This program will develop technology for friction drag reduction, and is focused on flow additives. Furthermore, we are focused on the practical implementation of these drag reduction technologies. We are interested in a broad spectrum of militarily relevant applications, and thus a wide variety of hull forms. In order to accomplish this, we will take advantage of advances in computational hardware and in problem-solving approaches enabled by those advances. Thus, this program is oriented around using computation and experiments (focused by these computations) to optimize the parameters associated with the flow additives and their implementation.

I should point out that right now we have an open BAA on the activity I will be describing; you can get at the solicitation on the DARPA web site. This BAA closes in October, and I hope that what I have to say here today encourages your interest.

Much of the emphasis in recent years on drag reduction has revolved around increasing ship speed. However, at constant power the speed is a weak function of the friction drag (in fact, changes as the cube root of the friction drag). Thus, even when friction drag dominates overall ship drag, very substantial decreases in friction drag are needed to get any meaningful improvement in speed.

However, there are other, substantial benefits to friction drag reduction. For example, when friction drag is reduced there is a proportional reduction in the requisite fuel load, and hence a large proportionate increase in overall payload. On the other hand, for a given fuel and payload fraction, proportionate increases in range and endurance can be achieved. In order to see meaningful speed increases, at least 50% reduction in friction drag is needed. However, friction drag reductions less than 50%, but better than about 20%, can nevertheless provide significant enhancement in other important performance parameters.

Friction drag constitutes a significant proportion of the overall hull rag; between about half and 2/3 of the overall drag. Over several decades two very promising technologies have been shown in the laboratory to reduce friction drag by as much as 80%: the addition of polymers or microbubbles to the flow. Unfortunately, these results have not transferred to the field; the effectiveness of polymers breaks down at high speeds, and perhaps more importantly, the consumption rates are very high. The power needed to create and introduce microbubbles into the flow is greater than that which if just put into propulsion would provide equivalent performance enhancement. As noted earlier, reduction in skin friction drag achieved in the laboratory from the introduction of polymers into the flow has not transferred to the field. There is a large body of experimental work; polymers are used, for example, in fire fighting to increase flow rates. Although some theoretical work has been done to explain why polymers work, the experimental data available does not sufficiently sample the relevant parameter space. However, recent computational work using DNS has shown excellent agreement with experiments. Thus, by using a constitutive relation that captures the physics of the polymer in the flow, and DNS, which captures the turbulent flow physics exactly, a way is opened up for optimizing the polymer properties for drag reduction. For example, one result that "whets the appetite" is that by increasing a particular polymer's chain extensibility by x3 the rate of consumption could be reduced by about x10.

Unfortunately, and not surprisingly, the number of degrees of freedom in the flow that can be captured by DNS is limited by the available computational power. The current state of the art for polymer modeling in DNS allows a maximum Reynolds number (expressed in terms of the boundary layer thickness) about 5000, which corresponds the about a million grid points. The Reynolds number needed to model a ship hull is about 1E6; since the number of needed grid points scales as the Reynolds number to the 9/4, we see that we are about 9 orders of magnitude away in computational power from modeling a ship hull in DNS.

The situation with microbubbles is considerably less well developed. Although substantial levels of drag reduction have been demonstrated in the laboratory, no full-scale implementation has been attempted; the Japanese are planning an experiment with, I believe, a fishing trawler. More importantly, there is currently no validated or accepted theory for microbubble drag reduction; in fact, what the property or properties of microbubbles are that are responsible for drag reduction is currently controversial.

What is known about both polymers and microbubbles is that they operate in the so-called buffer layer at the edge of the viscous part of the boundary layer. It is here that the incipient vortices that grow into full-scale turbulence are born. The flow additives are thought to inhibit their formation, although the exact mechanism is not well understood. Hence, the properties of the additives (that is, the polymers and microbubbles) that need to be tailored for optimal drag reduction are not well understood. In order to fully understand these issues both a physically based constitutive relation for the additive, and a good physics model of the relevant portion of the boundary layer, needs to be developed.

These graphics, however, also illustrate a further issue. In order to inhibit drag reduction it is important to keep the flow additives in the buffer layer. However, the nature of turbulence is to transport material out of the buffer layer as the fully developed portion of the layer grows downstream. Hence, analyzing schemes for inserting and maintaining (to the degree possible) the flow additives in the buffer layer are important if efficient and practical implementation of the drag reduction technology is to occur.

So, what is the approach we are taking? In essence, we will use DNS modeling over the Reynolds numbers where it is applicable, and with physically based constitutive relations for the flow additives explore the physics (in all its glory) within the buffer layer and incipient (remember, we can only use DNS at Reynolds numbers of about 10,000) full boundary layer. As the boundary layer develops, we will implement Large Eddy Simulations and Reynolds Averaged Navier Stokes models, informed by the physics developed within the DNS computations. We thus expect to develop detailed physical insights with the exact modeling (i.e. DNS), and use that insight to develop the inevitable approximations needed to model flow around a ship hull, and additive injection schemes.

Computation cannot be done in a vacuum, of course. As we develop physical understanding of the impact of flow additives on skin friction we will test these hypotheses in the laboratory. Eventually, with the insights developed from the modeling at all scales, we will develop candidate drag reduction implementation schemes and test them with near- full-scale models at, for example, the Carderock water tunnel facility operated by the Navy.

It is important to measure progress. In this program, we expect in about 2 years to have shown to our satisfaction that this multiscaled modeling approach can work, and further that there is some promise for tailoring the additives and their implementation to overcome the deficiencies that in the past have prevented their fielding. At the end of the program, in about 4 years, we expect to demonstrate this capability in near full-scale experiments.

In summary, then, we are looking for revolutionary levels of drag reduction. The idea of using flow additives has been around for decades, but has not been reduced to practice on ships and boats. We hope to move this field to the point where we understand the physics and engineering issues in depth, in order to allow optimal implementations that overcome the practical barrier