1.0 Introduction and Executive Summary

Some military analysts say that warfare at this time is undergoing a revolutionary change. If indeed there is such a revolution, the central element of it is information technology—the technological revolution in computers and communications. It is brought about by an underlying rate of technological progress that is unprecedented in the history of technology and military doctrine.

What makes a technological revolution? Analysis of other technology revolutions tells us that one power of ten of technological change makes a revolution. For example, automobiles transport us ten times faster than walking, and jet planes ten times faster than autos. It took half a century or more for these revolutions to change the face of modern life.

The wealth and security of this nation are increasingly driven by information and are based on knowledge. The engines of knowledge and information, computers and communications, have been doubling their power per dollar every twenty months. The pace is still accelerating. Over the past three decades this compounds to not one or two factors of ten, but six—a millionfold change. And the more powerful these engines become, the smaller they become and the more energy efficient. If this were myth rather than reality, one might say information technologists own a magic wand.

The global village—the wired world of people with shared interests—has been formed because of low cost communications. Computers are so cheap and useful that they are in everything. A tiny but powerful computer sits inside a weapon, guiding it with astonishing precision. Modern warplanes, like the B-2 or the F-22, are as much flying computer networks as they are flying airframes. The remarkable capabilities of modern radar and other imaging devices are as much derived from their computers as from the physics of their sensors.

It is a revolution when computer-assisted logistics planning for a force projection can be done in hours or days rather than weeks. It is a revolution when an accurate situational analysis can be made and given to a warfighter in seconds rather than minutes or hours.

It is a revolution when differences in IT capabilities can contribute in such a major way to a decisive military victory (Desert Storm)—a revolution in which the term "information warfare" is added to the list of future necessary combat capabilities.

The task of the Information Technology panel is to project the visible trends of the continuing revolution in information technology and, where projection fades at the horizon, to envision further progress. We have done this in two ways.

First, systematically we have surveyed the areas of IT work. Examples are communications, computer system architectures, the interface between computers and people, software and the technologies for its development, the emergence of artificial intelligence software that emulates human-like thought processes, software that learns and adapts itself to user needs, technologies for crypto-secrecy and for assured access to systems and networks, and several more. Appendix E contains a sample of IT "futures" of interest to the Air Force.

Second, we have projected and envisioned specific achievements, stretching out over twenty years or more—highlights of the information future. Some are evolutionary, "big wins" with high probability of being achieved. Others represent discontinuities; we do not know if they will arrive but if they do, their impact will be revolutionary. Still others represent technological, educational and organizational concerns for the future of the Air Force in the era of the information revolution.

Military needs no longer drive this revolution. The good news is that often we can buy off-the-shelf hardware, software, and communications that are much better than, and very much cheaper than, what we can have custom-built for us. The Air Force is challenged to adapt to this new way of doing business, and to benefit from the best that commercial technology can offer (just as our friends and enemies can). But some information technologies that the Air Force needs will not emerge from the commercial marketplace. Our panel made judgments about what these will be as a set of recommendations for continued Air Force and DoD R&D funding priorities for information technology. Our panel also points out where the Air Force can benefit from starting to rethink right now how information technology can improve its weapon system design, acquisition, management, education and career development processes.

What follows are summaries of various IT focus areas, concluding with our recommendations.

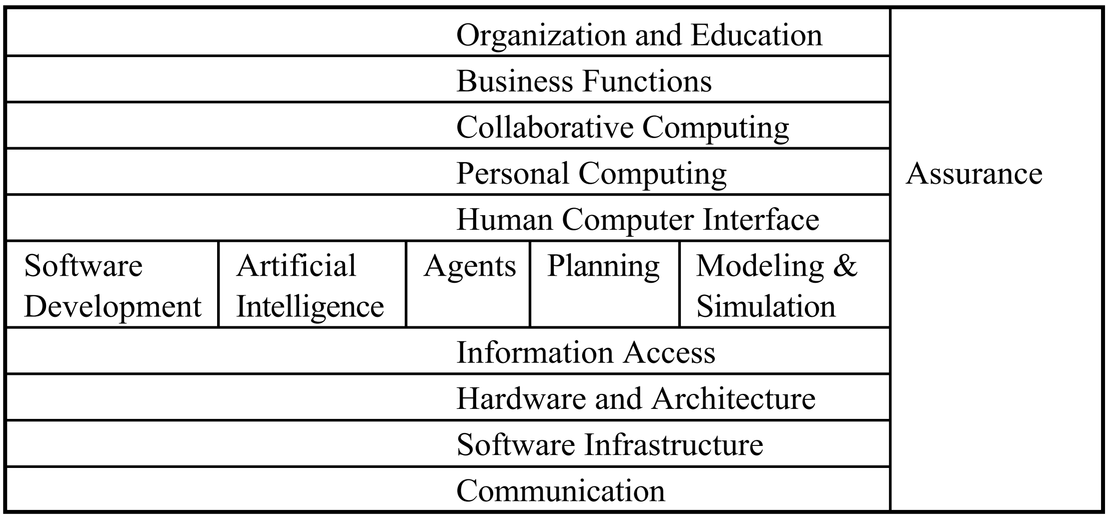

Figure 1 Information Technology Dependencies

Communications

In the field of information technology it is especially important the Air Force ride the commercial curve. The pace of technology here is arguably faster than elsewhere, and there is an enormous non-military market that keeps prices spiraling downward so long as the needs are not specialized.

The key to information technology is distributed systems, enabled by high speed computer networks. Historically the need for capacity in digital networks has doubled annually, though the applications that require growth in capacity have not been predictable. Thus it is evident the Air Force must plan for a growth in its networking capacity by about three orders of magnitude in the next ten years, and must reconcile itself to the expectation the uses of that future network cannot be foreseen. Although the prices of commercial communications have also shown an exponential decrease with time, it is not obvious dedicated Air Force networks, e.g., satellite systems, will show this same decrease.

In the near future the work will be networked with very high capacity optical fibers, using wavelength division technology with enormous capacity. The most cost effective communications will rely on fiber networks. However, in many forward locations, the Air Force will not have access to these fiber networks, so the critical problem for the Air Force will be communicating across the approximately 100-mile gap between its forward locations and the world fiber network. The other critical Air Force communications problem is enabling broadband communications into tactical aircraft from ground points not in line-of-sight to those aircraft. The Air Force will need to use satellites, airborne relays, indigenous wireless systems, and deployable wireless systems to cross those critical gaps.

At the current rate of growth most of the world's population will be connected to Internet soon after the turn of the century. The Air Force must plan for the use of this capability to optimize the efficiency of its operations, just as any other business. However, the Air Force must develop specialized skills in the defense and attack of computer networks. It is likely virtually unbreakable encryption technology will be widely deployed commercially and both network attack and defense will be raised to very sophisticated levels. Indeed, skills in the use of information technology will be the differentiating factor in the future for business, and this will likely be true in the military arena as well.

Personal Computing

"Personal Computing" is a category encompassing the information devices likely to succeed today's personal computers as commonplaces in personal and business lives. Thus this is not a category defined by technology per se; rather it reflects the convergence of technology trends from other categories, expressed in commercial products. This category is essentially one of packaging—what novel forms will various components and software be combined into?

In short, this category represents the trajectory of mass market information tools over the forecast period. Understanding this trajectory allows for exploitation of the economies of scale created by commercial deployment—including lowered cost, increased reliability and expanded understandings of systems performance. For example, if Pentagon planners a decade ago knew what Sun, Apple and SGI would be building today, how would that have affected planning? However, such exploitation is not without risk. Incorporation of complex commercially available systems may expose users to unknown risks of penetration and reliability failures.

Finally, it is vital to acknowledge the crucial role played by different age cohorts in defining this sector. The first PCs were invented by individuals who grew up in a mainframe time-sharing world, and thus it is no surprise that the first PCs (e.g., DOS) were near-perfect simulations of what a timesharing experience would be like at a local level. Now, a new generation raised on PCs is about to enter the workforce with ideas of its own. They are certain to redefine the PC sector as profoundly into something utterly new.

Human-Computer Interaction

The next twenty years will see two important ways computers will come to serve us. The first and undoubtedly the most compelling vision is their migration from a hands-intensive tool to a delegatable assistant. The ever-affordable surplus of computing cycles will be more and more dedicated to making the computer not just user-friendly but user-like.

The more straightforward use of computers today is as a framework within which application programs are run. The processors, the connectivity, the operating systems are becoming invisible, subordinated to the applications programs at hand. Within a decade those, too, will begin to sink below the conscious surface, yielding to task-oriented computing as the next level of work abstraction. To make this possible, the way people interact with computers will take on many of the attributes used when they interact with other people. Over the next few years, speech and handwriting recognition and understanding software will permit a wide range of computer interaction now confined to the keyboard and mouse. That does not predict their demise, however.

The second compelling use of computers will be to augment the physical, not just the intellectual human. Computers offer a very flexible, yet precise means to transform what we are equipped naturally to use into realms of functionality we would have never dreamed beforehand. While the range of such use may not be as broad as more mind-centered work, there are many situations where our dimensionality, our sensory package, our reaction times, our motor sensitivities, or simply our remoteness are inappropriate to the task at hand. The most general concept of such transformation is telepresence, providing human interaction potential to otherwise inaccessible environments. Emerging now are computer-mediated tool systems that permit exquisite sensory and tactile presence from a remote location and with dimensionality scaling where needed. The handling of dangerous material, the teleoperation of large- and small-scale systems, and remote surgery are a few examples.

At the intersection of the mind- and physical-centered worlds of computer use lie new fields like augmented and virtual reality. Augmented reality is the overlay and supplementation of real world, real-time events with simulations intended to instruct or focus the attention of the participant. Virtual reality involves a totally synthesized environment for the participant in which, ideally, all senses are used. Virtual reality systems are, of course, with us now but affordable systems that closely match our sensory capabilities are still a decade or so away.

Intelligent Software Agents

Though the notion of software-based agents have existed since the early 1980s, they are just now beginning to emerge as functional parts of software systems. The lack of a precise definition of agents, unfortunately, gives the developer and marketer wide latitude in just how much or how little functionality is present. At their best, software agents are capable of representing a user or owner in the accomplishment of specified tasks without his/her having to prescribe how it is to be done. Retrieving specific information is the most frequently suggested role for agents, but the complete range of functions is extremely broad.

We define agents broadly, as program that: have an owner, have some degree of autonomy, be goal and not means driven, and be able to create other processes or data. Given the predicted state of development over the forecast period, any use of agents in safety-critical situations must be guarded. The intelligence displayed by agent programs will evolve almost indefinitely. For the moment we define three levels: (1) directed-action agents have fixed goals and limited ability to deal with the environment and data they encounter; (2) reasoned-action agents have fixed goals and an ability to sense both environment and data and take reasoned action; and (3) learned-action agents accept high-level tasking and are capable of anticipating user needs based on general guidelines and can issue themselves new goals in the process.

Over the next decade agents will be able to provide such functions as advising and personal assistance. Advisory agents will be able to monitor a situation and give feedback and recommendations, such as in instructional settings. Personal assistants will most likely appear as managers of human-computer interaction, offering user assistance in specifiable tasks such as electronic mail, calendars, conference set-up, information or more general searches. They will come to represent the user in a wide variety of transactions. “Traveling” agents will be aware of the vast, network-based world of information and its indexing. Under specific requests and general constraints, they will retrieve information of all kinds, potentially operating within remote servers or hosts. They will be needed because the inventory of sources is so large, its quality so uneven, and its costs so varied that humans will not easily abide such searching.

Information Access Technology

Information Access Technology (IAT) provides the framework and foundation for accessing and transporting relevant information to the Air Force decision maker. Central in this task are the conversion of data from the many heterogeneous data resources available into an integrated information base that provides situation awareness. Additionally, IAT needs access to software for symbolic fusion and summarization. Advanced IAT services must also have access to simulation software, so the decision maker can develop and compare multiple courses-of-action within the system in terms of their potential results, resource consumption, and risks.

A critical task of IAT services is the reduction of data to a manageable amount of essential information. Integrating many streams of data further increases the volume of data delivered. It is crucial to avoid information overload to the decision-maker (whether an airman on the maintenance line, a pilot on a mission, or the commander of a joint task force), by presenting only relevant information at the appropriate level of abstraction. Information overload also has to be avoided when lower bandwidth links are to be used, often in the last 100 miles to the warfighter.

Two types of IAT modules are usefully distinguished: mediators and facilitators. A mediator performs such tasks as summarization, abstraction, and fusion at the behest of its owner. Mediating modules can either provide information according to a pre-planned schedule, or in response to a request. A facilitator, by contrast, is a module that searches the network for sources of data, and delivers newly discovered data to a mediator and its maintainer, or directly to an end-user recipient.

Multi-level, distributed IAT systems are enabled by the rapid progress in communication hardware and infrastructure technology. To gain the maximum benefit from such systems, we need experience with IAT concepts involving modern technology so rapid assembly of IAT systems will be possible, e.g., to assemble mission nets for new situation and rapidly assembled task forces.

Artificial Intelligence

The information technology called artificial intelligence (AI) is used to build software that performs the kinds of information processing tasks humans perform so well—using knowledge to solve problems, analyze situations and decisions, recognize patterns, form hypotheses, learn new knowledge, understand human speech and language, and so on. To date the technology has demonstrated limited but significant real-world uses in both commercial and military environments and is poised for widespread and powerful uses in the next two decades.

The key limitation to the AI technology has been a limitation of what AI programs know. To perform well, AI software must be more than narrowly smart, it must be broadly educated. The narrow specialty knowledge bases of today will be expanded in the next two decades to huge knowledge bases with tens of millions (later hundreds of millions) of pieces of knowledge and know-how. Much of human knowledge will be encoded for use by both people and AI software, and will be held and distributed on the Internet. The key bottleneck in doing this—acquiring the knowledge for encoding—will be overcome by technologies now emerging that allow the automation (or semi-automation) of the learning process.

We expect that accurate understanding of human language in text and speech will reach the 95% level in ten years, for areas of limited scope and will handle broad areas of human discourse within twenty years.

Early experiments suggested that AI technology can provide a powerful expanded framework for the problem of information fusion for situational awareness, allowing fusion not just of multiple streams of sensor data, but of situational knowledge, experience, and context as well. This fusion of signals with symbols will be a key to solving information overload, as well as understanding image data and intelligence collections.

Finally, AI application will bring big changes in affordability and rapid response in the areas of designing, simulating, building, and maintaining equipment and software.

Computer-Aided Planning

Improvements in planning and scheduling over the next twenty years will provide revolutionary advances in the speed, efficiency and effectiveness of Air Force operations. Existing techniques, such as constraint-based planning, when widely applied, will provide orders of magnitude improvements in operations planning. Additional advanced capabilities will arise from capturing plan rationales (i.e., the reasons why actions are being taken), enabling for example the speedy modification and re-use of existing off-the-shelf plans. Advances in decision theory and reasoning about uncertainty will enable execution-time plan modification even in the highly uncertain environments characteristic of conflict. Finally, a variety of increasingly powerful multi-agent planners will permit the integration of concurrent multiple viewpoints and, eventually, permit planning to be done continuously by multiple teams of people and software agents working together.

Modeling and Simulation

Computer modeling and simulation provides exploration of alternatives for the full spectrum of Air Force activities, from research and development through analysis, acquisition, test, evaluation, production and logistics to education, training, and operations.

Computer modeling and simulation has been evolving its broad range of Air Force capabilities since the first use of computers for ballistics applications in the 1940's. As a result, the current Air Force inventory of independently-developed computer models and simulations has formidable interoperability and compatibility problems. These have been overcome in some limited domains (e.g., flight dynamics models) and in some medium-scale training-oriented distributed interactive simulations such as Simnet. They have also been overcome in point-solution demonstrations and exercises linking wide varieties of models, simulations, real equipment, and operators. However, significant broad, regular-use operational issues such as interoperability, rapid configuration, and verification, validation, and accreditation (VV&A) are just beginning to be addressed.

By 2005, with a significant level of Air Force effort, basic large-scale interoperability support will be available, including consistent data definitions and fixed interaction protocols. By 2015, this will extend to dynamic interaction and interoperability agents. By 2005, simple user languages enabling rapid composition of models and simulations will be available. By 2015, these will extend to support automatic configuration of models, and simulations that address decisions such as choice of airlift capabilities.

By 2000, the Defense Simulation Internet will provide broadband support of point-solution "Louisiana Maneuvers" scale simulation. By 2010, it will be operationally robust and able to support regular exercises at this scale. Currently, VV&A technology consists of basic test suites and simple assertion checking (e.g., of conservation of energy, resources, etc.). By 2005, with Air Force investment, this can expand to simple mission-domain model checking and built-in-tests. By 2015, this VV&A technology can expand to domain model checking using automated agents and dynamic built-in-test, achieving much higher levels of credibility.

By 2015, the resulting modeling and simulation capabilities will enable combat operations options to be credibly simulated before and during combat, greatly increasing combat effectiveness. The same capabilities will enable continuous two-sided exercise of information warfare capabilities, honing Air Force pre-eminence in this critical area. With appropriate attention to acquisition restructuring (e.g., virtual competition groundrules), the technology will enable virtual system acquisition, or flexible migration from virtual to actual combat systems, with complementary closed-loop combat system exercise and improvement across the system's life cycle.

Software Development

Software development technology provides the Air Force with its best defense against tomorrow.

The other technologies addressed in New World Vistas are primarily focused on ensuring that on any given day in the future, say July 4, 2025, the Air Force is better prepared to prevail in combat than its adversaries.

However, suppose that on July 5, 2025, the Air Force detects that an enemy has discovered and is ready to exploit a critical weak link in Air Force combat capability. What technology can best enable the Air Force to repair the weak link and disseminate the fix to its full complement of forces?

An electronically disseminated combat system fix would best fit this need. The most powerful and flexible electronic fixes by far are changes to the combat system's software. Enabling the Air Force to design, develop, test, and deploy these fixes is the province of software development technology.

Software development technology consists of methods, processes, tools, and assets enabling faster, cheaper, and better development of computer software. Methods, such as object-oriented design, configuration management, and Cleanroom methods, enable improvements in software design, verification, version control, and quality assurance. Processes, such as incremental, evolutionary, spiral, design-to-cost/schedule, and product line management processes, enable more efficient orchestration of the methods. Tools, such as design, code generation, test, product and process management tools, can completely or partially automate software development functions. Reusable assets, such as specifications, plans, components, and test cases, enable more of a software system to be composed of already-developed artifacts.

As with other information technologies, software development technology is increasingly paced by commercial investments. From an information warfare standpoint, this must be considered a technology leveler with respect to the Air Force and its adversaries. Not using commercial software development technology would be a competitive disadvantage for the Air Force, but so would a purely reactive use of commercial technology.

Software Infrastructure and Standards

The breadth of computer use in commerce permits the military to exploit the massive investment in software being made for commerce, manufacturing, education, and entertainment. This investment will continue to drive progress, the benefits of which will be available to all: commerce, the military, our friends, and our adversaries. In this environment, speed is the key to remaining current: the Air Force must ensure that its acquisition processes enable it to move quickly in acquiring and exploiting new software.

The Air Force has a need for standards that enable interoperation that far outstrips what is likely to be produced by the commercial marketplace where individual vendors have interests in developing proprietary systems.

Progress Due to Commercial Interests.

Commercial interests are causing a rapid convergence to a smaller number of distinct software (SW) systems. We can project the ongoing commercial investment will be limited to one operating system for mainframe computation, a family of operating systems clustered around UNIX, and perhaps two or three families of systems on personal computers. There will also be broad use of standards among those systems, for instance SQL to enable UNIX systems to access mainframe databases, and object-oriented protocols to enable personal computers to access object-structured resources kept on UNIX-based servers.

These interoperability standards will continue to grow in breadth and capabilities. Similarly, features made available in one system will be rapidly replicated and superseded by features provided by a competitor. Even though the pace of change may slow down somewhat, there is little doubt throughout the next 25 years the commercially available software infrastructure will provide the foundation for most DoD and Air Force systems. In mission-critical applications, because of the need for security and trustworthiness, DoD will lag behind the curve with respect to features and cost-performance ratios. This lag should be minimized, so DoD SW availability and its capability to exploit modern hardware does not lag excessively behind adversaries, who may well be willing to proceed with fewer constraints on security and trustworthiness.

Capabilities Appropriate for Government Support Funding.

Users need to retain the flexibility to change platforms and use systems composed of hardware and software obtained from multiple vendors, including competitors. Standards conformance should be supported by government, to assure fair and early dissemination of sharable technology.

While NIST has the primary role for standards, there is a role for DoD research to support standards activities that can accelerate the adoption and availability of sharable technology of interest to the military from commercial vendors.

Conforming military subsystems, integrated into the commercially available infrastructure, will provide the basis for future military information and control systems. They will displace the bottom layer of the stovepipes that characterize DoD system architectures and provide the infrastructure for interoperation of general software development and the global information systems.

Capabilities Requiring Military Investment.

On top of the commercial and national infrastructure will be requirements that require specific military investment if US SW technology is to be maximally effective and superior to the technology of adversaries. Specific capabilities will include:

1. Highly robust real-time SW modules for data fusion and transmission.
2. Integration of simulation software into military information systems.

Computer Hardware and Architectures

The microprocessors made by a few merchant semiconductor manufacturers will dominate computer hardware designs. Since tens to hundreds of millions of these will be manufactured each year, the low cost of ‘printing” so many computers will be irresistible to computer makers.

The microprocessors will be arrayed in networks of various sizes to satisfy product specs: uniprocessors, small multiprocessors, super-scale arrays for major computing power, networks of workstations, and so on. Also scaled to the product design will be networking capability linking the common microprocessors.

Except for stand-alone computers in embedded applications, the slogan “the network is the computer” will become a reality. Computer systems architecture will be largely “plug and play.” This implies major changes for the system software, something discussed in another section.

Ultra-large-scale integration of circuits on silicon will follow its historical trend of doubling power per dollar about every 20 months for the next decade. At line widths of one-tenth micron, this remarkable path may end, and other solutions to obtain microprocessor power may have to be found. The solutions may come from new materials (e.g., "bio-organic"), new physics (e.g., atomic-level switching), or new designs (e.g., new approaches to parallelism) or from an entirely new concept not yet known (unlikely).

The wide use of just a few families of microprocessors will lead to the kind of defacto standardization that will make commodity items of all peripheral devices. Huge amounts of on-line secondary storage will be achieved by evolving into parallel-organized databases connected to high bandwidth bitways.

High Assurance Systems

Existing information intensive systems are currently blatantly vulnerable: recent studies have shown the domestic electric power grid, financial systems, and telecommunications infrastructure to have between modest and virtually non-existent protection against information-based attacks. Yet basic techniques exist capable of deterring many of these attacks, and continued development and dissemination of known cryptologic technology will be able to provide very high levels of security to individual systems. Attention should be paid to widespread integration of such technology into Air Force software at all levels (networks, operating systems, and applications). Important attention should also be paid to Air Force *policy* regarding cryptology: in particular, we recommend the Air Force employ a key escrow (or similar) system, in order to ensure that internal use of cryptographic techniques cannot provide an impenetrable wall of privacy to unauthorized action by Air Force personnel.

Difficult problems arise in providing high assurance and survivability for larger-scale distributed systems. A significant body of foundational work exists in fault tolerance for modest scales of distribution, but significant work needs to be done to provide assurance and survivability when potentially every computer in the Air Force will be interconnected. Of particular note will be development of techniques for graceful degradation—the ability of a system to provide appropriately selected partial functionality in the face of unanticipated failures, rather than the all-or-nothing functionality provided by today's approaches to fault tolerance.

Finally, we note with considerable concern while a great deal of attention has been given to the notion of information warfare, there is as yet no notion of rules of engagement in this field. We cannot tell when we are under attack, first because information attacks can be considerably more subtle than physical attacks, but more importantly because we have not yet established any notion of what constitutes a hostile act in cyberspace.

Collaborative Computing

"Groupware" is the label for the notion that computers and information can be used to support business teams, rather than mere individuals (the dominant personal computing paradigm in the last decade). Groupware thus encompasses both the creation of entirely new systems, as well as the pressing into group service systems designed for individual use.

The term "Groupware" was coined in the early 1980s by Peter and Trudy Johnson-Lenz, but groupware systems are yet older. One of the oldest, the Augment system built by Douglas

Engelbart at SRI in the 1960s, also happens to be among the most ambitious, incorporating features such as two-way video, group writing, and shared multiple-window screens.

Groupware products are proliferating today, yet the term remains more a concept than a product category in its own right. In the long run "groupware" as a discrete category will disappear entirely, as group-oriented features are incorporated into virtually every product offered in the PC sector.

Groupware as a product category is growing solidly but modestly. The single largest groupware product is Lotus Notes, which is enjoying considerable popularity among corporations, but still has an installed base which is minuscule compared to the total installed base of networked PCs in corporations. Notes itself does not have a bright future, and the features that make it popular will find their way into more generalized environments such as operating systems, advanced data repositories and even Internet browsers and servers.

Groupware will have its largest impact on organizational structures. Even the most casual glance at business history makes it clear that each time a new information infrastructure becomes available (e.g., railroad, telegraph, telephone) the entities which are ultimately most successful are also the first to reshape their structures in order to gain maximum advantage of the new information conduits. The new networks emerging today are "geodesic" (a term first noted by Peter Huber in the mid-80s in the context of telephone deregulation), that is, global, non-hierarchical and without any central node. It is a safe bet that our organizations will follow suit.

Business Applications

Information technology will change the Air Force way of doing business, thoroughly permeating the Air Force of 2025. From the desktop to the flight line, the business needs of the Air Force will be supported by information appliances.

The business side of Air Force operations will be contracted, not done in house. Outsourcing functions like payroll, personnel and property management will help meet down-sizing and budget constraints.

Information technology will provide the means to commercialize and to more effectively accomplish its remaining business functions. Bandwidth on demand for any application will allow telecommuting from anywhere to anywhere. Coupled with extensive desktop computing power, collaborative planning and telepresence will be the norm. This, EC/EDI, and improvements in our modeling and simulation capabilities will dramatically alter the Air Force procurement and acquisition process. Systems will be created using advanced modeling and simulation and electronic engineering and then they will be "test flown" in a Star Trek like holodeck before the Air Force buys or builds the first one.

The contract business of the Air Force will join the rest of the corporate world to become another paperless enterprise. Electronic tethers, in the form of personal communication devices, that use voice, video or data communications and intelligent assistants will keep blue-suitors in constant communication with their offices. The bottom-line, the business side of the Air Force will continue to be no different from the business side of the corporate world and COTS software will meet AF needs.

Organization and Education

The revolution in information and IT will profoundly affect the organization and education of the Air Force. As the industrial revolution created entirely new organizations of mass production, the information revolution will lead to new ideas of what organization and education mean. Further, as air power once significantly changed army and navy doctrine and organization, IT power will change the AF even if the primary responsibility for the Information War mission is consigned to another agency. Organization and education will be vital differentiators for the Air Force in a world of commodity technology.

But what are the characteristics of effective organization and education 25 years from now? The beginnings of an answer can be found in organizations that are today riding the IT bow wave. These enterprises are flatter and organized to produce hundreds of niche targeted products and services. To effectively adapt the Air Force must learn how to strike and defend with hundreds of varied lethal and non lethal weapons from physical ordinance to abstract bits and bytes. A second related characteristic of successful organizations is their attention to front line employees. These workers are empowered with intellectual and informational skills, and the power to act on what they see and observe. Currently, the Air Force is decentralizing the power to act on decisions, but does little *intellectual* and *informational* skill education necessary for sophisticated learning. Instead it tends to rely on training that emphasizes standardization, top down direction, on-again off-again phasing, and physical skill training. These training courses are still useful, but would only be one aspect of a multi-faceted educational system.

New educational processes within this flatter, networked, multi-faceted AF will be more on-going, continuous, and student-centered. Education, defined broadly to include the intellectual and information skills, then will become a vital daily transaction for the organization, in addition to sortie generation. Perhaps contracted mentor-nets involving hundreds of the best educators and thinkers in industry and academe will provide the opportunity for AF "cyber pilots" and "bit jocks" to hone skills, share insights, notice threats, exploit adversary weaknesses, and differentiate our capabilities from hostile organizations.

Organization and education are not distinct, but blended facets of information power are a prerequisite of successful organization. Reinforcing each other they help create a combined system capable of fighting and defending in hundreds of niches. This is similar to how smart terminals within simple networks have replaced large central controlling computer networks.

Recommendations

Prologue

Future development in information technology will come predominantly from the commercial sector. Military needs are a small part of rapidly growing commercial markets. The key drivers are commercial economies of scale in the production of chips, software packages and fiber bitways and from the importance of standards, de facto or official, that are critical to all information transfer.

However, not everything that the Air Force will need in the future will be available in the commercial marketplace. For those needs that we list below, the Air Force must make long term R&D investments. In some cases they represent added functionality and in others they will be strictly military-unique. These areas will help provide the differentiators so critical to a military future in which both sides have wide access to the same commercial information technology. This is our “focus” message for Air Force IT.

We also have a “defocus” message. We list below areas in which commercial firms will produce products that will be satisfactory for AF needs.

Needed Air Force Investments in long-range R&D (or shared in vestments with other DoD entities or private companies).

1. Information transfer over the backbone-to-mobile-platform link “the last N miles”. Consider intelligent compression, differential updates, high bandwidth directional antennas to create a highly available, minimum bandwidth core.
2. Information fusion comprising both signals and symbolic knowledge.
3. A widely available knowledge web of tens to hundreds of millions of pieces of knowledge. The AF shares in the research costs and develops AF specific knowledge for AF needs.
4. Software architectures that work with AF-specific knowledge, reusable components, safety-critical components, real-time systems, and other military-oriented capabilities.
5. The automatic indexing of images by their semantic meaning in terms of military objectives (intelligent image retrieval).
6. Automatic capture of the rationale for plans during planning activities.
7. Reasoned-action and learned-action agents whose goals are AF-specific.
8. COTS software components and CASE tools enhanced to meet AF combat needs (such as security, survivability, real-time performance, and scalability).
9. Architecture for “just-in-time” information systems and networks “when you need it.”
10. Multi-agent planning software.
11. Software that is survivable, displays graceful degradation.
12. Modeling and simulation for training; system design through acquisition; planning and decision making. This will include component interoperation; believable semi-autonomous forces; transition from virtual to actual system acquisition (in a non-proprietary way); validation verification, and accreditation.
13. Augmented reality—the overlaying of synthetic, spatially synchronized, cues and structures on real-time, real-world activity for training and for the maintenance of complex systems.
14. Human-computer interaction capable of sensory-matched control of all UAVs.
15. The technologies and rules of engagement for information warfare.

16. Telepresence, the real-time trans-lation of the human senses and physical dexterity into otherwise inaccessible spaces with possibly “non-human” scaling factors (e.g., very large, very small).

Defocus AF investments from these areas that will be well-handled by the commercial sector:

A. High capacity communications “backbones”; global telephone networks; world-wide wireless infrastructure, Internet, ATM.

B. Cryptography routinely embedded in systems

C. Compression (except intelligent compression)

D. Multimedia technologies.

E. Natural Language Understanding, including Speech Understanding.

F. Computer displays

G. Data mediators, request facilitators, information broker software

H. Basic directed-action software agents

I. Software for the “business” functions of the AF: logistics, personnel, finance, etc.

Next Steps:

1. Air Force laboratories must rethink their information technology R&D programs in the light of this New World Vistas report
2. The Air Force should rethink its advanced weapons system design from the info-centric point of view
3. The Air Force should rethink the education, career path, and reward structure for its officers and airmen in light of the IT future projections in this report
4. The Air Force should rethink its acquisition strategy in the light of advanced IT capability

A Sample of Forecasts in Information Technology Important to the Air Force:

1. All cryptographic codes will be unbreakable, but systems may still be breakable.
2. All computer networks and platforms will be scaled from the commodity components of personal computer and workstations.
3. Computers will understand natural language.
4. Bits-per-second in a backbone will be effectively infinite and of near zero cost.
5. Information transfer over the backbone-to-mobile-platform link will remain bandwidth-constrained.
6. End-user programming can harness large bodies of accepted code.

7. Information fusion will comprise both signals and symbolic knowledge.
8. Intelligent programs will carry out “what-to-do” commands instead of “how-to-do-it” commands.
9. Advances in modeling and simulation can enable significant advances in system design, planning, acquisition, training, execution, and reuse.
10. Human-computer interaction will enable sensory-matched control of all UAVs.
11. A profound shift toward information technology must occur in AF education centers and R&D laboratories.