Emerging Impacts of the IT Revolution upon Technology, Aerospace, and Society:
Creating Problems and Enabling Solutions

By Dennis M. Bushnell

ABSTRACT: The convergence of major ongoing technology revolutions has multiplying effects. The information technology revolution enabled subsequent technology revolutions to develop and spread: The world is avowedly technologically "flat." This paper explores the major technology revolutions— IT, biologics, nano, quantum, and energetics—their implications for aerospace research and space exploration, and their impacts on society at large.

IT REVOLUTION, AEROSPACE, AND SOCIETY

By Dennis M. Bushnell

The Multiplying Effects of Technology Revolutions

Much has been written of the major ongoing technology revolutions and their multiplying effects. The first of these, the information technology (IT) revolution, provided the means for subsequent revolutions, including biologics, nano, quantum, and energetics, and ensured that they spread worldwide.

The IT revolution began in the 1950s with the development of solid-state electronics. The biologics revolution began in the 1960s and 1970s with DNA and genomics, and the nano revolution, in the 1990s with self-forming nano systems and carbon nanotubes. Quantum technology is now developing rapidly, enabling nano systems, and the energetics revolution is providing ever more efficient and less expensive renewable energy sources. The energetics revolution is also generating nascent research on positron storage and low energy nuclear reactions, possibly via the weak force and collective effects.

The IT revolution has produced improvements of an astounding nine orders of magnitude in computing capability and speed since the late 1950s. As we shift from silicon to biologics, optical, nano, molecular, and atomic computing, we'll see improvements of another eight to 12 orders of magnitude. With

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quantum computing, increasing numbers of applications are projected to provide possibly 44 orders of magnitude improvements. As this is written, the fastest computer is a Chinese machine with over 30 petaflops of processing speed—essentially matching the speed of the human brain.

Machine intelligence is developing after suffering decades of inadequate machine capability to make serious progress and a detour into expert systems. Researchers in machine intelligence are now pursuing deep learning approaches, which are proving to be extremely useful and important. Many now believe the frontier of potential human-level machine intelligence may be found in biomimetics and brain-emulation approaches. There is even a possibility of "emergence"—i.e., when the machine intelligence is complex enough that it "wakes up," just as when human intelligence emerged via evolution during the million-plus years of the hunter-gatherer epoch. In fact, some posit that human intelligence can be improved upon and is only a cul-de-sac of what is conceivable.

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The IT revolution has produced massive changes in human society and economics—from the Internet, to the rapid expansion of knowledge (and even what is knowable), to an increasingly pervasive trend of "tele-everything." A relatively recent realization is that the extraordinary compilation, storage, and availability of truly massive amounts of information could—via processes under the mantra of "big data"—reinvent many of our technical and commercial processes and content. These processes will enable us to elucidate new heuristic governing laws for various situations.

The IT revolution will also accelerate the expansion of robotics' capabilities, which are on a clear path to pervasive autonomous systems. The machines are rapidly supplanting humans in more areas of employment; they are proving to be more productive, less expensive, and—in a growing number of areas—more capable than humans.

The development of five-senses virtual reality is a major advance in human–machine communications that bodes well for accelerating the tele-everything trend. IT-enabled 3-D printing is rapidly changing the manufacturing landscape from central factories that employ numerous humans to robotic home fabrication laboratories. This transition has potential major consequences for the field of aeronautics and space exploration in such areas as transporting cargo and manufacturing and using resources in space.

What we see evolving is a global brain, via the Web. When combined with manufacturing by on-site printing, this global brain is enabling a planet of inventors—both human and, increasingly, machine. The impacts are literally life changing and are occurring essentially simultaneously with other game changers, such as climate change and ecosystem degradation.

In aerospace, IT developments are enabling autonomous aircraft operations, air traffic control systems, and safe and affordable colonization of Mars via autonomous robotics, which will use 3-D printing and manufacturing to exploit the huge resources on Mars.

Impacts of the IT Revolution upon Technology

The massive increases in computing power and communications could be the "poster child" for illustrating the IT revolution's impacts upon technology. In the early 1960s and before, we were using mechanical calculators and slide rules; now we have exceeded 30-petaflop machines and anticipate the development of exoflop machines in the near term. Research is under way on carbon nanotube and graphene computing, as well as bio, optical, quantum, nano, molecular, and atomic computing. A major current issue for quantum computing is delay of decoherence, for which the recent discovery of quantum operation in several biological systems at "room temperature" may contribute solutions.

Increases in computing capability have fostered efforts in research on machine intelligence. There are three major approaches to such:

1. Soft computing—neural nets, fuzzy logic, genetic algorithms, "learning" software.
2. Biomimetics—nano-sectioning the human brain, replicating in silicon.
3. "Emergence"— the way humans evidently acquired intelligence: Make something complex enough and it "wakes up."

Soft computing is already making quite useful progress, including applications to the stock market, for example. Researchers are making efforts to greatly expand these capabilities. Biomimetics is a focus of several major billion-dollar projects to emulate the human brain, a "work in progress." Soft computing contributes to these efforts by enabling the development of ever more autonomous robotics and "automatic" systems. Increases in storage capacity are another major piece of the computing success story that borders on the fantastic. This is leading to what is euphemistically termed "big data," which could provide a fourth way forward in engineering design and analysis along with experimentation, computation, and analysis.

A massively liberating aspect of the IT revolution is the ability to produce personal IT and communications devices of ever decreasing size and cost and increasing capabilities. The connectivity bandwidth of such devices is increasing and can improve massively if we shift to optical communications. The mantra for all this is the "death of distance," which provides a critical capability for economic globalization. These personal IT devices increasingly enable us to work and interact with others from anywhere.

Augmented reality is coming online now, with five-senses virtual reality not that far behind. These are expected to provide superb immersive presence and are, along with other IT capabilities, shifting us to the Virtual Age, when we will be able to totally replace physical travel and presence. As an example, many scientific meetings are now open to virtual presentations, saving travel time and costs. All of this increased connectivity has greatly reduced communication costs today compared with the last century and produced an essentially flat technological playing field worldwide. The long latency that used to exist between obtaining results and their promulgation to a wide audience has shrunk to literally milliseconds or less.

"All connected humans can partake of this global mind—both use it and contribute to it…. To become an integral part of the global mind, humans will become cyborgs."

Along with this huge increase in personal communications has come access to truly massive amounts of information, which is the basis of ideation and creativity and is producing a global population of inventors. In the Industrial Age, we produced wealth largely by exploiting natural resources. Now, in the IT/Bio/Nano Age, we largely produce wealth by inventing things.

These IT developments have combined to produce machines that are proving increasingly more capable than humans. Compared with humans, the machines are far more networked, have massively more memory, have far less latency, make fewer mistakes, know far more, are many orders of magnitude faster, are far less expensive, and have increasing intelligence. They are also more patient and durable, do not tire, and, as they develop, are increasingly replacing humans in employment.

IT-enabled developments in sensors are facilitating the creation of a global sensor grid. We are putting sensors everywhere, and some predict estimates of several trillion sensors networked in a decade or so. This, along with the ever increasing machine speed, intelligence, storage, and connectivity, is producing a networked global mind. All connected humans can partake of this global mind—both use it and contribute to it. And it constitutes the "competition" to individual efforts. To become an integral part of the global mind, humans will become cyborgs, with brain chips and external data ports.

The technological results of IT writ large have been and will be truly game changing and life changing. We are about to enter an age with

- ubiquitous autonomous robotics, including personal service and transportation devices;
- an Internet of Things that, combined with networked sensors, can and will operate much of the infrastructure;
- modeling and simulation that increasingly replaces physical experimentation;
- big data as a new component of the engineering, science, and econometrics toolkit;
- tremendous advances in DIY capabilities, including tele-everything and on-site manufacturing;
- a huge percentage of the world's knowledge increasingly available at the granularity of the individual; and
- machine creativity and invention.

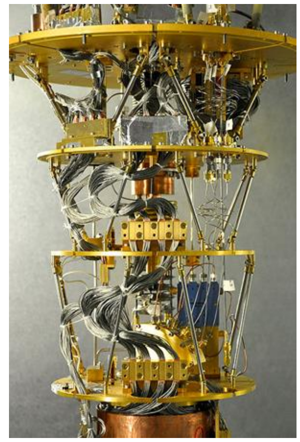
But with these technology developments, we are also essentially inventing ourselves—the human species—out of a "job." The machines, for excellent economic and functionality reasons, are supplanting us. There are many books and excellent minds now expressing serious angst about the eventual development of human-level machine intelligence and whether or not, either via malevolence or simply through untoward actions, such machines could be antipathetic to humans.

Impacts of the IT Revolution upon Aerospace

Most of the current rational for commercial space development focuses on telecommunications, a major industry that is based upon using and exploiting space as the positional high ground. Other IT-enabled computational sciences—e.g., structures, materials, fluids, systems—constitute the design backbone of aerospace. Simulation technology is rapidly evolving into a virtual flight capability; the result is less physical testing and more computation. For example, the number of wind tunnels and wind tunnel test hours is decreasing.

Aerospace has from its inception been married to IT technologies, such as for avionics, navigation, and so on. More than 80 percent of safety issues in aeronautics are due to human factors. Autonomous flight would be expected to have a better safety record. The technical capability is in hand now—and will improve going forward—for autonomous flight with uninhabited air vehicles (UAVs) and eventually autonomous personal air vehicles (PAVs), or UAVs carrying passengers.

Goddard technologist Mahmooda Sultana investigates applications for graphene. Credit: NASA / Pat Izzo



D-Wave Two quantum computer at the NASA Advanced Super-computing facility. Credit: NASA Ames / John Hardman

ISRU-based robotic construction tech-nologies. Credit: Behrokh Khoshnevis, USC

Mars. Credit: NASA

"Butch" Wilmore shows off a ratchet wrench made with a 3-D printer on the ISS. Credit: NASA

Wrench printed in space is tested at NASA Marshall SFC. Credit: NASA / MSFC / Emmett Given

The estimated markets for such robotic air vehicles are massive, but require an autonomous air traffic control (ATC) system to realize. Again, the many redundant, fail-safe IT technologies (sensors, navigation, communications, actuators/controls, machine intelligence, computers, software, etc.) are either here or on the horizon to produce an ATC system enabling millions of autonomous vehicles in controlled air space. Given such an ATC system, quiet vertical to short takeoff and landing (VSTOL) vehicles for human-sized and smaller-payload autonomous flight vehicles could operate off the street in front of an individual holding. Applications would include delivery, a wide variety of service functions, and personal transportation, with an estimated worldwide market on the order of a trillion dollars per year, mostly from PAVs.

Except for the relatively few human missions, most space campaigns have from the start involved vehicles and various devices that were tele-operated or even autonomous. The cost and safety issues for sending humans to Mars strongly mitigate in favor of establishing autonomous, robotic capabilities. These systems could exploit the vast Martian resources, including massive amounts of water to be used on Mars missions versus hauling it from Earth.

This approach is termed ISRU—in situ resource utilization—which would greatly reduce the number and costs of requisite flights from Earth. Small devices would be used to make fuels, habitats, life support, rovers—everything on the planet via printing would establish reliability, safety, and functional viability before the humans leave Earth. Robotic Martian exploration writ large over the past several decades indicates the presence of truly massive amounts of resources. Autonomous robotic transportation and extraction of these resources for manufacture offer the prospect of Mars becoming the "Walmart" for the inner solar system. According to some estimates, robotically manufacturing fuel on Mars and robotically transporting it to low Earth orbit may be less expensive than transporting it up from Earth.

IT Impacts Upon Society

The societal impacts of current and emerging information technology developments are massive in scope and import. They include:

- tele-everything and the emerging Virtual Age,
- machines taking human jobs,
- the econometrics shift created by "DIY on steroids," and
- humans becoming cyborgs, merging with the machines.

"Tele-everything" is not an overstatement. Starting with tele-entertainment and telecommunications in the early 20th century, tele-living has now expanded to telecommuting and teleworking, teleshopping, tele-travel, tele-education, telemedicine, tele-politics, tele-commerce, tele-socialization, and now, with on-site printing, tele-manufacturing.

The combinational advancements in bandwidth, device capabilities, and immersive or virtual presence have greatly accelerated the march to a Virtual Age. Holographic projection and five-senses virtual reality in development will proffer major improvements. The next substantive advance would be direct communication with the brain, as opposed to our current reliance on the senses. It is now common to see folks using their smartphones during meetings and in spare moments. With greater bandwidth, such communication could, going forward, be transmitted directly into the brain via infrared, radio frequency, or optics communications.

"These tele-everything developments enable two major societal shifts: the ability to live wherever one wants and the ability to be self-sufficient at that site."

These tele-everything developments enable two major societal shifts: the ability to live wherever one wants and the ability to be self-sufficient at that site. Distributed energy generation and renewable energy at the granularity of the individual holding are emerging rapidly and very affordably. Going forward, ever more homes will be off not only the electric grid, but also the food and water grids.

All of this conjures up a very different societal landscape. There would no longer be a requirement or much of a benefit to live in cities and their satellite suburbs. In the Agricultural Age, almost the entire workforce comprised subsistence farmers, and there were very few "jobs," with folks working for others. The IT and other technological revolutions proffer a return to such a jobless state, but this time as a self-sufficient electronic, tele-everything cottage with on-site manufacturing and nearly all services DIY or robotic. Even professional services such as tele-medicine and robotic surgery will be DIY. Tele-education is developing rapidly now, enabling folks to learn better, faster, and more creatively.

This prospective shift to independent, "return to the land" living is developing concomitantly with the machines taking the jobs. As folks no longer need jobs, thanks to distributed machines at the scale of the individual holding, income disparity and much of the current econometrics would atrophy. Our 200-year Industrial Age experiment with needing jobs and being beholden to employers would essentially end.

This end-point tele-everything societal construct would have far less impact upon the ecosystem. For example, teleshopping can reduce overall environmental impacts upon climate, energy, water, pollution, and so on by a factor of 50. The issues of the haves and have-nots will go away as everyone becomes a self-customized "have," with corresponding great personal empowerment and a stable, human-centered society overall.

This societal concept could also be applied to Mars colonization. Mars has truly massive resources, as we have learned from the now many satellites and rovers collecting data on the planet. The concept of in situ resource utilization, coupled with autonomous robotics and printing manufacture, could enable affordable and safe human colonization of Mars.

As for the nearly existential issue of the machines taking the jobs—including for aerospace pilots, air traffic controllers, aerospace designers and manufacturers, and aerospace operators of all flavors—there are three obvious solution spaces going forward. All of these services have a robotics future mapped out. With the expected and continued improvements in robotics and machine intelligence, there are very few, if any, jobs the machines cannot do better than humans under the usual metrics. Here are three approaches for humans going forward as the machines take the jobs:

1. A guaranteed income, using the wealth generated by the productivity and proficiency of the machines to support a comfortable lifestyle for everyone. This ensures a market for what the machines produce. Many people in many areas receive some sort of income assistance currently. We have been tending this way already. Approaches range from very progressive taxation to placing the machines in a global commons.
2. Humans merging with the machines. We are rapidly becoming cyborgs; humans will benefit from artificial retinas and hearts, printed replacement organs, and brain chips. This human augmentation is an emerging subject of social discourse and a major subject of concern to the transhumanists. The advent of on- and off-board brain adjuncts with beyond-the-senses connectivity is shifting the argument from "humans versus machine" to the emerging "human-contaminated machines." Brain uploading is now openly discussed. This approach, overall, is also ongoing.
3. DIY on steroids, no jobs required. This approach is also now developing rapidly, both with respect to the requisite technological capabilities and actual instances of folks going off all the grids and living in electronic cottages, approaching tele-everything. The local 3-D printing and manufacturing capability is developing rapidly and at ever less cost. The conditions are developing toward a "takeoff" in

this DIY lifestyle, which would reverse the recent trend toward ever more urbanization, as well as vastly alter much of current econometrics.

The machines *are* taking the jobs. Unlike in the Industrial Age, we are now creating a new intelligent robotic species, which is replacing us in the workforce. This issue—along with many other serious issues, such as climate, energy, and a crashing ecosystem—lacks substantive societal planning going forward. As a species, we appear to be bumbling forward without serious applicable foresight efforts to ensure that where we are going and what we are doing are in the best interests of society as a whole.

All of these societal issues should be considered in a holistic manner, as should prospective solution spaces. In the Industrial Age, societal responses tended to lag some 10 to 15 years or so behind evolutionary technological changes. In the current IT/Bio/Nano Age—on the way rapidly to the Virtual Age—technological changes appear to be occurring exponentially or faster. The requisite societal considerations and changes are simply not keeping up. We may even reach a point where untoward things are happening that will be difficult or impossible to undo if we cannot identify and consider them in a timely fashion.

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