Space Technologies: Tools for the Final Frontier

Thank you John

Imagine that today, we are holding this DARPATech in space!
What technologies would we rely on?

A central part of the VSO charter is to develop the new technologies that will enable us to travel, work, and live in space.

The barriers to working and living in space are forbidding, and in the next few minutes I am going to briefly describe some of the technological challenges that we must overcome.
These challenges range from materials to power to design, as well as needs for ensuring reliable and productive operations.
I will also talk about some of the bold research that DARPA is undertaking to tackle these problems - some of which involve inventing completely new paradigms.
We are cognizant however that this is just a first step along an extremely difficult path.

Let me begin with one of the most obvious problems facing operations in the space environment: developing lightweight platforms and construction approaches that will survive launch, provide robust operations in space, and, if necessary, survive reentry.
This is a materials sciences problem.

Clearly materials will continue to improve: better resins, stronger fibers, higher temperature-capable ceramics, even new metal systems such as those in our Structural Amorphous Metals program.
But our experience with the National Aerospace Plane has taught us that nature's periodic table has limitations.
Concentrating on developing better materials is not sufficient for the challenges of space; we have to think about materials in a completely different way.
Indeed, we need to change the way we define materials altogether.

This leads us to the concept of "multifunctional material systems," an approach borrowed from Nature, that efficiently combines multiple functions into a single material.
For example, bones not only provide structural support but also act as depositories for vital resources such as calcium which the body draws on as needed.
By analogy, what if we could design a structural material that withstood the stresses of launch but once in space, and no longer useful, became fuel for on-orbit operations? That is exactly what we have demonstrated in the laboratory.

In this video a prototypical load bearing structural member of a satellite is repeatedly and controllably fired to provide significant thrust on demand that could, potentially, be used for in-space maneuvers, station keeping and the like.
This is achieved without the production of any solid reaction residue to contaminate any instruments.

Such Multifunctionality may, in fact, be an enabling technology for both large structures, such as the Innovative Space-Based Radar Antenna Technology and micro satellites, where volumetric efficiency is paramount.

Let us consider for example, structures, large or small, made from carbon fiber composites where the reinforcing carbon fibers (the same ones that provide the structural rigidity) also act as the host or substrate for Li ion energy storage devices.
The entire structure is in essence transformed into a large area Li ion battery, possibly segmented, that is distributed throughout the platform.
This eliminates the need for separate batteries, cables, and connectors.

In this concept you can simply plug your devices into the wall of the spacecraft. How would this attribute change the design and function of the satellite or platform?

But we can go well beyond these so called "powerfibers" that we have demonstrated in the Synthetic Multifunctional Materials program. We can think of structures with multiple fiber types: piezoelectric for actuation, optical for communication and health monitoring, electro chromic for spectral control and many others. Such multifunctional composites or membranes enable us to expand the design paradigm of space structures and may be effective assets in our toolbox.

Multifunctionality could also help us deploy and control large space structures such as ISAT. We are investigating structurally efficient, actively controlled structures. These are structures that have actuation built into them.

The structure you are seeing in the video is called a tensegrity structure - it is made of only two elements, the columns which are in pure compression and the tendons which are in pure tension, that are set in topologically-unique arrangements. This structure can be easily deployed and can change its shape by simply adjusting the length of one or more of the tendons. It is in equilibrium over a large spectrum of conformations and thus achieves diverse shapes with virtually no change in stored elastic stress.

Once locked in position it is very stable and optimally controllable. Imagine that the tendons are made of piezoelectric fibers that can be actuated to control adaptive or deployable optics.

In this the realm of micro satellites one can imagine exploiting reconfigurable constituents or even identical building blocks that can dynamically assemble, morph, exhibit self state and situational awareness, and self-heal if necessary. Such ensembles would be capable of changing shape and structure (including combining with other satellites), reconfiguring their sensors and reacting to events and changes in the space environment - Once again very much like the behavior found in intelligent, biological systems. A truly reconfigurable mini-satellite system that could be optimized for many different missions or adapt in real time to a changing mission.

This concept presents lots of challenges: communication, control, navigation, and attachment - in addition to maintaining thermal, structural, and electronic integrity. But solving these problems would transform the paradigm of operating small satellites in space.

Let me offer you one solution that is dependent on innovative material systems. Consider building blocks with textured surfaces that include distributed conductive wires, an electrical "Velcro" if you wish. Imagine how easy it would be to assemble these building blocks or for them to attach to any point on the structure of another similarly surfaced satellite. These units could physically connect, establish communications, share power and carry out the new mission.

Whether reconfigurable or not, power is an issue for all satellites and especially for small satellites. Certainly better batteries or even fuel cells might provide some solutions. There has also been great progress in direct thermal conversion. Ultimately, however, one might have to concede that power cannot be intrinsic to the satellite, but rather needs to be produced off board either terrestrially, on board a larger satellite or even from an airship.

This power could then be beamed to the unpowered satellite system.
Although this concept has been around for quite a while, until now we lacked the technology to make it practical.
However, recent work under our palm power program in nano and mesoscale structured materials (yet again!!) has led us to believe that we might greatly increase the efficiency of rectifying antennas and microwave generators to above 80%.

. These technologies hold the promise for a robust network (an orbiting power-grid if you wish) providing continuous and virtually unlimited power to satellites and spacecraft.

Regardless of how successful we are in developing new satellite concepts and ways to power them, a major challenge that we face is assured access and return from space.
Here again, we might seek structurally efficient material systems that are capable of sustaining the extreme structural, acoustic, and thermal loads of launch and re-entry.
But as the space shuttle Columbia tragedy reminds us, conventional materials solutions might not be sufficient if we want to create a rapidly reusable and safe system.
We are just beginning to examine ways in which we can manipulate the enormous kinetic energy associated with hypersonic re-entry to actually control the spacecraft - much like controlling an aircraft in-flight.

One far-side idea is to exploit the interaction of the craft's physical structure with the harsh plasma environment of launch and re-entry.
We believe that this can be accomplished by using magnetic fields to manipulate the flow field of the plasma around the vehicle.
Relying on multifunctionality principles and optimization, we are considering multilayer material panels, with integral thermal protection systems, and embedded conductive wires, to generate controllable magnetic fields.
These can be used to selectively and locally control the plasma around the vehicle.
Using the electromagnetic panel in reverse, we can in fact extract energy from the plasma.
Thus we reduce the thermal load on the vehicle and convert the energy to useful electrical power.

We estimate that, as a vehicle begins to re-enter the atmosphere, very large amounts of power can be extracted and used for the flow field manipulation - up to 3.7 MW at Mach 12 at an altitude of 100,000 ft.
Similarly to beamed-power concepts, these re-entry energy recovery and maneuver concepts are not new.
What is new are technologies such as multifunctionality and MEMS controls that may enable more favorable weight tradeoffs.

So far, I have discussed the physical capabilities that we need to go into space.
Perhaps just as important are new approaches to navigation, control and communication.
These become increasingly complicated as we venture more frequently and further into space and as the number of assets increases.
In this domain we look to new approaches in mathematics for guidance that will guarantee performance of complex systems while managing the uncertainty that is inherent in large, multi-scale, highly interconnected and dynamic systems.

We must also design and optimize software development approaches to dramatically reduce the time and cost to produce high-performance software for sensing and communications systems.

New mathematical techniques for geospatial representation will have a significant impact.
They will enable exploitation of complicated, multispectral images, and provide new approaches for rapidly calculating gravitational fields with the accuracy needed for

space operations.

I leave it to Carey Schwartz to make this all clear on Thursday morning - but the need is critical and the research opportunities endless.

Before I get off the stage, I want to describe one more, very far out idea - copied, again, in some small way from biology.
This would truly be out there in what Dr. Tether calls "the far side."

There is much talk of manufacturing in space.
But, ultimately, it is the assembly of structures that is even more complicated than manufacturing a specific material.

Think of a spider weaving its web.
Now imagine a processing plant out in space that moves freely and "deposits" a structure - builds a web-structure, if you will.
There would be no limit to the size of a structure that could be "woven" in space -even ISAT.

What a tangled web we weave!!!!

In closing, we ask you to help us develop the technology tools for conquering the final frontier.

We need to build a technology portfolio that will yield intelligent platforms of many scales.
They could be made from stowable, multifunctional structures that can deploy or assemble on demand.
They could reconfigure, self-heal, regenerate, exhibit self state and situational awareness, and be capable of autonomously or cooperatively reacting to events and changes in space or on land.

We look for means of efficiently harvesting available energy and of generating or beaming power.

We look for effective mathematical techniques and fast algorithms for signal processing, reasoning, and control.

Space access and operations represent the quintessential DARPA-hard problem.
Remember that space was the challenge that launched DARPA itself!

To achieve these goals, we will need your very best ideas in science and technology, your innovation and imagination.
Please come and talk to us! Thank you for your attention.