Testimony on "Department of Defense Investment in Technology and Capability to meet Emerging Threats" before the Subcommittee on Emerging Threats and Capabilities of the Committee on Armed Services of the U.S. House of Representatives

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This paper is intended to provide a short outline of current and emerging threats facing the Department of Defense. The objective is to try and match these with new scientific and engineering developments. I will begin with defining the "far term" and "near term" threats and possible counter moves. Then, I will describe two emerging scientific and engineering developments that are, or might be, relevant to the threats I have defined.

I. Near Term and Far Term Threats and Responses

1.) China and the Importance of Sea Power

The only far term competitive nation we need to be concerned about is China. China poses an existential threat because it has, or will have, enough nuclear weapons with their delivery vehicles that can strike the United States with a crippling blow. However, having lived through the Cold War, my first assessment is that China is not nearly as dangerous as was the old USSR. The Communist ideology promoted by the Soviet Union had temporary (circa 1917 to 1970) appeal that transcended national boundaries. This was dangerous because the Soviets could and did use internal subversion to take over sovereign nations. In addition, the Soviets were willing to use military force, their own (Afghanistan) or their surrogates (North Vietnam, North Korea, Angola, Nicaragua, etc. etc.) to intimidate people and to expand that ideology. The Chinese strategy is very different. It is based on two principles: First, dominate the world's economy by successful competition using capitalist methods and second, develop sea and aerospace power to limit American access to the Western Pacific. China's first target would be in and around the East Asian littoral regions and expanding later to a wider area of dominance. To counter this, we need to make continuing investments in sea and aerospace power as a first priority. We must make certain that we stay ahead of the Chinese in these military capabilities. We need not fight a hot war with the Chinese but we need to keep Sun Tzu's maxim in mind: "The best way to defeat an opponent is to persuade him that he cannot win". We also need to grow our strategic alliances in the region. Japan has been a trusted and reliable ally for half a century and we need to maintain this relationship. In addition to Japan, we should develop a strategic alliance with India. India has reason to fear China and we have good reasons for helping them to reduce that fear. We have much in common in that both nations are democracies and that many millions of Indians speak English. My sense is that it might be best to initiate a move to such an alliance by sharing technology. India has a scientific tradition and also an excellent system of technological universities. Such an approach could grow into a strong alliance that would contain any Chinese move to dominate the region.

2.) The Persian Gulf

The major near term threat is that the oil flow from the Persian Gulf is interrupted or completely curtailed. In the 1980 "State of the Union" message by President Carter he said: "Let our position be absolutely clear: An attempt by any outside force to gain control of the Persian Gulf region will be regarded as an assault on the vital interests of the United States of America, and such an assault will be repelled by any means necessary, including military force". The Persian Gulf is still a most important area because in this small region almost two thirds of the world's easily recoverable known oil reserves are concentrated. This is why President Carter defined its loss as an existential threat. The Gulf is about the same size as Lake Michigan and the oil fields are mostly within 100 miles or so of the shore. Iran is on the northeastern shore, Saudi Arabia and the Emirates are on the southwestern side. Diplomacy is most important with all who live there. However, we should be prepared to keep the oil tankers moving in the Persian Gulf as we did in 1987 and 1988. The U.S. Fifth Fleet has a major base on Bahrain, an island between the coast and Qatar. The presence of the U.S. Navy in the Gulf now stretches back more than thirty years to President Carter's speech. For the near term this is an important position, but the region is politically unstable so that things can change suddenly. Given the military functions of this fleet, short term innovations in communications, transportation and small craft used in littoral warfare are probably the most important. We are building the Littoral Combat Ships (LCS) and a new group of more powerful "Arleigh Burke" class destroyers for such inshore missions. My hope is that these ships will be armed with advanced weapons such as the electromagnetic railguns being developed at this time. These will contribute to enhancing the capability of the new ships and therefore the probability that they will successfully accomplish their missions. Eventually, as new oil and gas resources become available around the world, we can withdraw from the area.

In the case of air power, the most important objective has to be to preserve the extremely valuable "Global Reach" that we now have. In Libya, (to provide a recent example), both B-1B "Lancer" and B-2A "Spirit" aircraft participated in the campaign flying from bases in the continental United States. To do this, the aircraft must be refueled in flight. This requires a small number of strategically located bases around the world. In the Pacific, we have Guam, Midway and Hawaii, all of which are U.S. territories. In the Atlantic we have bases in the Azores Archipelago, which is a Portuguese territory and Ascension Island which is British. Both nations are staunch allies which, hopefully, will continue to be the case. In the Indian Ocean we have Diego Garcia in the Chagos Archipelago which is also British. I would feel more comfortable if we had two or more bases of this kind around the world, especially in the Mediterranean Sea. We should develop diplomatic initiatives to acquire access to air bases on small islands that are likely to be easier to defend and hold than those on large land masses.

3.) Terrorism

The other near term threat is terrorism. I have always been uncomfortable with the term "war on terrorism". Terrorism is a military tactic, not an enemy against which you can fight a "war", be they Irish nationalists, Sudanese militias, the Arab Al-Qaida, FARC in Colombia or the Mexican drug cartels. In a civilized world, all terrorist movements are unacceptable and must eventually be eliminated. What is most important in controlling terrorism is intelligence because the most effective strategy to defeat a terrorist group is to find and kill the leaders. This means knowledge of their activities and also what drives them to commit terrorist acts. Technology plays an important role in the containment of terrorism, especially in the gathering of facts. But we must do more to nurture the "soft" skills of judgment, anticipation and the ability to act when necessary. Having said all of this, it is very critical to recognize that terrorism does not pose an existential threat to the United States: Al Qaida, or any other terrorist organization, cannot destroy the nation. We should ratchet down the talk but, as I have already indicated, we should spend more time and effort to penetrate terrorist organizations, kill their leaders and isolate their allies and clients to pre-empt future attacks. My judgment is that we have been successful in this effort and we will eventually see a reduction in terrorist activities.

3.) Summary

The existential far term threat is China. This must be met by superiority at sea as a first priority. Sea power must be supported by aerospace power equipped with weapons that the Chinese cannot match.

In the near term, we have to secure the oil supply from the Middle East upon which the industrial world now depends. Thus, this is also an existential problem today. As more oil and gas is discovered around the world and alternative fuel sources are developed, it will cease to be in that category. As the resource in the Middle East becomes less important, the United States and the rest of the industrial world can begin to withdraw from the region. My guess on the time scale for the decline of the Persian Gulf region is ten to fifteen years.

Finally, there is the matter of terrorism. Let me repeat that this is not an existential threat. It will arise around the world periodically and the most important capability that we need to deal with it as a nation is good intelligence.

II. Strategic Basic Research Areas and Engineering Developments

Technological forecasting is a risky business. I will not make a list of things that I believe will happen because my opinion is no better than that of anyone else. What I will do is to talk about two developments that are on the technological horizon with which I am personally familiar. That is to say, I can make judgments about them based on personal experiences that I have had with other, similar systems. It is because of this experience that I place the two I have mentioned at the highest level of priority.

1.) Quantum Computing

On May 15, 2010, the Chief Scientist of the Air Force issued a new "Report on Technology Horizons". This is something that the Air Force does periodically and I think that it provides a good guide for the development of a set of priorities for basic research. The central theme of the Air Force document is to exploit our strength in electronics, in solid state devices and in computer architecture, to create a new class of weapons that could operate without having people in the neighborhood to operate them. In order to accomplish this objective we need to have much better sensors and much more capable computers.

In the past fifteen years there have been some remarkable experiments that have been able to explore in great detail the behavior of single atoms in an ultra-high vacuum enclosure suspended and standing still. An appropriate combination of laser light beams or other possible combinations of electric and magnetic fields are used to achieve this condition. Experiments performed with single atoms under such conditions have revealed that they can interact with each other at very long macroscopic distances, meaning many centimeters. These interactions are not caused by forces such as the electromagnetic one which operates by the exchange of "virtual" photons. Rather, they are caused by the wave functions that characterize the atoms when they become "entangled". Therefore, they can cause the atoms to "feel" each other's presence. The ability to manipulate atoms in this way is purely a consequence of quantum mechanics. (It is of interest that the current U.S. Energy Secretary, Steven Chu, was awarded the Nobel Prize in Physics in 1997 for conducting the first experiments related to the one I have described.)

The ability to manipulate single atoms in this manner has raised the question of practical applications. The most interesting one is whether it might be possible to store information and also to develop switching elements that could be assembled into a computing device. Conventional computers are assembled with transistors as switches and various information storage devices that depend for their operation on the same properties of the solid state as do the transistors. These transistors and the storage devices depend on the cooperative behavior of a million or so atoms in semiconductors that also depend on the laws of quantum mechanics. They control the electrical currents that move the information in a way that is consistent with both quantum mechanics and electromagnetic theory. In the case of single atoms that interact with "tangled" wave functions, could a much smaller number of atoms be arrayed in such a way that they could store information and to act as switches through "entangled" and "superimposed" wave functions? If this were possible, then we might be able to assemble computers with switches and storage elements that consist of a much smaller number, say hundreds, rather than the millions necessary for the conventional computer.

For some years now, many people have been trying to develop computers based on the principles that I have tried to describe. For a conventional computer, the term used for a unit of information is the "bit" which is a binary unit that can have either the value of 0 or 1. In a quantum computer the equivalent term is the "qubit". This term does not have the same simple description as a "bit" but it does describe the ability of a quantum computer to process information. What the "qubit" does is to provide a measure of the "size" of the "quantum computer".

There have been some tantalizing experiments with various kinds of "quantum computers" that can perform simple but very large arithmetic operations. One example is generating random number tables which are of great interest to cryptologists. Other arithmetic operations include the factorization of large numbers. What I have just described is a basic research project that clearly deserves strong support. It is equally important to support work to find the practical applications of the new knowledge.

For more than three decades, we have been able to "predict" advances in computer technology using something called "Moore's Law". Gordon Moore, one of the co-founders of Intel, noticed in the early 1980's that that the capability of computers had doubled roughly every two years. The "law" was an extrapolation of Moore's observations. The ultimate size of a transistor is determined by known rules of the quantum mechanics of the solid state. People realized in the late 1970's that we were nowhere near the quantum size limit. Thus, the massive effort to reduce the size of transistors and information storage devices was justified and what we now call "Silicon Valley" resulted. Gordon Moore's quantitative statement produced a true revolution in the field because until we reached the size limit of transistor devices, investments made in Silicon Valley usually paid off.

In the past decade, people began to realize that the smallest reliable transistors or storage devices would have to consist of ordered arrays of about a million atoms, that is, devices in the size range of tens of nanometers. If transistors get smaller than that the band gap structures that make them work become blurred, so Moore's Law is no longer valid.

I believe that quantum computing is, therefore, very probably the next step. There are now groups working on the assembly of "qubits" in such a way that these can be used to perform mathematical operations in certain limited cases. We were in a similar situation in the late 1960's when we ran up against another limit in computing machines which was the speed of light. At the time the speed at which a central processing unit (CPU) could calculate was determined by the speed of light with which signals move from one transistor to the next. Doing this required very elegant designs for the geometry of the circuits. Eventually, people recognized that the speed of light limit might be circumvented the by having more than one CPU working in parallel with others on the same problem. The Illiac IV was the first massively parallel computer with 64 CPUs running on the same clock. The machine was built before we knew how to program it but we were convinced that the parallel architecture would eventually work. The Illiac IV was installed at the NASA-Ames Research Center in the spring of 1972 and we began essentially by "hardwiring" the CPUs and by November 1975, we had several algorithms working with a crude operating system. Eventually, higher level languages were developed so that machines having a parallel architecture could be programmed for a great many different problems. The Illiac IV was decommissioned in 1982, having proved the concept that parallel processing works. Today all the really large computers have the parallel architecture with thousands of CPUs working together at the same time.

I have a feeling that the same approach might work to bring quantum computers into existence. We ought to fund people to build different kinds of quantum computers and then experiment with them the way we did with the Illiac IV and see what works.

This research should have the very highest priority. If we really can make quantum computers they would have the capability to run much more "intelligent" machines and weapons than those that now exist. Equally important is that the concept of "entangled" wave functions could also lead to the development of exquisitely sensitive detectors and extremely accurate timing devices. There is no question in my mind that the impact of this would have the same kind of impact that the introduction of aircraft made to warfare a century ago.

2.) Hypersonic Propulsion.

The two great "revolutions" in aviation were preceded by the development of new means of propulsion. The era of flight itself, began with the introduction of an internal combustion engine on an aircraft in 1903. Sustained supersonic flight began with the introduction of the turbine engine circa 1945. There is good reason to believe that we are ready now for a third era and that is sustained hypersonic flight.

The term supersonic means flight above the speed of sound which is about 1224 km/h (761 m/h) at sea level and normal temperature. The dividing line between supersonic and hypersonic speed is normally defined as five times the speed of sound or 6120 km/h (3805 m/h). Rockets routinely fly at or above hypersonic speed as they carry payloads into Earth orbit. However, a rocket must carry along its own oxidizer for its fuel because it is ultimately designed to fly in space. The objective is to develop an engine which can propel an aircraft to hypersonic speed using the oxygen in the atmosphere to burn the fuel. During the 1970's and the 1990's, there was considerable interest in hypersonic flight. The propulsion would be provided by a scramjet (supersonic cruise ramjet) engine. This is a derivative of the ramjet engine which was developed during the Second World War by the Germans for their V-1 unmanned flying bomb. It consists of a tube which has three sections. There is a constriction of the air flow in the front end of the engine to compress the air. It then passes to the combustion region where fuel is injected and lit off to burn. Finally, the heated combustion gases are passed through an exit nozzle and this then provides the propulsion. A major drawback of the ramjet is that it cannot start without some other way of moving the aircraft as it begins its flight. The air must be "rammed" into the inlet of the engine in order to start working. In the case of the German V-1, the thrust to accomplish this was to catapult the aircraft from a long starting ramp riding on a rail propelled by a small rocket. Once it had enough speed to get air going through the engine, the fuel was injected, lit off and from then on, the aircraft could fly. To launch a ramjet or a scramjet without a catapult and a launching ramp, a two stage propulsion system is required. The first stage can be a rocket or a turbojet engine. These must accelerate the aircraft to a high enough speed to start the ramjet engine, which in the case of the ramjet, is relatively easy. For a hypersonic scramjet, which must fly at speeds above five times the speed of sound (Mach 5), the first stage must reach at least Mach 2 or 3 in order for the hypersonic inlet of the scramjet engine to pass the air to the combustion region so that the oxygen can burn the fuel.

During the 1980's, there was great interest in new kinds of aerospace vehicles. The "Orient Express" was supposed to be a Mach 20 civilian aircraft that would make the trip across the Pacific Ocean in less than an hour by achieving suborbital flight. There was also the dream of a "single stage to orbit" space launch vehicle which would replace all conventional multistage launch vehicles as well as the space shuttle. None of these ever went beyond the preliminary test stage. The principal problem was that supersonic and hypersonic flows are devilishly complex. There are many shock waves in the inlet, complicated by ionization and chemical reactions in the case of hypersonic speed air. These phenomena are very hard to program into a computer. Twenty five years ago, we simply did not have the computer capability to calculate the behavior of such high speed flows nor the ground test facilities to verify the calculations.

During the 1990's both NASA and the Air Force began to look at the problem again. The principal reason was that a hypersonic cruise missile was deemed to have important new military capabilities. In addition, a larger hypersonic vehicle might be a good first stage for a reusable space launch vehicle to replace the space shuttle. Experiments in available ground based facilities were performed and better computers were also available. By the early 2000's, several designs for small hypersonic vehicles were developed by NASA, DARPA and the Air Force. Toward the middle of the decade, two of these, the X-43 and the X-51, were ready for testing. Each of the test programs has been partly successful and more tests are scheduled.

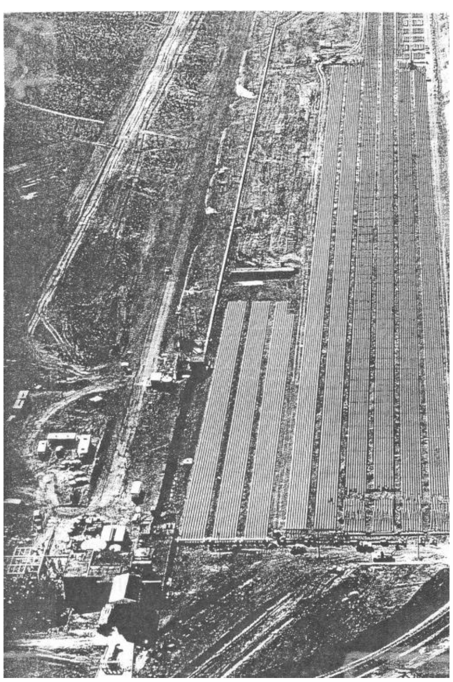
The principal problem that hinders rapid progress is that there is no ground based test facility that can accurately reproduce the flight conditions above five times the speed of sound (Mach 5). The nation has had to face this problem in the past. During the 1930's, there were many high performance fighter aircraft on the drawing boards, but no one knew which was the best. In 1938, with war looming on the horizon, the National Advisory Committee on Aeronautics (NACA) authorized the construction of the largest wind tunnel in the world at the newly established Ames Aeronautical Laboratory, which had a test section with dimensions of 40 x 80 feet. This tunnel was operational in 1940. The performance of every American fighter aircraft was established using this facility. It is not an exaggeration to say that our air superiority in World War II was in large part due to this facility. When the Cold War with the Soviets was ramping up in the 1950's, we needed to have test facilities that could reach supersonic speeds. The Congress passed the "Unitary Plan Wind Tunnel Act" in 1949, and by 1960, each of the NACA aeronautical laboratories, now run by NASA, had brand new wind tunnels which had supersonic test sections. All of the aircraft and space launch vehicles that were used during the Cold War were tested in these facilities. Again, one of the few technologies where we still have leadership and a positive balance of trade is aeronautics and astronautics. The Unitary Plan Wind Tunnel Act passed by a far sighted Congress sixty years ago can take the credit for this state of affairs.

Is there an analogy with what I have described in the case of hypersonic flight? The people working on hypersonic flight tell me that a ground based test facility would make all the difference. Conventional wind tunnels can reach hypersonic speeds only by heating the flow using chemical reactions or electrical power which distorts the results. The air entering the inlet of the scramjet engine in real flight is not hot. It is possible to reach hypersonic speeds equivalent to what a flight vehicle would experience in "blow down" facilities. These have an air supply under high pressure which is "blown" through a small orifice which causes the air to reach hypersonic speeds. Existing "blow down" facilities with large enough orifices to make full scale tests can sustain flows of this kind for short periods of time - perhaps tens of seconds. This is not good enough for accuracy.

In 1964, we did have a very large "blow down" facility to test a ramjet powered by a nuclear reactor. It was part of a project at what was then the University of California's Lawrence Livermore Radiation Laboratory and located at the Nevada Test Site. A picture of this facility is on the next page. The facility stored 450,000 kg. of compressed air which was blown into the inlet of a 500 megawatt nuclear reactor at high speed for five minutes. Although I have not looked at the details, I believe that this facility could have been modified to do tests on the on the hypersonic vehicles that I have mentioned. The question is whether we should make the investment now to build a similar facility. I believe that the existence of such a facility would substantially hasten the advent of hypersonic aircraft.

PROJECT PLUTO

This picture shows the “Tory II C” reactor system. The air intake for the reactor is on the left side of the system pointing toward the concrete blockhouse. The air exhaust is the large circular aperture on the right. The reactor core itself is inside the cylindrical structure and it is about 2.0 meters long and 1.5 meters in diameter. The reactor was an air cooled beryllium ceramic moderated system with a beryllium reflector control system. It operated at a temperature of 1600 degrees centigrade. The reactor ran at a power level of 513 megawatts for five minutes at the Nevada test site on May 16th, 1964. The thrust developed by the reactor was 35,000 pounds. The test proved that the reactor could be made to work, but it was not operated under flight conditions. The Pluto program was canceled on July 1st, 1964.



The high pressure air supply for the Pluto reactor was built using oil well drilling casings as the “pressure vessel”. About 25 miles of 10 inch diameter casings were laid out on the desert and huge pumps were borrowed from the Navy to bring the air supply to pressures of several thousand pounds per square inch. The picture on the left shows the facility as seen from a low flying aircraft. The reactor facility with the track on which the car carrying the reactor runs is shown at the extreme lower left.

3.) Summary

Probably the most promising approach to achieve an increase of several orders of magnitude in computer power is quantum computing. We are now investing about $70 million per year in this enterprise from various sources. My feeling is that there are enough good ideas around that a fifty percent increase to about $100 million is not out of bounds. This is a high risk investment but I believe that the risk is worth it.

The achievement of sustained hypersonic flight is a very different proposition. This is an engineering enterprise, not scientific research. The current tests are interesting enough to warrant further investments. Our computers are still not quite good enough to rely on them alone as can be done in the lower speed flight regimes. Therefore a ground test facility that would probably be an investment in the billion dollar range today is necessary.

III. Concluding Comments

There are too many people in our country who have lost confidence in our ability to achieve important ends. I have described two enterprises that carry inherent risks which I believe need to be taken. The effects on our military and on our society of having a working quantum computer would be huge; almost beyond the imagination. The cost today of research is small because throwing money at it will not help speed up the progress. What is needed is the "breakthrough" idea which, I believe will come in due course.

In the case of hypersonic flight is different. Building a vehicle to achieve this objective would be expensive – in the billion dollar range at least. The application to cruise missiles would also be expensive but it would be a weapon that could travel at a speed of 1.06 miles/second. Thus, it would essentially be impossible to shoot down. No one else in the world could produce such a weapon on the same time scale that we can. I would make a comparison of this technology with "stealth" technology which was also costly. A good argument can be that the rapid victory that the United States achieved in "Desert Storm" was in no small part due to the new "Lockheed F-117 "Nighthawk" aircraft that demolished the Iraqi command and control facilities on the first day of the war. We had "stealth" aircraft fifteen years ago but now other nations are building them so that this was a temporary advantage. The same can be said about hypersonic cruise missiles. They will also be expensive, but what price can be placed on victory?