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WHOSE FLIGHT IS IT ANYWAY?

Understanding Humans and Automation – and their Teamwork in the Stratosphere

Plus

- To 4DT or not 4DT: Is there really a question?
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WHOSE FLIGHT IS IT ANYWAY?

Understanding Humans and Automation – and their Teamwork in the Stratosphere

By Aaron Kagan, Google

Humans, Machines, and Teamwork

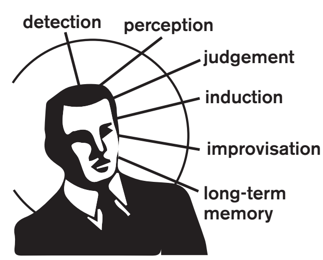
While humans and automated machines have interacted for decades – think of traffic lights, cash machines, or the significantly less popular automated assistance on help lines – the ways that humans and automation should interact or team up, especially in increasingly complex systems, is still an open and highly discussed question. How, for example, should a company that relies on automation set up, staff, and maintain their products and services when the efficiencies and abilities of their automation are constantly evolving? How should they determine job roles, design interfaces, and construct their employees' work environments? Who should be handling what? Humans, machines, or some combination of both? What are the best ways for humans and machines to team up together in a company?

When applied to system design, this inquiry, known to professional circles as human automation teaming, relies heavily on the capacities and limitations of both humans and machines. Humans, for example, are neither great at, nor strongly desire, drudgery – conducting the same task over and over again. Machines, on the other hand, handle tedium incredibly efficiently and without complaint (at least for now). While great at drudgery and performing complex calculations, machines are not nearly as good as humans with respect to making judgments, reasoning inductively, or dealing with novelty.

Much ink has been spilled on this compare and contrast between humans and machines. Take Paul Fitt's famous 1951 list of what humans are better at and what machines are better at (Figure 1).[1]

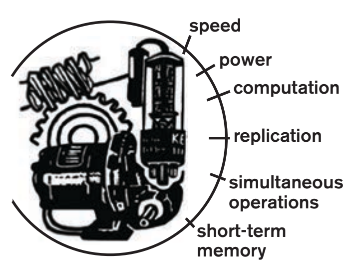
While dated by today's standards, Fitt's list nevertheless illustrates an interesting universal, or highly general set of insights, and there is no popular or universally accepted "new version" of these rules, despite advances in technology and cognitive science. There are established limitations around human and machine capacities (e.g. humans' reaction time cannot be quicker than 0.2 seconds, vigilance taps out at around 30 minutes, etc.), but there is still a lack of more precise principles and normative claims based on this sort of information. How

HUMANS SURPASS MACHINES IN THE:



- Ability to detect small amounts of visual or acoustic energy
- Ability to perceive patterns of light or sound
- Ability to improvise and use flexible procedures
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time
- Ability to reason inductively
- Ability to exercise judgement

MACHINES SURPASS HUMANS IN THE:



- Ability to respond quickly to control signals, and to apply great force smoothly and precisely
- Ability to perform repetitive, routine tasks
- Ability to store information briefly and then to erase it completely
- Ability to reason deductively, including computational ability
- Ability to handle highly complex operations, i.e., to do many different things at once.

Figure 1. Fitt's Diagram.

Now that there's an automated plate spinning system, it's time to add more plates…lots more plates. In business terms, this is called scaling.

moodboard/123RF

Figure 2. Airplane cockpit vs. drone command and control (above and opposite).

to design systems so that humans and automation do only what they should and team up in the right sort of ways?

There are a few reasons why this question is so hard to answer. Automation, for starters, varies greatly between companies and a system's capabilities change as the technology develops. Moreover, most advanced systems are highly specialized, making general rules, principles, and regulations hard to come by. Given the lack of more applicable standards, this suggests that each industry must work to establish their own.

Consider Loon's situation: a technology relying on high-altitude balloons to provide connectivity to remote parts of the world. While it is winding down as a company, its business case and methodologies are still more than relevant in the rapidly changing aerospace system. Loon boldly went where few had gone before and stayed there, with over 1 million hours of flight time[3] and record-setting balloons that stay in the stratosphere for more than 300 days.[4] They grew beyond an experimental R&D project and celebrated their first commercial launch, providing connectivity to remote parts of Kenya.[5] The success of Loon's program created a new set of challenges for the aerospace industry; as the first to market, new vehicles, and new regulations. As Loon grew, more balloons were put in the air, more people were hired, and their autonomous systems evolved. How were they to determine the human-automation teaming for their unique system(s)? This was the challenge for Loon as they scaled. Their systems and job functions changed; their automation became more versatile and reliable. However, when systems, especially those with advanced automation, evolve:

- So do the functions and tasks for which the automation is responsible.
- So do the functions and tasks for which humans are responsible.
- So does the teaming up or working with human and automation.

kesu87/123RF

So, what was the proper human-automation teaming for a company like Loon? It was a new kind of system, in a new kind of space (i.e. the stratosphere), that did a new kind of thing (i.e. provided connectivity infrastructure to remote areas via floating cell towers attached to unmanned balloons). To complicate things further, these autonomous high-altitude balloons did not operate like traditional aircraft; for one thing, no one was piloting them. In fact, people rarely assume direct control over the balloons.

Stratospheric Internet Balloons

For better or worse, a surprising amount of Earth's population has little or no internet connectivity. "More than half of the world's population still does not have access to the internet," and in developing countries roughly 60% of people are not connected.[6] For people in more remote parts of the world, a major barrier to connectivity is the lack of infrastructure. It is, for example, very difficult (and expensive) to run the cables and construct the satellite towers necessary to provide connectivity to diffusely populated regions. As connectivity becomes a necessity in today's world, those without it become disadvantaged.

High-altitude balloons can provide the infrastructure or "pipelines" that allow the delivery of internet to remote and underserved parts of the world. Loon provided a network of "floating towers" attached to balloons that float through the stratosphere (a largely unoccupied part of the sky nestled between the area where planes fly and satellites orbit), a critical infrastructure for telecommunications companies. These 'airborne cell towers' were a unique part of Loon's system, receiving continued attention from both the aviation world and the general public (who sometimes mistook the balloons for UFOs [7]).

To provide coverage, the balloons must maintain their relative position over the desired area. However, they float in an environment

(the stratosphere) that is harsh and windy, blowing the balloons around at high speeds. The balloons "aim" to stay in position by lowering and elevating their altitude and exploiting wind direction to maintain their position. This is, roughly speaking, how the balloons "fly."

Flying Vehicles

When picturing a vehicle flying through the air, navigating its way through the environment to fulfill an intended purpose, it's naturally assumed that:

- A person (or crew) controls it.
- The controlling, or flying, happens aboard the vehicle itself or via remote control.

Iconic images come to mind of crews in cockpits or mission control areas huddled in front of panels with intimidating amounts of lights, buttons, levers, and joysticks, astutely monitoring, coordinating, and controlling the flight of the vehicle. These thoughts are only natural; after all, someone has to control a moving vehicle, be they a driver, pilot, captain, conductor, etc.

The interfaces, controls, and environments for these users have evolved over time, typically in accordance with advances in technology and (ideally) the understanding of the human factors involved (i.e. the ways that people engage with objects in the environment – reaction times, attention limits, or control/button sizes). The formal discipline aimed at designing systems or environments in accordance with such human factors, known as Human Factors Ergonomic Sciences, grew out of this very scene.

The Driver:Vehicle Paradigm

For as long as there have been vehicles, there have been drivers. It is understood that there is a person, or set of persons, with immediate and direct control of a vehicle – someone behind a steering wheel, helm, joystick, control panel, etc. Therefore, it's a historically accurate and natural assumption that there are always humans in direct control of moving vehicles – the "driver:vehicle paradigm."

Today plenty of vehicles operate outside of this paradigm: "conductorless" monorails at airports that take passengers between terminals, the various types of driver assistance (e.g. cruise control, assisted steering and breaking) in modern cars, Roombas. These examples are, in many respects, old news, generally accepted by the public, and do not seem to raise much concern. Despite the increasing prevalence of autonomous systems, the driver:vehicle paradigm nevertheless pervades the thinking about moving objects, particularly when it comes to the large scale, fully autonomous vehicles, carefully emerging from early R&D stages in the automotive and aerospace industries.

Take stratospheric internet balloons, for example. Most would presume there are humans directly controlling the balloons. In an organization's early days, this job would be done by a number of skilled professionals. As a system grows, this would no longer be the case, thanks to the evolution of an automated system. The role of the human-in-charge evolves as systems evolve, the automation developed new capabilities, behaving more reliably and efficiently than even the best technologists had expected (e.g. Loon's balloon "loitering" [3]).

Loon's balloons, for example, flew via a sophisticated combination of both ground-based and on-board automation. Though humans could jump in and directly control individual balloons, their focus was typically one step or more removed from individual flight operations.

evgeniysbkolenko/123RF

Loon's Flight Engineers (FEs), as they were called, did not operate the balloons like remote control cars. This is to say, they were not piloting the aircraft. Though the FEs could theoretically control individual balloons – albeit with a large delay in their ability to change the balloons' behavior (often more than several minutes) – the primary focus of an FE was to supervise the automation that flies the balloons.

The natural question at this stage to ask is: So, who or what is flying the balloons?

This question is particularly important for the aviation world to answer, so they can appropriately determine how to classify, regulate, and coordinate with these objects in the sky. Answering this question is trickier than initially conceived.

This aviation world is steeped in the driver:vehicle paradigm, and rightly so. Historically, aircraft are always controlled by humans, either remotely or with an onboard crew. Even the autopilot is constantly monitored by human pilots who are able to jump 'in the loop' to control the plane at a moment's notice. However, for high-altitude balloons, the driver:vehicle paradigm is a poor fit. Humans do not fly the balloons (though they can, if needed), instead, automation is the pilot. However, there is an easier way to start answering this question: picture plates spinning on sticks.

Spinning Plates

The "plate spinner" typically seen in circus or variety acts, sets up and maintains the speed of plates so they stay balanced on top of sticks. This, in effect, results in the plate spinner monitoring their ever-growing 'fleet' of spinning plates. When one plate slows down, or starts to wobble, the spinner runs over to it and deftly increases that plate's speed. They repeat this process over and over again until reaching capacity – i.e. the amount of spinning plates cannot be maintained by this one person (Figure 3).

One might assume that the job of supervising the fleet of Loon's balloons was similar. Someone monitors the position of the fleet of balloons, tending to each one if they look like they might start to veer off course. At first glance, this appears to be exactly what the FEs did. They monitored the fleet, were alerted of 'anomalies' (i.e. issues that indicate a balloon might be heading off course) and remedied the situation ('spun the plate') so the balloon went back on track.

However, taking a closer look at Loon's system and the FEs' work, in reality, things were a lot more complicated. They did a lot more than just spin and monitor plates. The FEs were primarily concerned with automation – a complex system of software programs, commands, and algorithms, that adapt and "learn" to navigate the balloons. This automation, or machine-based intelligence, is a cornerstone of the cutting-edge technology that separates these autonomous high-altitude balloons from many types of airborne objects, and most of the transportation world. It is also the hardest to wrap one's head around because it challenges the "plate spinner" view, a.k.a. the driver:vehicle paradigm.

In Loon's system, it was the automation, not the human, acting as the plate spinner. Picture a set of sensors that monitor the speed of each plate. When a sensor detects that a plate's speed is becoming dangerously low, it alerts the plate spinner, perhaps with a flashing light or a beeping sound. This alert suggests to the spinner that the plate's speed should be increased. These alerts could allow the spinner to increase their fleet of plates, since they wouldn't have to constantly

Henrik Bothe/Wikimedia Commons

Figure 3. Henrik Bothe plate spinning.

Automation, for starters, varies greatly between companies and a system's capabilities change as their technology develops.

monitor all the plates at once. They only need to respond to alerts. Humans don't like monitoring; maintaining vigilance, especially in a complex system, decreases over time. However, this description still doesn't quite describe the system or the FE's job.

In addition to the sensor, imagine there is a "spinning machine" next to each plate. In simple terms, this machine can safely increase the speed of a plate. So, this modified system is composed of a plate speed monitor and a spinning machine. Now all that is required is to program some logic that says, "When the plate's speed gets too low, turn on the spinning machine. Then, turn the spinning machine off when the plate reaches a stable speed. Keep doing this forever."

Now there is a kind of "automated plate spinning machine." When the plate's speed is low, the sensor tells the machine to speed it back up and to stop spinning when the speed is correct. From here, one might say that the entire process has been "outsourced" to automation. So, what happens to the plate spinner's job? No longer needed to monitor or spin individual plates, the plate spinner's primary role now is to oversee the safe and smooth operation of the automated plate spinning system(s), tracking and handling potential issues or irregularities with hardware or automation itself. This is similar to what happened to the FE role at Loon. Once the automation was reliable enough to "fly" the balloons, the FE's job radically changed; the number of humans necessary no longer depended on the number of objects (be they plates, balloons, etc.), but on the frequency of issues with the automation, machine maintenance, etc.

Now that there's an automated plate spinning system, it's time to add more plates … lots more plates. In business terms, this is called scaling. In this example, more plates are added; in Loon's case, they added more balloons. As operations scale, new issues arise. Suppose over time (and unbeknownst to the plate spinner) the original set of plates starts to slow down much more rapidly than the rest of the fleet, say, from plate wear and tear over time. This would, over time, wear out the plate spinning machine, costing more money, and potentially breaking some plates in the process. How could the plate spinner realize there is wear and tear and prevent it from happening?

To determine that this slowdown is even happening in the first place, the plate spinner needs to outfit a system to measure the rate of plate slowdown. The plate spinner is not predicting that there will be an abnormality in plate slowdown, but rather that the necessary steps are taken proactively to set up the ability to measure and track these sorts of things. The plate spinner also needs to set up a system of notifications or alerts that brings attention to any deviation in plate slowdown rate (e.g. notify if the rate of re-spins starts to dynamically increase all of a sudden). These alerts allow for the ability to diagnose problems at a deeper level rather than having to remember (or realize) that more time is spent speeding up this set of plates than the other sets of plates. Stated differently: the plate spinner needs to proactively develop "re-spin measurement alerting" into the automation. In order to scale, these actions are now central to the job; the plate spinner's role no longer requires split-second reactions to wobbly plates or the deft motor skills needed to re-spin plates.

Thus, with systems like the re-spin measurement and alerting system in place, a plate spinner can do things they, as humans, are well suited for and much more interested in, like:

- Detecting and responding to novel situations.
- Connecting (seemingly) disparate and incomplete sources of information together.
- Coming up with possible explanations (viz. hypotheses) for phenomena.
- Testing their hypotheses and modifying accordingly.
- Evolving a theory so that it comes closer to being fact and things get "boring" (i.e. the hypothesis is reproducible, verifiable, and gives predictive power).

Once a phenomenon is well understood, there are few, if any, anomalies with which to deal. There is a safe, established, repeatable procedure, and automating the process can now be considered. This process of investigating phenomena and developing explanations that increase understanding of it, until such time as the issue(s) and solutions become predictable and "boring," is known as scientific thinking or, as Karl Popper called it, maintaining the "critical attitude."[10] Here is where humans largely differentiate themselves from machines. Humans are excellent at, and often passionate about, enacting scientific thinking. Dealing with novelty, challenges, and the unknown is much more interesting to humans than mundane and monotonous tasks. Plus, humans are also better at dealing with novel situations, circumscribing phenomena, pulling together and relating disparate sources of data, and then coming up with different explanations or hypotheses about a thing. Then humans test these ideas and iterate on them, until things become so verifiable that they become boring and can subsequently be codified under hard and fast rules and, as a result, automated out of the FE's role.

While both the FE and plate spinner roles rely a great deal on automation to maintain the fleet – e.g. to let one know when, where, and how all the plates in the fleet get re-spun – understanding the fleet and diagnosing issues at a deeper level remain human responsibilities. The plate spinner has to notice that there is a disproportionate amount of re-spin from this particular part of the fleet. An automated system can certainly be designed to help bring this to the attention of an FE, but it is ultimately up to the (human) expert to notice a thing and judge that "this doesn't seem right" or that "something here is off." Once this significance has been created (e.g. "There is a real issue here, what is the deal with this anomaly?") the investigation can begin. Humans and machines can team up, run tests, simulations, verifications, explore a pattern in further detail, and try to understand the pattern's implications.

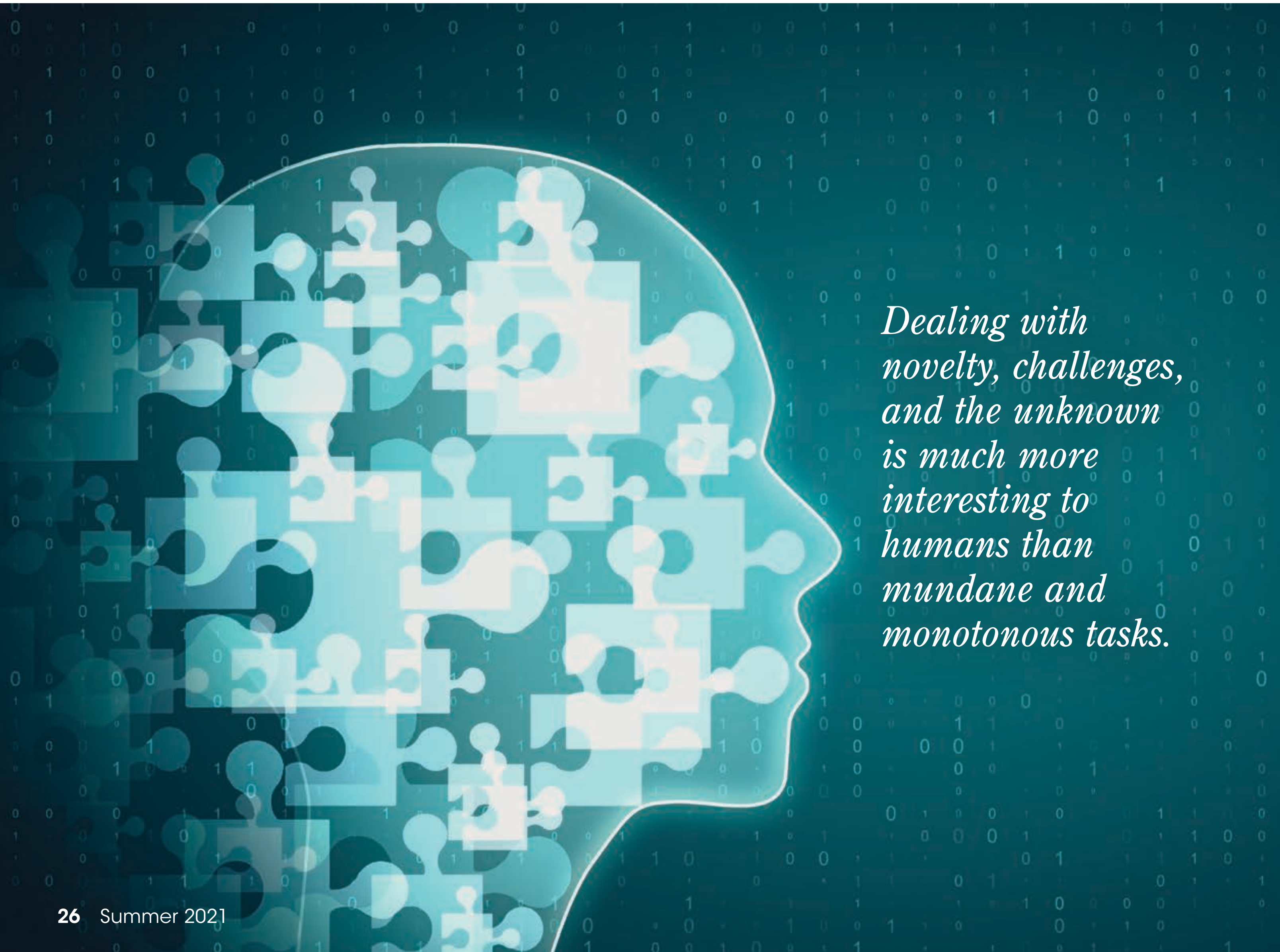
Say the plate spinner notices an inconsistency in re-spin rates for different parts of the fleet. Through scientific thinking (i.e. research, testing, and verification) of the slower set of plates, the plate spinner determines that the plates are actually worn out from overuse. Through further testing, analysis, and research, the result is a relatively precise, repeatable, and physics-based explanation that is verifiable. Now that the 'why' is understood, the treatment can be determined: replace the plates. With this new piece of knowledge (i.e. plates get worn out and need to be replaced) a procedure, and even a set of standards, can be implemented: Plates that are over 200 days old need to be retired and replaced by new ones. This may become such a standard procedure that the entire replacement process can be automated. Once again, humans set up the automation to do what is now a repetitive task. However, this new bit of automation, call it the "plate retirement/replacement system," needs its own set of sensors, monitoring, and reliability standards and needs to be safely integrated into the current system. These are complex, technical issues that can only be resolved by specialists familiar with the system. The role of the plate spinner has now changed so dramatically that the plate spinner role is more of a Plate Spinning Fleet Engineer. The plate spinner gets further and further away from what they did previously. Both the automated functions and job descriptions change.

In reality, of course, things are much more complicated; the evolution of automation systems is ongoing. Nevertheless, as this example shows, automation evolves in a system, job roles change, and humans and machines team up as systems scale.

Conclusion

When a growing company reaches this point of growth in scaling its fleet of spinning plates, they've come full circle. The question, "Who is spinning the plates?" must be asked.

There's no simple or (more importantly) static answer to this question. Despite what many may think, the goal of these automated systems isn't to replace human jobs, but rather change their responsibilities and position descriptions, (hopefully) for the better. While the short answer to who is spinning the plates now might be "automation," the longer, and more accurate answer is that it's an ongoing balance between humans, machines, and their teaming up. There will always be a need for humans to monitor a system, anticipate changes, and diagnose systemic issues, no matter how much automation takes off their plate.



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  Falls Church, VA
- **Midwest ATC Services, Inc.**
  Overland Park, KS
- **Millenium Engineering and Integration Co.**
  Arlington, VA
- **Moog, Inc.**
  Salt Lake City, UT
- **Mosaic ATM, Inc.**
  Leesburg, VA
- **Nanjing LES Information Technology Co., Inc.**
  Nanjing, China
- **NEC Corporation**
  Tokyo, Japan
- **New Bedford Panoramex Corporation**
  Claremont, CA
- **Noblis**
  Reston, VA
- **Nokia Corporation**
  Murray Hill, NJ
- **Objective Area Solutions**
  Arlington, VA
- **Objectstream, Inc.**
  Oklahoma City, OK
- **OneSky Systems, Inc.**
  Exton, PA
- **OST, Inc.**
  McLean, VA
- **Parsons**
  Centreville, VA
- **PASSUR Aerospace**
  Stamford, CT
- **Perspecta**
  Chantilly, VA
- **Raytheon Technologies**
  Marlborough, MA
- **Real-Time Innovations**
  Sunnyvale, CA
- **Red Hat, Inc.**
  Raleigh, NC
- **Regulus Group, LLC**
  Woodstock, VA
- **Ricondo & Associates**
  Chicago, IL
- **Rigil Corporation**
  Washington, DC
- **Robinson Aviation (RVA) Inc**
  Oklahoma City, OK
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  Columbia, MD
- **Russ Bassett Corp.**
  Whittier, CA
- **Saab, Inc.**
  East Syracuse, NY
- **SAIC-Science Applications International Corporation**
  Washington, DC
- **Scio Teq**
  Kortrijk, Belgium
- **Searidge Technologies**
  Ottawa, Canada
- **Selex/Leonardo ES, Inc**
  Overland Park, KS
- **Serco Inc**
  Herndon, VA
- **Service Now**
  San Diego, CA
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  Sparks, NV
- **SJ Innovations**
  Oklahoma City, OK
- **SkyGrid**
  Austin, TX
- **SkySoft-ATM**
  Suwanee, GA
- **Solace Corp.**
  Ottawa, Canada
- **SpaceX**
  Hawthorne, CA
- **Spatial Front, Inc.**
  McLean, VA
- **Spectrum Software Technology**
  Egg Harbour Township, NJ
- **STR – SpeechTech Ltd.**
  Victoria, Canada
- **Subsystem Technologies, Inc.**
  Arlington, VA
- **Sunhillo Corporation**
  West Berlin, NJ
- **Systems Atlanta, Inc.**
  Kennesaw, GA
- **TACO Antenna**
  Ontario, Canada
- **Telephonics Corporation**
  Farmingdale, NY
- **Terma North America, Inc.**
  Arlington, VA
- **Tetra Tech AMT**
  Arlington, VA
- **Thales Air Traffic Management U.S.**
  Overland Park, KS
- **The Capital Group**
  Washington D.C.
- **Thunderbolt Software, LLC**
  Tuckerton, NJ
- **UFA, Inc.**
  Burlington, MA
- **UNICOM Government, Inc.**
  Herndon, VA
- **Veracity Engineering**
  Washington, DC
- **Verizon**
  Las Vegas, NV
- **Volanno**
  Washington, DC
- **Watts Antenna Company**
  The Plains, OH
- **WCG-Washington Consulting Group, Inc.**
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