Thank you.

Today I'm going to talk about MEMS-- Micro Power Generation -- or MPG.

MEMS is one of the core enabling technologies upon which many innovative programs are built.

It leverages the fabrication techniques from the I-C industry to create ultra-miniaturized components including mechanical devices, photonic devices, chemical devices, biological devices, as well as electronic circuits.

Using this approach, we can create a broad range of radically new applications.

Examples of MEMS fabrication techniques include bulk micromachining, surface micromachining, wafer bonding, and the LIGA process using deep X-ray lithography and plating, plus many more.

The four unique attributes of MEMS are that:

1. It's based on IC fabrication technology, and thus it enables the integration of multiple functions on the same substrate or platform.
2. Micromachining is inherently precise, and so the devices perform better than their traditional counterparts.
3. It is batch fabricated, and therefore it reduces manufacturing cost and time.
4. And most important of all, it creates miniaturized devices.

As a result, we reap many benefits, including portability, ruggedness, low power consumption, easy and massive deployment, easy maintenance, and minimal harm to the environment.

Here is an example that illustrates the advantages of MEMS in aeronautic applications.

A micro shear-stress sensor created at Caltech has been flown side-by-side with the state-of-the-art Stanton sensor on an actual flight test on board of an F-15.

This device is 4 orders of magnitude smaller than the Stanton counterpart, consuming far less space and power.

But most importantly, it out-performs the competition, exhibiting 10 times the response bandwidth as illustrated in this plot.

The MEMS shear stress sensor accurately resolved the high-frequency fluctuations in shear stress resulting from turbulent flow.

The Stanton sensor did not have the required bandwidth and missed a lot of important information.

Satellites are classified by weight. A pico satellite weighs less than 1 kg.

The goal of the DARPA pico satellite program is to develop a low-cost space platform to demonstrate MEMS sensors, actuators, and communication components in space.

Potentials for using these ultra-miniaturized satellites include cooperative constellations, sparse aperture antennas, inspection and servicing missions for other space vehicles, and launch-on-demand robust communications and surveillance systems for short-term missions.

In January this year, we successfully launched the first pair of pico satellites linked by a tether.

The 100-foot tether was used to allow easier ground tracking and to prevent the pair from drifting too far apart.

Shortly after the pair was in orbit, we successfully established RF communication and operated the MEMS RF switches in space.

In the future, we will demonstrate additional capabilities like micro propulsion, MEMS inertial reference, inspection, and optical communication links in space.

One of the most critical factors in establishing battlefield superiority is timely and accurate information and assessment of the theatre.

A distributed wireless micro sensor network that can be quickly deployed can allow for surveillance and intelligence gathering in a manner that has never been possible before. Also, with the availability of these sensor networks, we can implement condition-based maintenance, health monitoring, and environmental monitoring on board of a broad range of platforms including battleships, aircrafts and rotorcrafts, land vehicles, and space-borne platforms.

We have demonstrated such a sensor network on board the USS Rushmore, and field-tested at 29 Palms for detecting land vehicles and troop movement using seismic and acoustic sensors.

One of the key technical advances that enable a broad spectrum of MEMS applications is packaging.

Since MEMS devices serve as the interface from the physical, chemical, and biological worlds to the electronic world, the packaging technology for MEMS is significantly different than that for electronics.

One of the common needs is a micro vacuum chamber, with well-controlled humidity, in which the MEMS devices can operate. These MEMS devices include IR sensors, RF switches, variable capacitors, accelerometers, and gyroscopes. We have demonstrated a wafer-level vacuum packaging technology for use with an array of IR imager. We have also demonstrated a micro encapsulation technique to protect MEMS devices with moving components, such as accelerometers, gyroscopes, and resonators.

These packaging techniques have been shown to provide a stable 10mTorr vacuum for two and a half years. They have also shown to survive 10,000 g of shock, further improving the robustness of MEMS devices.

It should be noted that these approaches are low cost and mass producible as two additional benefits.

Micro Power Generation (MPG) is one of the latest thrust areas enabled by MEMS technology.

The goal is to generate power at the micro scale to enable stand-alone micro sensors and micro actuators.

These stand-alone packages will have wireless communication and on-board electronics, as illustrated in this conceptual drawing.

In order to achieve that goal, we must explore alternatives to existing batteries. Chemical energy storage in the forms of solid or liquid fuels is inherently much higher in density than the best lithium ion batteries.

For example, the energy density of methane is more than 12,000 W-hr/kg, which is at least 100X higher than the best batteries.

Assuming a modest conversion efficiency of 10%, a methane-based electric generator is still 10X smaller than an equivalent battery.

The success of this program will enable new strategies for weapons systems and battlefield monitoring.

There are several approaches in extracting chemical energy in the micro scale.

One is to create micro combustion engines to generate mechanical outputs, as in the case of the UC Berkeley micro rotary engine.

The Princeton combustion chamber, on the other hand, converts thermal energy into electricity with thermoelectric generation.

In both cases, we have demonstrated the capability to machine high-temperature materials such as SiC and alumina to create these micro combustion engines and combustion devices.

One of the most important breakthroughs is that we have demonstrated a self-sustained combustion within a 1 mm3 chamber using hydrogen and air.

USC is funded to pursue another project based on thermoelectric conversion.

In this approach, a counterflow Swiss-roll combustor is created using 3-D solid free form machining.

The long counterflow channels are rolled up in 3 dimensions to maximize the thermoelectric element surfaces between the cool in-coming reactants and the hot combustion products.

This design also minimize the loss of thermal energy to the environment.

One of the keys to this approach is the ability to fabricate and integrate thermoelectric elements on the surfaces of the counterflow channels.

The advantage of this approach is that there are no moving parts in the core of the elements.

Another approach to micro power generation is the micro fuel cell concept funded at Case Western Reserve University. A conventional fuel cell consists of a proton exchange membrane, or PEM for short, that extracts electrical energy from hydrogen and oxygen, generating water as the by-product.

One of the key innovations in this micro fuel project is the use of palladium hydride as the source for hydrogen, eliminating the need for a cylinder of compressed hydrogen gas.

In parallel to this approach, Battelle is developing a micro fuel reformer to extract hydrogen from liquid fuel. This fuel reformer will be integrated with a variation of the micro fuel cell.

However, during fuel reforming, a small amount of CO will be generated, which is detrimental to a conventional PEM.

We are developing a novel polymer material to be used as the PEM for this approach.

As illustrated in this plot, we have demonstrated operation at an elevated temperature and in the presence of CO.

So in conclusion, we will continue our commitment to the maturing MEMS projects as well as the new thrust area in Micro Power Generation. We will emphasize transitioning the many research results in the MEMS program into DoD systems as well as commercial applications.

As a core enabling technology, MEMS will continue to serve as the foundation for many new and exciting programs.

In addition to micro power generation, a new program has been approved to pursue the next generation in ultra miniaturization and power reduction for RF communication.

This new program, "Nano Mechanical Array Signal Processors," uses arrays of nano- precision resonators that operate at the UHF band to function as an RF communicator.

This will allow a 100 times reduction in size, and a 100 times reduction in power consumption.

I will be available to talk with you about the Micro Power Generation program, the new NMASP program, and other MEMS- related issues during the sidebar sessions tomorrow afternoon and Friday morning.

You are also welcome to visit our display booths.

I'll be happy to chat with you during breaks and lunchtime as well.

Thank you for you attention.