Hoc test (Table 6) showed the highest level of commitment first among the senior level military (colonel or above) and second senior civilians (GS-15 and above) who responded to the survey. The lowest level of commitment was found among the lowest enlisted level of military employees (E-1 through E-4). According to Brown, commitment reflects the current position of an individual.[72] Higher level supervisors can make the greatest impact on an organization by the authority of their position. They are not only considered part of the company or organization but are considered *the organization* because of the impact of their decisions on the organization. Their goal and values are often reflected in their decisions.

		Sum of Squares	df	Mean Square	F	Sig.
Sum OCQ	Between Groups	3476.205	9	386.245	2.970	0.002*
	Within Groups	41362.157	318	130.070		
	Total	44838.363	327			
Sum LPI-O	Between Groups	38473.784	9	4274.865	0.980	0.456
	Within Groups	1386840.700	318	4361.134		
	Total	1425314.500	327			

* indicates significant ($p < 0.05$)

Table 5. Analysis of Variance (ANOVA) by Position in the Air Force

Post Hoc	
Sum OCQ	6>10>5>3>4>2>7>8>9>1
Survey position numbers and position name in descending order of commitment	
6.	Colonel or above
10.	GS-15 or above
5.	Major through Lt Col
3.	E-7 through E-9
4.	Lieutenant through Captain
2.	E-5 through E-6
7.	GS-5 through GS-9
8.	GS-10 through GS-12
9.	GS-13 through GS-14
1.	E-1 through E-4

Note: Numbers correspond to position number in Part III of survey

Table 6. Post Hoc Test for Sum Organizational Commitment by Position in the Air Force

Research Implications for Air Force Leaders

Although military personnel showed higher levels of commitment than civilian Air Force employees, leaders can still accomplish extraordinary achievements through their military and civilian personnel by using the following leadership practices.

- Challenge the process
- Inspire a shared vision
- Enable others to act
- Model the way
- Encourage the heart

Leaders using these five practices can turn challenging opportunities into remarkable successes.[73] The results support previous research by Stevens, Beyer and Trice which show that organizational tenure, positional tenure, seniority, and perceptions concerning the importance of performance and technical skills in promotion, positively related to higher levels of commitment.[74] Air Force leaders can obtain higher levels of commitment of both active duty (military) and government civil service (civilian) Air Force employees by following the leadership practice strategies of Kouzes and Posner.

Survey Question Number	Military Group (n=215) Mean (Std Dev)	Civilian Group (n+113) Mean (Std Dev)	Sig. (2-tailed) P-value
1. Effort to be successful	6.36 (.819)	6.26 (1.016)	0.329
2. Talk up as a great	5.99 (1.074)	5.62 (1.160)	0.005*
3. Loyalty	6.06 (1.638)	5.56 (2.018)	0.015*
4. Accept any job to remain	4.18 (1.796)	4.07 (1.893)	0.603
5. Similar values	5.92 (1.141)	5.40 (1.264)	0.000*
6. Proud to tell others	6.64 (.742)	6.12 (1.062)	0.000*
7. Change for similar work	4.13 (1.693)	3.65 (1.757)	0.015*
8. Inspires best performance	5.22 (1.302)	5.00 (1.302)	0.149
9. Change in circumstances	5.00 (1.697)	4.96 (1.727)	0.858
10. Glad selected the organization	6.13 (1.190)	5.65 (1.280)	0.0001*
11. Gain by staying	5.21 (1.756)	5.20 (1.582)	0.977
12. Agreement with policies	4.55 (1.687)	3.98 (1.631)	0.003*
13. Care about Air Force	6.46 (.931)	6.27 (1.037)	0.099
14. Best organization to work	5.44 (1.288)	5.34 (1.320)	0.485
15. Decision to work for Air Force	6.65 (.782)	6.27 (1.269)	0.001*
TOTAL	83.9488 (11.34144)	79.3628 (11.86009)	0.001*

Table 7. Organizational Commitment Survey (OCQ), T-Test for Military versus Civilian

Conclusion

This article explores the practices and behaviors of Air Force leadership on organizational commitment, specifically of Air Force employees. The results may also be applicable to other organizational situations. Furthermore, the results here are consistent with those found in other studies including a large music company,[75] multinational corporations,[76] CPA firms,[77] the fire service,[78] and the North American automobile industry.[79] This study extends the research to the military and government civil service employees who support the military, thereby expanding the organizational commitment research knowledge base.

The results show a positive relationship between the five leadership practices developed by Kouzes and Posner and organizational commitment.[80] High levels of organizational commitment are statistically correlated to a decrease in turnover and the intention of turnover behaviors. Higher levels of organizational commitment are also linked to higher levels of individual, group, and organizational performance.[81]

With the exception of an employees' position, the effect of demographic characteristics on organizational commitment was not established. However, leaders should understand organizational commitment as it impacts effectiveness, performance, and turnover of Air Force employees. The results did show personnel in senior positions having the highest levels of organizational commitment. According to Brown, commitment reflects the current position of an individual.[82] This is significant because higher level supervisors can make the greatest impact on an organization by the authority of their position and are considered *the organization* because of the impact of their decisions on the organization.

Finally, the results show that active duty Air Force employees reported higher levels of commitment when compared to government civil service employees. This is not surprising since the nature of the jobs associated with the active duty military requires a higher level of organizational commitment than most civilian jobs. Active duty members are required to take an enlisted or officer oath, and abide by a set of core values that stem from the higher level of commitment required.

The leadership challenge today is in providing trained, motivated, and committed employees for the defense of this country in the current dynamic environment. The real and perceived leadership practices of Air Force supervisors directly influence the organizational commitment of their employees. Although accomplishing the mission is the primary task of every organization and everything else must be subordinate, a successful leader recognizes that people perform the mission, and without their support, the unit will fail.[83]

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It will not do to leave a live dragon out of your plans if you live near one.

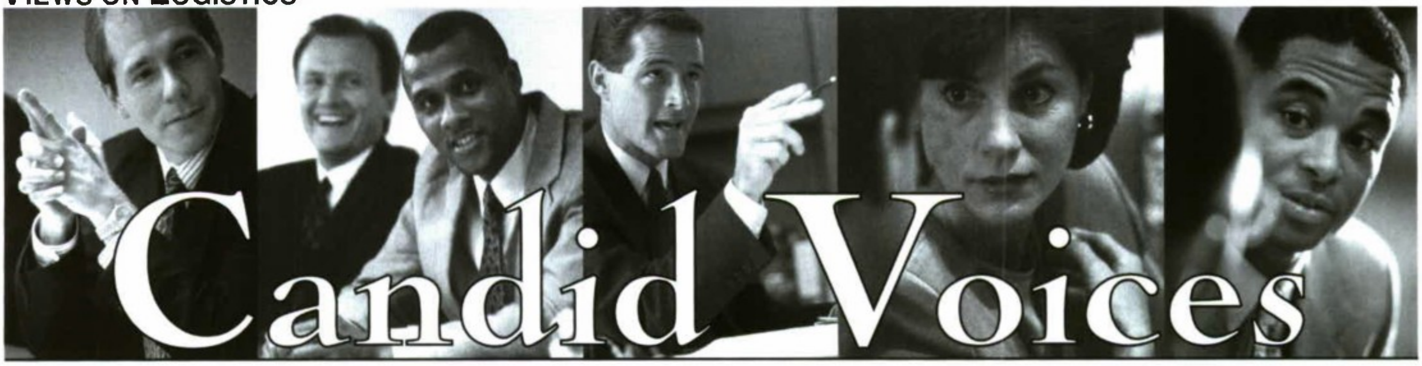
—John Ronald Reuel Tolkien

Tomorrow's warriors will have to relearn the things that today's warriors have forgotten.

—Gen Billy M. Minter, USAF

Knowledge is of two kinds. We know a subject ourselves, or we know where we can find information on it.

—Samuel Johnson



Talking Back—Weapons, Warfare, and Feedback

Victor J. Glover, LCDR, USN

Introduction

A man who wants to make a good instrument must first have a precise understanding of what the instrument is to be used for; and he who intends to build a good instrument of war must first ask himself what the next war will be like.

–General Giulio Douhet

The Department of Defense (DoD) has no shortage of weapons programs that are over cost, behind schedule, and defunct of performance. The Government Accountability Office (GAO) has released multiple reports stating that the DoD's management of major weapons systems is high-risk and in need of reform.[1] For example, the Joint Strike Fighter (JSF) program is expected to be over cost and behind schedule "primarily because of contract cost overruns and extended time needed to complete flight testing."[2] The JSF program, DoD's most expensive acquisition, is experiencing trouble manufacturing and developing test aircraft even though DoD continues to heavily invest in it. Without test data to support performance specifications, DoD is expected to "procure 273 aircraft, costing an estimated $42B before completing flight testing."[3] Congress recently passed weapon systems acquisition reform in an attempt to reign in problems with major weapons programs by increasing oversight and communications. While GAO identified numerous areas where improvements are necessary, this article will focus on technologies to support the timely development and improvement of DoD weapons systems.

When operational users have a problem with a weapons system, they seek assistance from the acquisition workforce to address and correct problems. Operational employment data is requested in order to begin replicating the conditions of the issue. This data is usually gathered from pilot reports, with the help of recorded cockpit or weapons system audio and video, when available. This data is usually incomplete as government and contractor testers and developers generally conduct analysis and evaluation with instrumented test weapons modified to capture and telemeter high-fidelity data.

Currently DoD engages in integrated test and evaluation (IT&E) in order to improve risk mitigation by introducing operational test and evaluation (OT&E) earlier in a program's life cycle. Operational test is conducted by operational users in actual or operationally representative environments and scenarios in order to evaluate suitability and effectiveness, often developing or refining tactics, techniques, and procedures. However, "[d]evelopmental test and evaluation (DT&E) is an engineering tool used to reduce risk throughout the defense acquisition cycle."[4] DT&E efforts are often specifications compliance assessments during the development of a system, with decreasing influence as a system nears operational capability. The current testing paradigm, while intending to integrate these two efforts, is in reality coordinated DT&E and OT&E with little overlap, vice true integration. This distinction

Article Acronyms

AIM – Air Intercept Missile
ALIS – Autonomic Logistics Information System
AMRAAM – Advanced Medium Range Air-to-Air Missile
CEO – Chief Executive Officer
DoD – Department of Defense
DT&E – Developmental Test and Evaluation
ENIAC – Electronic Numerical Integrator and Computer
GAO – Government Accountability Office
GPS – Global Positioning System
ID3 – Integrated Design, Development, and Deployment
I-DAP – In-flight Data Acquisition Pod
iNET – Integrated Network-Enhanced Telemetry
IT&E – Integrated Test and Evaluation
JDAM – Joint Direct Attack Missile
JSF – Joint Strike Fighter
JSOW-C-1 – Joint Standoff Weapon
NATO – North Atlantic Treaty Organization
NEW – Network-enabled Weapons
OT&E – Operational Test and Evaluation
PHM – Prognostics and Health Management
PIN POINT – Precision Instrumented Networked Propelled Ordnance-Interchangeable
US – United States

is important to understand in light of current development programs. Referring back to the JSF program, the DoD agreeing to buy articles without an assessment of performance, has accepted "undue concurrency of development, test, and production activities and the heightened risks it poses to achieving good cost, schedule, and performance outcomes."[5] The current weapons systems acquisition context is one of budget and schedule overruns and performance deficits. While this is a reflection of larger policy issues, there are areas where technology can assist in cost, schedule, and performance goals.

DoD is under pressure to reduce time in the weapons acquisition process. "At the program level, the key cause of poor outcomes is the approval of programs with business cases that contain inadequate knowledge about requirements and the resources—funding, time, technologies, and people—needed to execute them."[6] This article is focused on technology to reduce the time between conceptualization and fielding of weapons while increasing the technology knowledge base for a particular system. During the development of weapons systems, DoD engages in testing efforts to gather weapons specifications, performance, reliability, suitability, and effectiveness data. Much of this testing is done with instrumented weapons, on test ranges, in simulated environments, and against simulated threats. Developmental and operational flight testing attempt to conduct tests in operationally representative environments and actual operational environments when possible. However, actual operational usage of weapons systems provides a host of data in actual operational environments that goes untapped.

Technology Trend Impact Analysis

The way we make war reflects the way we make wealth.

–Alvin and Heidi Toffler

Throughout American history our technology has directly impacted how we make war. The evolution of the United States has included agrarian, industrial, and information revolutions. Our warfare capabilities have incorporated aspects of each of these revolutions in attempts to improve effectiveness and efficiency. The nature of war has thus evolved to encompass isolated face-to-face combat, mass destruction, and the information warfare paradigm of today.[7] The information warfare paradigm spans the range of military operations from command and control to psychological operations, from direct attack to cyber attack. The Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*, defines information superiority as "the operational advantage derived from the ability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same."[8] A key enabler of the information warfare paradigm is the network and increased connectivity. The following is an excerpt from the Chairman of the Joint Chiefs of Staff Joint Capability Areas framework.

> Network Centric: The ability to provide a framework for full human and technical connectivity and interoperability that allows all DoD users and mission partners to share the information they need, when they need it, in a form they can understand and act on with confidence, and protects information from those who should not have it.[9]

Current information communications technologies directly impact our warfighting capabilities by enabling us to bring weapons effects on a target faster, over greater distance, and more precisely. However, when it comes to weapons development and improvement, a key link between the warfighter and the weapons developer has remained in the industrial age. This link between the warfighter and the weapons developer needs to be supported by the same information communication technologies that are enabling the evolution in tactical operations. This link will be via a user centered, networked, data gathering weapon.

Information communications technology can improve the link between the fleet user and the future requirements and development or improvement processes by capturing the data and information available in real-world training and tactical missions. This data can be fed directly into real-time decision cycles to change some aspect of current tactics or used to develop updates to the current systems or follow-on weapons. The type, frequency, and fidelity of data can be user selected via mission planning systems to provide a particular data set based on user requirements. In training, the user may want to see various types of information that will support building habit patterns, reviewing procedures, and enhancing learning processes, while experienced fleet users may want data that provides information on tactical advantages, employment recommendations, or real-time systems health. Examples of this type of data are the same types of data that operators use in training today, to include: ranges, angles, and closure rates. Embedding the acquisition of this data into the weapons systems, which the operator can use later to reconstruct employment timelines or review procedures, enables enhanced training and debrief capability as well as data to support suspected hardware or software malfunctions and potential causes. This combination of technologies and processes, used mainly in DT&E and some OT&E, should be expanded to operational use.

The technologies required to gather and transmit user specified information are currently available in disparate systems and need to be synthesized into future weapons concepts. Examples of these types of weapons are the instrumented test assets that are used by DT&E personnel. While the fidelity of information required for test and evaluation may not be required by fleet users, some level of data acquisition will enable this improved linkage between users and designers. Information communication, storage, and computing technologies are currently revolutionizing system development, operations, maintenance, and logistic processes.

Computing and Communication Technology Trends

From the dawn of automated computer hardware with the invention of the Atanasoff-Berry Computer in 1937,[10] to the current computer software and network-driven information age characterized by social networking and network centric warfare, the military has maintained a close relationship with the development of computing and networking theory, hardware, and software. Soon after the invention of the first computer, the military, spurred by the outbreak of World War II, partnered with the University of Pennsylvania to develop the electronic numerical integrator and computer (ENIAC) to compute ballistic firing tables.[11] From the Internet to the Radar processor, from the computer programming language compiler to the data-link, the military has influenced and benefitted from computing and communications innovation. These trends are still shaping society and therefore military weaponry.

Based on the so-called laws (actually heuristic planning goals, predictions, or observations) of Gilder, Metcalfe, and Moore, the future of computing and communications technologies will provide opportunities to transform the paradigm for weapon system development and improvement. The three laws were chosen as they represent widely accepted guides for the information and communications technology industries.

Gilder's law states that "bandwidth increases threefold each year."[12] Futurist George Gilder's law comes from a concept known as Winners' Waste, which means that business models will exploit less expensive resources and conserve expensive resources. Computer processing power and bandwidth are currently the less expensive resources compared to personnel, and so the trends follow that socioeconomics will rely more on networks and computers.

Metcalfe's law states that "...the value of the network increases in direct squared proportion to the number of persons or things connected to the network."[13] This law is named after Robert Metcalfe, inventor of the Ethernet and cofounder of the 3Com Corporation. While defining *value* may be difficult, the benefit of this heuristic is in the importance it bestows on networking. Over the last 20 or more years the trend toward networking has created new ways to engage in many daily tasks, from phone calls and messaging, to research and publishing. Networking is also prevalent in warfare (will be discussed later). The amount of value espoused in the law is less important than the presence and relationship of value. The more connections, the more valuable a network is.

Finally, one of the more common computing trends, described by Moore's Law, states that "the number of transistors on a chip doubles every 18 months."[14] Gordon Moore, cofounder of the Intel Corporation, stated in 1965 that "complexity for minimum component costs has increased at a rate of roughly a factor of two per year."[15] Over the next 10 years he would refine that to a 2-year period.[16] Computer processing speeds have managed to double in capacity between one and two years since then. This performance prediction refers to the state-of-the-art technology, but for those left in the wake of the leading edge there are still implications from Moore's law. This trend also means that for a baseline of performance the cost will be reduced by about one-third every year or about one-half every 18 months. As costs have come down over time, the ability to field smart and network-enabled weapons has come to fruition.

In comparison, Moore's law is outpaced by Gilder's law and thus Metcalfe's as well. In Gilder's terms the cheaper resource of bandwidth is utilized to connect systems. The rate of advance of bandwidth is almost twice as much as processing power (doubling every 8 months compared to 12 months for Moore's law). Therefore, according to Gilder, the resource to exploit at this time is bandwidth. As we utilize bandwidth, we will realize an increased value in our networked systems, according to Metcalfe. Again it is important to realize that these laws are not laws of physics. They do not allow for performance or effectiveness comparisons, as they do not have a common frame of measurement. Their real use is in big picture trends, and the overall trend is one of self-perpetuating growth. In reference to future weapons, the next step is to develop optimizing capabilities into the weapons themselves that enhance connectivity and bandwidth. Operational weapons feedback capitalizes on this increased processing power, connectivity, and bandwidth by enhancing weapons with an optimizing capability that is customizable to testers, trainers, or tacticians.

In the computer world there is an anonymous and humorous saying that "what Andy giveth, Bill taketh away." The saying is referring to Andy Grove, then chief executive officer (CEO) of Intel, a computer chip manufacturer and Bill Gates, the CEO of Microsoft, a software manufacturer. In other words, as computer hardware gets faster, computer software will be developed to capitalize on the improved capability. While it seems intuitive that as the technology gets better the applications of the technology get better, what may not be so intuitive is that this capability excess creates a self-sustaining vortex. There is always something big and new on the horizon. In the last 20 years graphical user interfaces, Web-browsing, massive search engines, and hand-held computing have become accessible to millions. Corporate America is exploiting these trends and adapting business and workforce models to match. DoD must do the same. However, in approaching this new paradigm it is important to keep another computing industry law in mind, Amara's Law, which states that "[w]e tend to overestimate change in the short run, and underestimate it in the long run."[17] There are no magic bullets, even if they are networked and instrumented.

Weapons Technology Trends

Network and Data-Link Capability. Network-centric warfare synthesizes the capabilities of ground power, sea power, air power, electronic warfare, intelligence, surveillance, reconnaissance, command, and control into a revolutionary capability that transforms the speed and efficiency with which wars are fought. According to the *Joint Vision 2020* and *Joint Capability Areas,* DoD and Service leaders have supported the trend toward network-centric warfare and the development of hardware and software architectures to support it. According to the pioneers of network-centric warfare theory, Arthur K. Cebrowski and John J. Garstka, network-centric warfare enables a shift from an entrenched to a dynamic warfare style characterized by speed and self-synchronization.[18]

Network enabled weapons (NEW) represent the current trend in precision strike weaponry. Traditional weapons systems generally rely on a single source to provide aim point, update, or guidance information to engage targets. The trend in strike weapons engagement has evolved from unguided bombs to guided variants, while generally relying on a single source of information and one-way communications. Guided weapons include the infrared or heat-seeking Air Intercept Missile (AIM)-9X Sidewinder; active Radar-guided AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM); Global Positioning System (GPS) aided Joint Direct Attack Munitions (JDAM); laser-guided weapons such as the Paveway bomb series and Laser Maverick air-to-ground missile; single-source data-link weapons such as Walleye and the Standoff Land Attack Missile-Extended Range (SLAM-ER); and the first network-enabled weapon, the Joint Standoff Weapon, JSOW-C-1.

Technology trends have allowed for affordable, small form factor, open architecture radios to be integrated into current weapons. While the current data-link architecture for NEWs is Link-16, the analysis in this article applies to future weapons in general. Link-16 is a North Atlantic Treaty Organization (NATO) standardized data exchange format. Military Standard 6016, *DoD Interface Standards, TADIL J Message Standard*, defines the Link-16 message format. Link-16 enables sea, air, and land forces to exchange situational awareness, targeting, and employment data in near real time. Link-16 supports the exchange of position and status, text, imagery, and up to two channels of digital voice (2.4 or 16 kilobits per second [kbps]).[19] "The hardware component of Link-16 is the Joint Tactical Information Distribution System (JTIDS) or, its successor, the Multifunctional Information Distribution System (MIDS). These high capacity, ultra high frequency (UHF), line-of-sight (LOS), frequency-hopping data communications terminals provide secure, jam-resistant voice and digital data exchange."[20] The network is critical to the future of warfare.

Data Acquisition and Management

DoD is engaged in an effort to overhaul the telemetry capability of national test and evaluation complex. The integrated Network-Enhanced Telemetry (iNET) program's "goal is to find a feasible upgrade for the basic architecture of the test and evaluation ranges' telemetry systems"[21] One aspect of iNET being currently developed is the Telemetry Network System (TmNS) which "will provide its installations' computer networks with a wideband wireless capability that covers hundreds of square miles. As a result, flight test centers will be able to dynamically adjust the spectrum required for test vehicles." Along with wireless network hardware to upgrade currently aging telemetry systems, iNET will also enable a more efficient use of the frequency spectrum so that bandwidth is not wasted, and it is available when needed.[22] One of the added benefits of the new technologies will be the capability for "program managers and aircraft manufacturer personnel to monitor tests from off site."[23] Data acquisition technologies are not only apparent in the test and evaluation community, but they are also gaining momentum in the operational community.

The JSF is a watershed weapon, marking today with the network and data enhanced weapons of tomorrow. Take for example the JSF Prognostics and Health Management (PHM) System and the Autonomic Logistics Information System (ALIS) which stand to revolutionize aircraft operations and logistics support via automated and networked information communications technologies. At a conference for life-cycle management Captain Simon Henley (United Kingdom Royal Navy), Andrew Hess, and Leo Fila presented a paper on the JSF PHM and ALIS systems. The following is an excerpt from their presentation.

> The JSF program is supported by the automation of the logistics environment such that little human intervention is needed to engage the logistics cycle. Actions that will be automated within the JSF supportability concept include maintenance scheduling, flight scheduling, ordering spare parts, and the like. The cornerstone of autonomic logistics (AutoLog) is an advanced diagnostic and Prognostics and Health Management (PHM) system. The PHM provides the data, information, and knowledge for initiating the AutoLog chain of events. PHM is the ability of the aircraft to do fault detection (FD), fault isolation (FI), and accommodation real-time on board the aircraft. The PHM architecture will directly interface with [ALIS], which is the information system that will enable the autonomic logistics functions. The [ALIS] could automatically forward to the original equipment manufacturer (OEM) data on problems that arise within the fleet, thus alerting them to a developing situation sooner and enabling them to provide faster, cheaper fixes to these problems.[24]

Data is the lifeblood of the PHM and ALIS systems. The network (wired and wireless) is the vascular system. The nervous system is the web of sensors dispersed in key locations in the aircraft and work spaces. Humans are the muscular system that gets it all going in the right direction. Together these systems bring new life and capability to the operations and support systems. Operational weapons feedback is a concept that aims to do the same for weapon systems development and improvement by harnessing, processing, and sharing data.

In translating test, training, or tactical information into useful knowledge that will aide in the development or improvement of weapons systems, the networking of weapon systems with customizable data acquisition and analysis capabilities will move weapons (and thereby the product life-cycle process) further up the hierarchy of knowledge. Connected weapons supported by data acquisition templates or algorithms that are based on the user's specific needs will provide not only data, but information and at times knowledge. As systems thinking pioneer Dr Russell Ackoff defines it, the "application of data and information [which] answers 'how' questions."[25] Questions such as, How can the warfighter use what they have more effectively? And how can the warfighter adapt what, they the warfighter, have to get the new capability he or she wants?

The Apple iPhone and Microsoft Windows are examples of products that are continuously being improved by networked systems and automation. The products, processes, technology, and business models support the workforce at each of these companies, enabling innovative and market competitive products. Widespread and connected usage actually enhances the development and update processes by enabling Apple and Microsoft to collect information about system performance, deficiencies, user preferences, and more. The testing and development efforts of Microsoft are enhanced by automated feedback from users. The downloadable applications and customizable interfaces allow users to optimize the iPhone to his or her personal or professional liking. If we want to reduce the time required to field effective weapons systems in DoD, then we must adapt our weapon systems to do the same. The synthesis of future communications, computing, and networking technologies provides an enabling vision for the future.

Future Concept of Operations

Too often we forget that genius, too, depends upon the data within its reach, that even Archimedes could not have devised Edison's inventions.

–Ernest Dimnet

Future Concept of Operations Vignette

The year is 2030 and international tensions over energy resources threaten to escalate into hot war. The United States Armed Forces have increased their operational tempo, conducting more exercises with the dual purpose of calming tensions via presence and also preparing for operations in a multi-theater conflict. US land forces are spread thin around the globe, US maritime forces are forward deployed on long rotations to ease the interdeployment readiness cycle, and US Air Forces are conducting around-the-clock expeditionary flight operations.

The US Air Forces are a mix of fourth and fifth generation manned fighters and unmanned strike, intelligence, surveillance, reconnaissance, and communications platforms. The weapons suite has evolved to include a highly precise, low yield variety of weapons that are designed to surgically remove key enemy personnel or infrastructure nodes. Directed energy and nonlethal weapons have also reached full operational capabilities. One particular weapon development that has reached initial operational capability and has been recently deployed is the Precision Instrumented Networked Propelled Ordnance-Interchangeable (PIN POINT). The PIN POINT program began as a cooperative development between government, industry, and research labs via a shared knowledge base of past weapon system data. The design objective was to create the true jack-of-all-trades air warfare weapon. PIN POINT is a modular weapon making it easy to update and integrate. The warhead is reconfigurable (thermobaric high explosive, electromagnetic pulse, tungsten fragment, and propulsion augmented) to enhance the effectiveness of the small weapon. The sensor and guidance section is also interchangeable (millimeter wave, infrared/laser, electro-optical, acoustic, and Radar homing). The weapon is the size of a small legacy air-to-air missile, supporting internal and external carriage on all existing manned strike aircraft as well as all full size unmanned aerial vehicles.

The weapons are network enabled via the encrypted Link-X data-link network. PIN POINT is also able to capture data onboard and telemeter that data back to host platforms via data link. The data sampling rate is adjustable depending on the level of data needed, from single samples per second to the low thousands per second. The sampling rate can also be automated via selection in preflight mission planning. The data transmission rate is adjustable and controlled by automated processes dependent on phase of employment and type of data to be transmitted.

Fleet use has continued to optimize the weapon's autopilot algorithm, sensor gains, and warhead effectiveness models via direct feedback from developmental testing, operational testing, and operational usage. Recently, information on Eastern Europe and Northern Arabian Gulf climate effects on seeker and propulsion modules was collected from PIN POINT weapons being used by forward deployed Air Force and Navy squadrons. This information was fed back into the AWIX System (Automated Weapons Information Exchange), the secure weapons data repository and analysis system for DoD. The updated information was integrated into the contractor software models and used to develop the latest autopilot and employment profile which will be included in the weapon's next software update. Software updates are done by physical connections like most legacy systems as well as by secure data link. Generally the land-based Air Force squadrons use physical connections because of the increased reliability, while sea-based squadrons use the wireless capability to upload software because of space constraints on aircraft carriers.

The first operational use of PIN POINT was during a Joint exercise in Alaska known as Northern Edge. The target was located and tracked via an airborne early warning aircraft, and the track file information was passed to a manned fighter via Link-X data-link. The manned fighter assigned weapons priority to the track file, which was designated as hostile. The fighter was directed to engage the hostile (a low-cost drone aircraft). The manned fighter then assigned targeting to an unmanned air combat vehicle, which was carrying the PIN POINT weapon. The unmanned air combat vehicle intercepted and engaged the drone from its left side. The drone was crossing from right to left in front of the unmanned fighter as it approached the launch point. The weapon sent a cue to the operator of the unmanned system to turn slightly to the left prior to firing the weapon. The operator complied and the weapon was fired once the shooter was in the launch acceptability region. The weapon closed on the drone and just prior to impact the data acquisition rate was increased to the maximum sample rate and the telemetry stream increased to maximum bandwidth to relay real time target maneuver updates to the Link-X track file and video of the weapons sensor image until impact. The drone's preplanned evasive maneuver was no match for the PIN POINT's maneuverability. Splash one! The first operational PIN POINT employment was a massive success for the PIN POINT team as well as the Joint find, fix, target, track, engage, and assessment kill chain.

Post flight the data was downloaded from the aircraft data transfer unit in the unmanned air combat vehicle as well as a data stream from the manned fighter who assigned the targeting. The airborne early warning platform also had target state information that was transmitted via Link-X back to the network operations center at Elmendorf Air Force Base since the aircraft would remain airborne to support an upcoming exercise. The on-site analysts and off-site contractors viewed the event and associated data stream in real time. The program manager drafted a quick-look report which read, "Congrats Team PIN POINT, the first operational PIN POINT shot matched the modeling and simulation data. This event was a success for the integrated product team, the program office, and most of all–the WARFIGHTER!" The analyst and engineers; however, were already hard at work reading through the system flags and cues (weapon generated indicators of potential issues or suggestions for improvement) and looking for ways to improve pilot or operator cueing, flight profiles, and data automation algorithms.

How Do We Get There From Here

Currently most weapons have no requirements for data acquisition. Weapon requirements are focused on weapons employment, logistics, and support. Excluding DT&E efforts, weapons data is currently limited to visual and auditory cues. Examples of potential data feedback for a few select weapons are (to include but not limited to) as follows.

- Aim-9X Sidewinder: seeker acquisition and track range, seeker video, presence of countermeasures.
- AIM-120 AMRAAM: onboard Radar active, onboard Radar acquisition, presence of countermeasures.
- Paveway Series Laser Guided Bombs (LGB): seeker acquisition, seeker track, seeker track lost, impact velocity, impact angle.
- Joint Direct Attack Munitions (JDAM): align quality, satellite vehicles tracked, signal jamming, impact velocity, impact angle.
- Joint Standoff Weapons (JSOW): align quality, satellite vehicles tracked, signal jamming, impact velocity, impact angle, seeker video.

Once appropriate data requirements have been identified and codified, the data has to be acquired and transmitted. Current aircraft hardware and software support data transmission to and from weapons while connected to the aircraft (as is required for GPS-aided weapons such as JDAM and JSOW). This utility needs to be expanded to all weapons and dedicated hard drive space apportioned for storage and retrieval of weapons information, audio, and video. For example, the AIM-9X uses a system called the In-flight Data Acquisition Pod (I-DAP) during DT&E flights to capture data from the missile. The I-DAP has an internal high-capacity flash memory drive. "The I-DAP also monitors and records the Mil-Std-1553, *Aircraft Internal Time Division Command/Response Multiplex Data Bus,* traffic to the missile. Analog real-time video of the missile seeker is provided out to the launcher pylon connector. A ground station (personal computer with large capacity disk drives) is used to download the data from I-DAP, after the aircraft returns to the base." For operational weapons the data storage hardware should reside in the aircraft due to the possibility of employing the weapon, while captive training rounds could contain on-board storage.

Collected weapons data also needs to be transmitted when weapons are in flight. The current capabilities for data transmission are tactical and Radar data-links. Based on the previously analyzed trends Link-16 (and any future follow-on system) will be the focus. Link-16 is the most common tactical data-link in DoD aircraft. The data rates and security of tactical networks need to be improved. The bandwidth needs to be able to support high resolution imagery and video. For comparison, DT&E "flight test instrumentation systems collect more than 200 megabits of data per second, [and] data transmission rates remain at 5 megabits per second."[26] While the test and evaluation enterprise is aiming to improve this data acquisition and transmission capability, this is a good place to start for operational weapons. These data rates currently support high fidelity data acquisition and transmission to include voice, imagery, and video.

Integrated Design, Development, and Deployment (ID³)

Operational weapons feedback capability will enable continuous product improvement of fielded weapons by integrating phases of the product life cycle. By connecting the weapons and user processes via automated data processing, systems will be continually monitored or assessed for product and process improvement. Data on usage patterns will enable DT&E and OT&E personnel to leverage their testing efforts with information provided by fleet users. Also DT&E and OT&E efforts would be more responsive to fleet issues as system deficiencies are identified and workarounds or updates are developed sooner. This enhancement of current product life cycles will facilitate better communication and requirements refinement between warfighters and acquisition personnel.

Perpetual Test and Evaluation

Operational weapons feedback could support the evolution of integrated developmental and operational test (IT&E) to perpetual test and evaluation where systems are tested throughout their life cycle by operational users in training and combat environments. In the 23 November edition of *Defense News*, the Director of Defense Research and Engineering for DoD, Zachary Lemnios, said that the military will "fight with prototypes"[27] in order to integrate combat experience into weapons upgrades. Mr Lemnios was commenting on ways to reduce cost and field arms faster. Weapons that support this paradigm will enable faster sharing of data pertinent to combat employment and training efforts.

Operational weapons feedback will mean that once a weapon system is fielded the test and evaluation process is not terminated for that particular build, block, version, and so forth. The systems will now support evaluation efforts vis-à-vis actual operational use and operational environments. A greater number of users will be able to evaluate tactics, techniques, and procedures in comparison with current capabilities. System and procedures development efforts will be expanded across a greater range of users—in essence perpetual testing.

Weapons Development *Feedforward*

While fighting with prototypes and perpetual testing will enable feedback into upgrades and improvement of existing weapons, the data gathered, organized, and archived from operational use (in conjunction with DT&E and OT&E data) could be used to feed forward into new weapons design and development programs. When requirements for future capabilities are developed, the data from operational weapons feedback can support priority and decision recommendations. Archived data of prior systems can be tabulated in a format that highlights current systems and capabilities gaps or limitations. This process is currently conducted; however, computer models, flight test data, and limited operational data are currently compiled.

Information on employment limitations, actual usage versus planned usage, air-to-air weapons features that aircrew would like to see in air-to-ground weapons and vice versa, launch-to-eject dynamics modeling, sky and ground background clutter data, and a whole host of other types of pertinent information could be gathered quickly across a range of weapons types and may be useful to weapons designers of future weapons (within proprietary and security constraints). Adding actual use trends, issues, and analysis would enhance the current requirements generations process supporting the design and development of new weapon systems. *Feedforward* is an added benefit of operational weapons feedback and the automated information exchange infrastructure to support it.

The combination of current test and evaluation practices with the added systems optimization capability of operational weapons feedback will enable the ability to perpetually test systems. The added weapons feedback and automation of data acquisition and analysis will enable feedforward into design, development, and improvement efforts. The improved communications, reduced data gaps, and automation decision support processes will support integrated design, development, and deployment (ID³).

Barriers

In trying to reach this state of continuous product and process improvement there are multifaceted barriers. While specific technologies are the primary focus of this article, the abilities to sense, record, store, and transmit data are the areas where we have made the most progress in legacy weapons development. The disparate technologies required to support operational weapons feedback exist or are being developed. The processes and standards to do so are where we are lacking. While some of these technologies are not very complicated, understanding what they can provide and how best to use and categorize these capabilities are questions we need to answer. Our ability to sense the world around us and gather reams of data is not the challenge; our challenge is to find better ways to store and share data and knowledge. DoD needs to better understand and invest more in data mining and knowledge discovery (the ability to glean information and knowledge from large quantities of data). As bandwidth and computing process continue to advance the prospects for larger and larger databases is a reality. Storing and managing data are equal to if not more significant than using the data.

Standards are another barrier to successful integration of operational weapons feedback. In the DoD's first network-enabled weapons, the JSOW C-1, the architecture was designed to maximize accountability and security, which detracted from flexibility and speed. The architecture was well thought out, but it was created by engineers and not by warfighters. The architecture development process requires technical specialists as well as operational specialists. Standards provide a way of ensuring interoperability and repeatability. The Link-16 message format is a NATO standard, however, the displayed Link-16 information in an F/A-18 Hornet is quite different from that in the F-16 Falcon. Standards need to be flexible, but they need to be comprehensive and cover what is important. The Bluetooth and the 802.11 standards have created a networking capability for consumer use that is robust, securable, and user friendly. While our security requirements can be a limiting factor, we can have this same success with military standards if we have the right people involved.

People are the principle reason for the integration of the technologies in this report. A significant barrier to operational weapons feedback resides in people. Addressing these issues requires an understanding of the integrated nature of the problem and associated opportunities. Educating operators, businessmen, and supporters about future technology and business processes will be essential to making headway. Again, the purpose of these technologies is to enable better decisions by humans. The nature of the changes inherent in the aforementioned processes requires looking at the technologies in a holistic sense and not in terms of bandwidth, processing power, or even electrical engineering or computer science. The feedback problem is an enterprise wide issue that can only be addressed in a systematic approach. According to Mr Tom Dabney of the Joint Strike Fighter Program Office, "achieving our vision involves multiple disciplines and a high degree of integration ... that have to work towards a *common true north*...single program/service cannot effectively achieve [the] vision alone."[28] While Mr Dabney was speaking on operational health and decision support, the vision applies across a range of DoD weapons systems. The challenges are DoD wide, but so are the opportunities.

Conclusions and Recommendations

Keep on the lookout for novel ideas that others have used successfully. Your idea has to be original only in its adaptation to the problem you're working on.

–Thomas Edison

Conclusions

Future operational use of weapons information storage and communication technologies will provide weapons developers and users with required information to create and improve weapon systems and tactics. The focus of this article was to identify technologies and processes that support the future of DoD's evolutionary weapons system acquisition process. The premise of this article is that operational weapons need automated data acquisition technologies in addition to the current trend in network-enabled functionality to reduce time in designing, developing, deploying, and improving future weapons systems. A similar case was evident with the trends in precision timing and navigation hardware and software systems which resulted in global positioning system (GPS) receivers in many weapons and commercial applications. As the cost of computing, storage, and information communications hardware becomes more acceptable, future manufacturing technology will enable the integration of these technologies into network-enabled weapons. This will allow flight-test-like data to be gathered from weapons that are deployed operationally, where most weapons spend a majority of the life cycle.

Operational weapons feedback will enable the next generation of networked weapons to process, store, and transmit data for acquisition professionals and operators to use in the design, development, deployment, and improvement of relevant weapons programs and procedures. When combined with current acquisition practices this will reduce the time required and cost incurred to develop and improve future weapons systems. Operational weapons feedback will also enable users to develop tactics that reflect actual capabilities of current weapons by providing timely access to system performance in operationally representative or actual operational environments.

Operational weapons feedback could improve the information flow between users, developers, and maintainers. Synthesis of these technologies and processes will allow weapons systems to evolve into a feedback mechanism to the development and improvement process by gathering, communicating, and archiving information that is tailored to the stakeholders' needs. It can also potentially reduce data requirements as better information is provided via automated processing and analysis.

Smaller, faster, and cheaper computing enables systems to be embedded with processors that make networking, automation, feedback, and actuation possible. The miniaturization of the GPS receiver enabled the synthesis into what we refer to as a *smart weapon*. Smart systems, however, combine communications, control, and decision modeling technologies into systems that have sensory, calculative, and active or reactive capability. In a paper published by a Japanese research group, they collate research on an aircraft fuselage that was developed using smart sensors and materials. The fuselage was able to sense impacts, determine fuselage damage, and suppress damage "using embedded shape memory alloy films."[29] Technologies and concepts of operations like these have the potential to develop our current smart weapons into intelligent integrated network systems. Current precision location and identification capability will be augmented by the abilities to impact decisionmaking (targeting) by monitoring system health; detecting faults and taking or recommending action to the human-in-the-loop; providing imagery; predicting conflicts in space, time, and the electromagnetic spectrum; providing feedback on employment and resulting damage; and other unforeseen uses.

Better Weapons Systems and Tactics

Operational weapons feedback will not only enable the development and improvement of weapon systems, but logistics support, training systems, and tactics. Instead of stand-alone weapons, or even network-enabled weapons, future weapons systems must be able to become a part of the interactions that are facilitated by designers, developers, testers, users, and program managers. Operational and training usage of weapons provides a wealth of data that could be automatically and expeditiously fed back into weapons improvement efforts. In referencing JSF's "undue concurrency of development, test, and production activities and the heightened risks it poses to achieving good cost, schedule, and performance outcomes,"[30] weapons systems based on the future of information communications and computing trends provide a way to mitigate this risk for future acquisitions by reducing time and increasing quality of data sharing among stakeholders. While the risk may still be high for a new development, operational weapons feedback will reduce technical risk over the life cycle of a weapon system.

According to warfare scholar Barry Watts in the *Air and Space Power Journal* article "Doctrine, Technology, and War," "getting doctrine wrong can lead to military disaster ...superior technology in and of itself does not, and cannot, guarantee military success ...technical feasibility is not equivalent to operational utility ...and, finally, old doctrine seldom makes the most of new hardware."[31] While the nature of the relationship between doctrine, technology, and war has long been the subject of warfare studies dialogue, for this analysis the important fact is that they are related. Finding ways to improve connectivity and reap the benefits of this relationship between technology, doctrine, and war is in our best interest. Referencing the notional product lifecycle, operational weapons feedback shrinks the entire life cycle into a networked process characterized by the automated and expeditious flow of specified information. Imagine that each arrow touches the preceding and succeeding arrows, as well as being closer to, or even touching others around the circle. In reference to the relationship of technology, doctrine, and war Mr Watts concludes, "[t]he larger lesson is clear. Technology is important, but so is doctrine. Even more important is a harmonious fit between the two."[32] Operational weapons feedback is a technological mediator between technology, doctrine, and war.

As the acquisition process, policy, and technologies are changing it is up to DoD to redefine where it wants to go. If the doctrinal answer is still network-enabled warfare, then we need to ensure that information communications and computing capabilities are being exploited in a manner which will support shortening the time between the conceptualization and fielding of viable, effective, and suitable weapons and associated employment methods. Operational weapons feedback can help shorten this process.

Recommendations

DoD should integrate data acquisition and analysis capabilities into future weapons systems concepts. DoD should also develop architectures, processes, and infrastructure to support automated data acquisition and analysis of operational weapons feedback. The reason to integrate these technologies and processes is to support human assessment and decisionmaking. Technologies like integrated Network Enhanced Telemetry (iNET); Link-16; Joint Strike Fighter, Prognostics and Health Management (PHM) System; and the In-flight Data Acquisition Pod (I-DAP) should be analyzed for broader application in the DoD weapons portfolio. Also, processes and support systems such as the Joint Strike Fighter, Autonomic Logistic Information System (ALIS); and the Telemetry Network System should be expanded or mimicked in support of weapons systems.

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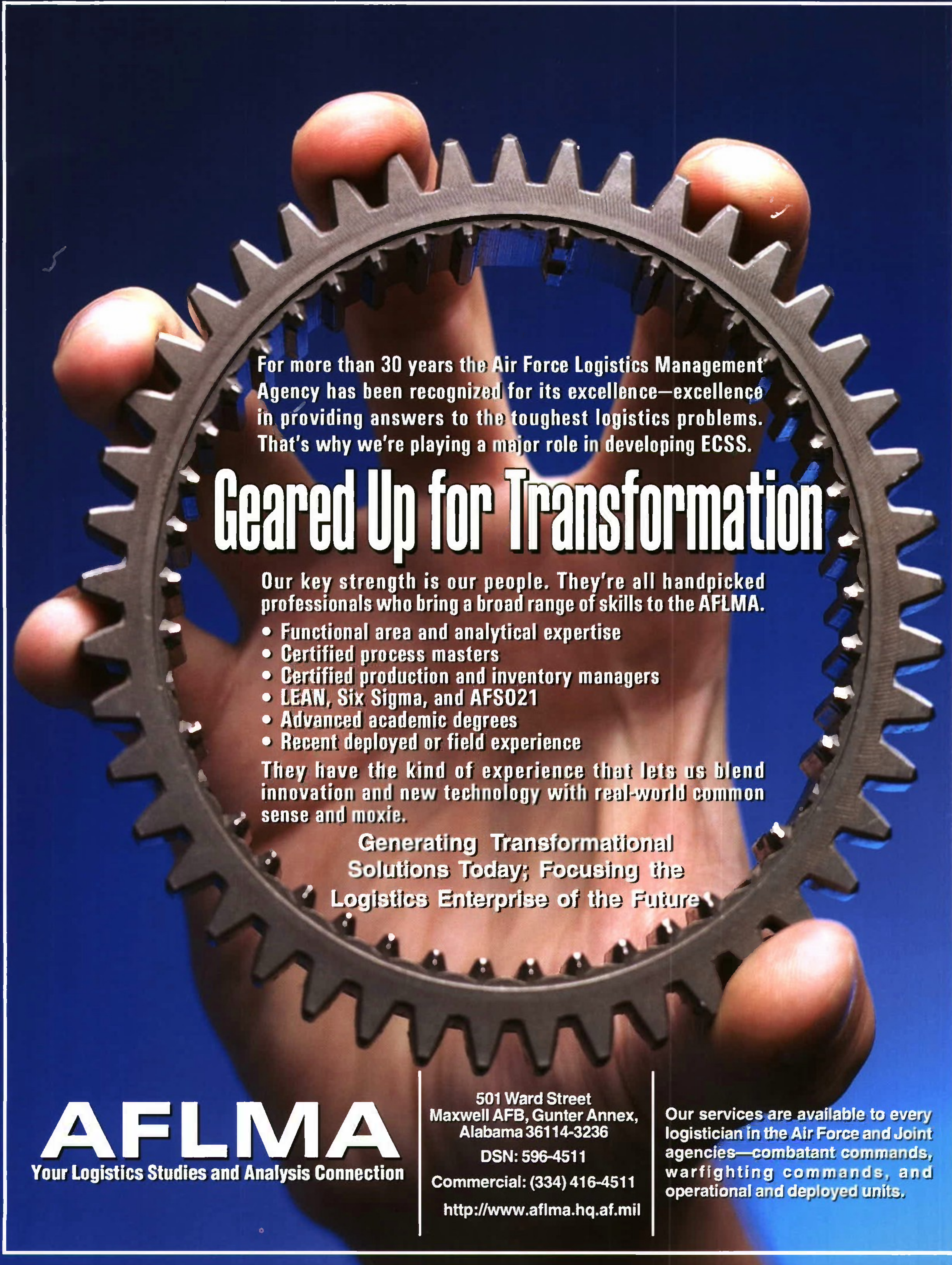
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