The Pursuit of Unobtainium
John Main

Good Morning.

Today I am here to talk about "unobtainium."
If you are not familiar with the term, "unobtainium" is magic material that outperforms all known materials and is therefore unobtainable - it's what invisible aircraft are made of and it's what keeps aluminum and steel ships from corroding.
Unobtainium can be formed into a ship hull that can change shape to adapt to ocean conditions or an aircraft wing that can morph to be efficient in any flight condition.
Low cost titanium is unobtainium.
I could take a bar of unobtanium and build a robotic end effector that could move and grasp like an elephant's trunk.

In order to be completely truthful I should say that "unobtainium" is not a positive term - it is usually a term of contempt.
Having the chief engineer declare that your design relies upon unobtainium for success is not a sign that you will soon be advancing in the organization.

But DARPA is definitely not your typical organization.
At DARPA "unobtainium" is not a term of contempt.
We look at wringing unobtainable properties from materials as a challenge, not as an insurmountable obstacle.
In the Stealth program DARPA developed materials that do, in fact, make aircraft invisible to radar.
Amorphous metals - metals without grain boundaries - promise to make ship hulls that are corrosion resistant and nonmagnetic.
And inexpensive titanium? Right now we have several new processes that may result in low cost titanium, perhaps as low as $2 per pound - a 6 to 14 dollar reduction.
If successful, these processes will make titanium the material of choice for virtually every lightweight application.
As these examples illustrate, "unobtainium" is not impossible in DSO, unobtainium is actually our goal.
In DSO's view, structures will soon gain such unobtainable properties as the ability to change form, store information, self clean, act as sensors, and perhaps even think, all while doing the usual job that structures do - carry load.
This is our vision.

The vision of new materials with breakthrough properties was present in DARPA even before the creation of DSO with its specific charter to do materials research.
In the 1960's DARPA helped nurture the then new discipline of material science through the establishment of Interdisciplinary Research Laboratories at 7 Universities.
The groundbreaking research done by these laboratories led directly to the formation of material science as a distinct scientific discipline.

Now, 40 years later, DSO continues to support a robust materials program.
Yet, once again, we are attempting to change the way research in materials is pursued.
In fact, we are trying to change the way the term "material" is defined.
One reason for these changes is the interdisciplinary nature of the Defense Sciences Office itself - an office attribute that exists because we take it as an article of faith that the most fruitful places to look for advances in science and engineering are the interfaces between disciplines.
Leo Christodolou explored this topic in his discussion of breakthrough materials for space applications and I want to reinforce this idea today.

The intersection of materials science and nature appears to show great promise for delivering materials with unobtainable properties.
Natural materials are truly magnificent.
Living bones grow, repair damage, remodel to distribute stress, and produce blood.
Muscle turns lipids into work to help us regulate body temperature, maintain balance, and walk.
Plant tissues grow, distribute nutrients, isolate injury, self-clean, support leaves, and sometimes even move with surprising force, such as tree roots upending concrete sidewalks.
All of these characteristics are unobtainable if you limit yourself to the world of conventional materials.
Yet they are all clearly possible, because nature has supplied us with examples to study and potential paths to follow to create similar capabilities.

The study of naturally occurring materials may seem to be an academic exercise without obvious payoff, a curious concept that we are pursuing with no real idea of what might result.
I admit that part of this is actually true.
We are occasionally unsure of the specific payoff at the end of an exploration, but in this case we are confident that a payoff is there because of the enormous time and effort nature spent to optimize natural materials.

This freedom to explore without a specific goal in mind is one of the strengths of DSO.
In fact our confidence in the utility of naturally inspired material systems has already proven to be well founded.
A naturally-inspired multifunctional UAV skeleton has already been developed that combines a load-bearing structure with electrical energy storage.
It is, in essence, a micro air vehicle fuselage that is also a battery.
The payoff is that the air vehicle range was increased by a factor of 3 using the multifunctional structure inspired by nature.

Exploration of this and other materials by DSO has laid the foundation for new research areas that promise to further debunk the idea that the pursuit of "unobtainium" is a fruitless endeavor.
These ideas exploit pervasive biological concepts such as "soft" actuators including elephant trunks, skins that change color, and cellular structures for robust, survivable systems.

"Soft" actuation is a truly challenging problem.
The ability that humans, elephants, and even squids possess to gently grasp and lift heavy objects has never been reproduced in a synthetic system.
DARPA's multifunctional materials program has already successfully demonstrated compliant actuators based on electro-elastomers designed to act as both extensor and flexor muscles.
However, to fully realize the vision of a powerful but gentle remote manipulator, it is likely that new materials and design concepts will have to be developed in order to better match the dexterity, bandwidth, and strength of, for example, cephalopods and snakes.

One approach is to develop material systems which might be based on truss structures.
Add integrated sensors and actuators to the truss and you get something akin to nervous and musculoskeletal systems.
Add computation to interpret the sensor input and feedback to distribute the information to the actuators and you can imagine a synthetic material system that could behave in some respects like the trunk of an elephant.
A robotic end effector like an elephant trunk is a compelling idea and we are looking for ways to make it happen.

Active materials that duplicate the ability to softly grasp and lift a heavy object are significant, but imaginable, extensions of current technology.
But what happens when these materials get damaged?
Living tissue responds to damage by healing itself.
In the future materials that emulate living tissue by adaptively changing shape, color, and texture and can self heal will be explored.
This effort will make use of some of the technical concepts being developed in both DSO and MTO, but integrate them into a fully multifunctional skin that will help small robots sense their environment, avoid detection, and recover from injury.
Like living tissue, delivering the ability to change color and self-heal will require a multidisciplinary approach to material design.
We very well may be talking about adding circulatory systems to materials in order to achieve these so far unobtainable goals.

The idea of adding circulatory systems to materials opens revolutionary avenues for materials development.
Many plant structures rely upon internal pressurization for mechanical stability and shape maintenance.

Some plants generate motion for activities such as prey capture and sun tracking by modulating the fluid pressure within 10-100 micron diameter structural cells.
This pressure modulation is achieved by actively transporting fluid through the cell walls - a rudimentary circulatory system.
Essentially these plant structures are highly distributed and redundant hydraulic actuation systems.
The impetus for this work is the need for active materials that possess the power density of conventional hydraulic systems and can be used to build smooth and adaptable structures such as aircraft wings, helicopter rotor blades, and submarine propellers.
The ability to change the shape of robust structures in response to changing mission requirements would be a powerful capability, but the materials to enable these structures have not yet been developed.

Natural materials also evolve specialized structures to deal with the environment around them.
Lotus leaves use unique surface structures to self clean.

Can we use materials chemistry to develop coatings that provide biocidal protection and a self-cleaning capability in synthetic materials?
Cephalopods instantly change the absorptive and reflective properties of their skin when threatened.
Can we engineer synthetic materials that can change color as conditions change?

The challenge of turning knowledge of natural materials into breakthrough synthetic materials is in discerning the intelligence innate to these natural materials and utilizing this evolutionary wisdom.
This is what is forcing us to relax the definition of the word "material."
Natural tissues are materials which are not solid and inert like steel or even composites, they are really material systems that burn energy, perform multiple parallel functions, possess structure on a variety of size scales, and depend on combinations of mechanical, electrical and chemical processes to function.
When you think about this description - energy consumer, multiple functions, a range of size scales, and multiple process domains - it is apparent that natural tissues have much more in common with an automobile than a plate of steel.
The message may be that unobtainable properties are obtainable if we look at materials as energy consuming systems rather than inert load-bearing supports.

Acceptance of this message may be a tall order for a community that generally thinks

of materials and structures as static and inert.
But we believe that this change in how we think about materials is critical to extracting dramatic new levels of performance.
We have seen in the multifunctional materials program that we can combine electrical energy storage into a load-bearing structure.
Why not establish a much broader vision for the future of materials research?
In the future structures will serve as memory, completely change shape and color on command, provide biocidal protection, and even act as cameras or sensors.
The concept of biologically inspired materials will be carried into the manufacturing arena as well.
There is great promise that biological systems and components will be used to direct synthesis of high performance materials that are currently difficult to produce by conventional manufacturing.

There are enormous challenges, of course.
Chief among them is the ability to develop the chemistry and processing to produce distinct and multiple functionalities in materials that can be activated on command.
These challenges are difficult, but successfully developing a new class of materials that, like biological tissues, consume energy and perform many functions is the first step in building an "unobtainable" structure that has self awareness, adaptability, and perhaps even the ability to think.
Imagine a structure such as a ship hull that can autonomously change its own shape to glide through the water easily and smoothly regardless of speed and ocean conditions.

At DARPA we believe that revolutionary things like thinking materials are possible because our successes, from radar absorbing materials to amorphous steels, have proven to us over and over that "unobtainium" is not a barrier, it is a goal.
It is clearly possible to wring "unobtainable" performance from structures if we are willing to give up our conventional prejudices about what a material should be.
We are on the cusp of a revolution - in the future materials and structures will no longer be simple load-bearing components.
Structures will soon gain the ability to change form, store information, act as sensors, and perhaps even think, all while doing the usual job that structures do - carry load.
This is our vision.
We hope it has fired your imagination, because ultimately it is you, the research and engineering community, which drives materials research forward and makes the vision come true.

Now it is time to really show the multidisciplinary nature of DSO - Jay Lowell is going to take over and completely change the direction of this presentation.
Stick around - he's going to talk about light, navigation, and quantum physics.