THE EVOLUTION OF HYPERSONICS: ITS IMPACT ON THE FUTURE OF WARFARE

An Interview with Dr. Mark Lewis

THE FUTURE OF POWER PROJECTION

REPORT 8

The Evolution of Hypersonics: Its Impact on the Future of Warfare

In January 2011, Second Line of Defense sat down with Professor Mark Lewis to discuss the current status and dynamics of hypersonics. Mark J. Lewis is chairman of Clark School's Department of Aerospace Engineering at the University of Maryland, College Park, and President of the American Institute of Aeronautics and Astronautics. He was the chief scientist of the U.S. Air Force from 2004 to 2008.

An earlier piece by Professor Lewis on hypersonics can be found at http://www.sldinfo.com/?p=5888

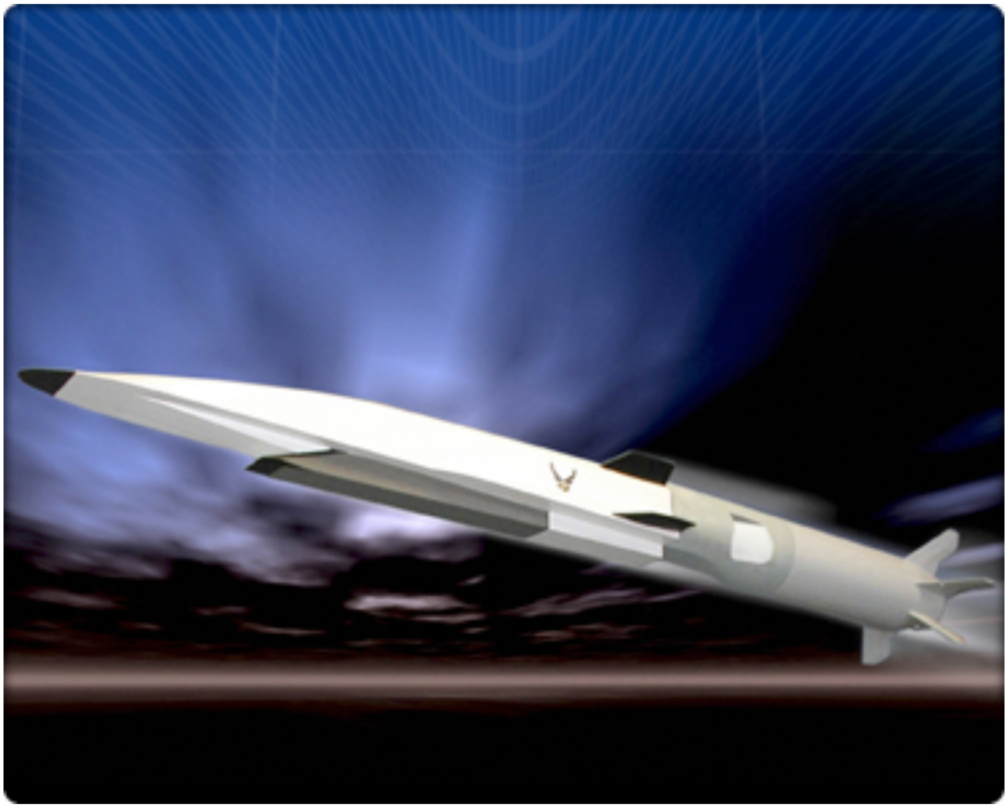
SLD: Can you give us an update on how the hypersonics programs are going?

Figure 1 For the X-51 Test Flight http://www.youtube.com/watch?v=0qGNEmDMVDU

Lewis: We've just come off a phenomenal year in hypersonics punctuated by three major flights and a host of other smaller, but in some ways, just as significant efforts. The three major flights were the X-51, the HTV-2 and the X-37. Each of those was important in its own way.

SLD: Before you review each of the programs might you clarify what is a flight test program and what do you have to do to achieve success?

Lewis: I'm delighted you asked that question because that was actually something I focused a lot of attention on when I was working for Air Force Secretary Mike Wynne, the whole question of what is "flight test?"



And I argue that flight test is experimentation; it means that you put a vehicle in the air to learn, to explore the frontiers of science and technology. When you do that it should always be with an eye towards how you apply that technology to a realistic, practical, operational system.

Figure 2 X-51 http://www.boeing.com/defense-space/military/waverider/index.html

I think it is important to draw a distinction between "flight test" and "flight demonstration". There were lots of people I'd run into in the Pentagon and outside of the Beltway who wanted to do flight "demonstration" –- in my definition, demonstration means I'm simply trying to prove something that I already know. To me is a generally worthless thing to do. If you already know it, you don't have to prove it! If it works, no one really cares, you already knew the answer; and even worse, if you fail, you have just fallen flat on your face.

The contrast is what I think of as flight test, where I know that there are things that I know, and I know that there are things that I don't know, or at least that I'm not sure about, so I build a vehicle that captures the best of my understanding and the best of my technology. The goal is to push the frontier.

I think the ultimate example of that was the X-15 rocket plane. That program ran through the 1960's. It was a hypersonic aircraft, rocket-powered, dropped from a B-52. There were

199 flights of the X-15, and every single one was designed to gather data, to learn more about the system, to learn about the flight regime, to understand how we build a realistic vehicle that flies faster than about fives times the speed of sound.

The X-15, was never intended as an operational vehicle, but the physics that we learned, the engineering that we learned, the problems that we solved, were absolutely instrumental in a range of other programs, including manned space flight activities leading up to the space shuttle.

SLD: Could you explain what hypersonics is exactly?

Lewis: Hypersonics is generally considered to be flight in excess of about five times the speed of sound, or Mach five. There's no hard and fast definition by the way, so the definition is a bit fuzzy. Unlike when flow goes from subsonic to supersonic and the physics actually changes very dramatically, as the flow goes from supersonic to hypersonic the changes are somewhat more subtle.

Interestingly, in the Russian language, there is no word for hypersonic; they just refer to high supersonic speeds. At hypersonic speeds, the surfaces of most vehicles under typical flight conditions become so hot that the chemistry of the air can start to become important. That's the reason we use the term hypersonic. Also, most of us know that a vehicle flying faster than the speed of sound generates a shock wave in front – that's a sudden jump in pressure and temperature - but at hypersonic speeds, that shock wave is pressed very, very close to the surface of the vehicle, and that changes the aerodynamics considerably as compared to lower speeds.

SLD: Could you describe then the characteristics of hypersonic vehicles?

Lewis: I think about hypersonic vehicles inhabiting two general categories.

The first category includes vehicles that are meant to be decelerators; that is, they are designed to slow down. For example, spacecraft coming back from orbit, including the Space Shuttle, an Apollo capsule, a spacecraft entering the atmosphere of Mars, all of those are designed to be slowing down on their way to a planet's surface from space. They're all hypersonic though; when the Space Shuttle first enters the atmosphere on its way back home, it's flying at about 24 times the speed of sound. That's clearly hypersonic flight, but the goal is to slow down.

Then there are vehicles at the other end of the spectrum. They're the ones that are more difficult to design and build, and the ones for which we have much less experience. Those are vehicles that are designed to either cruise at constant speed or accelerate - speed up - as they go through the atmosphere.

Each of those vehicles types has its own set of challenges. The biggest problem that we run into for all vehicles is that at hypersonic speeds, as I mentioned previously, heating be-comes very important, and the sharper your vehicle's leading edges are, the sharper the surfaces are, the hotter they get.

The general rule of thumb on a hypersonic vehicle is that, if we want to prevent the leading surfaces from melting, we make those surfaces big and thick and blunt. You know that the heat shield on an Apollo spacecraft was a big, blunt, round object. The leading edges on the Space Shuttle wings are also rather thick and blunt. Having thick and blunt leading edges also means that there's lots of drag, which really is not a difficulty for something like a Space Shuttle. Remember, the space shuttle wants to slow down on its way back from space.

Figure 3 Launch of HTV-2 http://www.youtube.com/watch?v=DjNugnGWaBU

Now, if we want to build an accelerating vehicle, or one that's just going to cruise, says a missile or an airplane, we need to have low drag. That means we have to build it with sharp leading edges, and those are going to get hot at hypersonic speeds.

So when we talk about hypersonics today, implicit in that definition is hypersonics applied to things that can accelerate, things that can spend a lot of time in the atmosphere, which in turn means slender, low drag shapes. That's the technology frontier that we're working on right now.

Think about what we could do with that type of vehicle, what I term a "low drag, high lift", hypersonic vehicle. There are three main categories for this sort of craft.

The first is the weapons category, including high speed cruise missiles and maneuvering re-entry vehicles for long-range strike.

The second category is airplanes. This would include a high-speed reconnaissance airplane, perhaps a penetrating ISR platform, sometimes called the "SR-72". That craft might be designed to perform an SR-71 type mission, but do it at much higher speed to be less vulnerable.

And the third category is access to space, the category of hypersonic vehicles that might fly into space more like an airplane and less like a rocket. I call that the holy grail of hypersonics because if we can do that, if we can build a vehicle that works that way, we've suddenly opened up space to be very much more responsive and more accessible. Imagine being able to fly into space with something that operates more like an airplane and less like a rocket. We wouldn't have to spend something like the 4,000 man-months I takes today to prepare the Space Shuttle for launch. We might instead be able to fly up to orbit on something that is maintained with the ease and accessibility of an airplane.

(For a Mitchell Institute Paper on Hypersonics and Power Projection see http://www.afa.org/mitchell/reports/MP6_Hypersonics_0610.pdf)

SLD: What is your sense of the realistic path to progress in the hypersonic area?

Lewis: In my mind, very clearly, the first step in developing hypersonic systems is the weapons application. It's the lowest hanging fruit. It is, frankly, the least technologically challenging, and I think it's also the biggest short-term payoff. This includes high speed weapons, high speed cruise missiles, high-speed maneuvering re-entry systems that give us responsive long-range strike. That's where I see the bulk of our research investment being made today.

Next, the high speed reconnaissance airplane also has many attractive applications, most notably as a gap filler if we lose space assets or to give us ISR capability when space is not available. We can learn about building such an airplane from our experiences developing the weapons systems, since the physics will be similar.

I'll also mention that there have been a lot of studies into the application of hypersonic systems, and really the most significant of those came in the year 2000, a study called "Why and Whither Hypersonics." It was done by the Air Force's Scientific Advisory Board, and it was based on a question posed by Secretary Whit Peters, whom, I think, frankly, might have thought that the Air Force was spending too much money in hypersonics. The study asked the very pointed question of whether hypersonics was a rat hole that money was being dumped down, from which nothing would ever emerge.

The Scientific Advisory Board did an extensive, exhaustive study, complete with a red team that questioned every result, and they came back with a very positive recommendation on what hypersonic technology could do for the Air Force.

Since that time, there have been a number of studies, including several National Academy reports, a number of other Scientific Advisory Board studies, and all have come back and said, "Look, hypersonics can be a real game changer." If we can fly somewhere at speeds of Mach 5, 6, 7, 8, or more, that is, if we can reach reasonably long distances in very short periods of time, that has very important implications in modern warfare.

Modern warfare is about doing things quickly. It's about achieving fast effects, getting results quickly. If you want to affect something quickly, I can think of basically three options.

The first option is that you have ubiquitous presence. That means you've got an asset anywhere you need it. That asset might be unmanned, and frankly, that's a lot of what remotely piloted aircraft are enabling for us - having small assets available and re-locatable at a moment's notice. Of course, ubiquitous presence is only good in a limited area; We obviously can't have ubiquitous presence at every location around the globe, but that's one part of the solution that is already changing warfare.

The second option for doing things quickly is to operate at the speed of light. For my aerodynamics friends, the speed of light is about a million times faster than the speed of sound. Operating at light speed means using directed energy systems and/or cyber systems, which are among the other things that Mr. Wynne championed when he was Secretary of the Air Force. And of course, there's a lot of development underway right now in directed energy systems, and lots of corresponding questions about how we ultimately would deploy them, as well as how we would ultimately use cyber systems.

If you don't have the first two available, or if they cannot deliver the desired result, a third option is the you get to where you want to go as fast as you possibly can. That's the advantage of hypersonics. This could be to perform reconnaissance of some sort, do some sensing, or to deliver weapons on a target. In order to do that, we need to master the technology required to fly at hypersonic speeds.

Hypersonics would also give us a degree of invulnerability. We know that the application of stealth technologies has been a tremendous game-changer, but that stealth advantage won't last forever. I would argue that the next step beyond stealth is speed.

There are complicated trade-offs there. Obviously, when we fly faster we'll get hotter. That makes the vehicle more observable, but the combination of both stealth and speed in some overall way is a very attractive combination for future systems.

If we look at those applications, we can ask, "what are the technical challenges," and one I've already posed is that when we fly faster we tend to get hotter, so first it's a challenge of materials. It's also a challenge in aerodynamic design; this is a realm of aerodynamics where there are still some very basic questions to which we don't have complete answers. In some cases these are questions that we can answer satisfactorily at lower speeds, but we can't answer them at higher speeds.

But the biggest challenge, perhaps, is that of propulsion. If we want to fly through the atmosphere at hypersonic speed, we will need a very special type of engine or a category of engines that will enable us to do that. And so that's properly where the bulk of our technology investments are being made.

SLD: You have provided a very helpful background on hypersonics. Now let us return to the question of the progress last year.

(For NASA's explanation of hypersonics see
http://www.grc.nasa.gov/WWW/BGH/bgh.html)

Lewis: There were three flights: X-37, HTV-2 and X-51. Now let me explain their significance in that order.

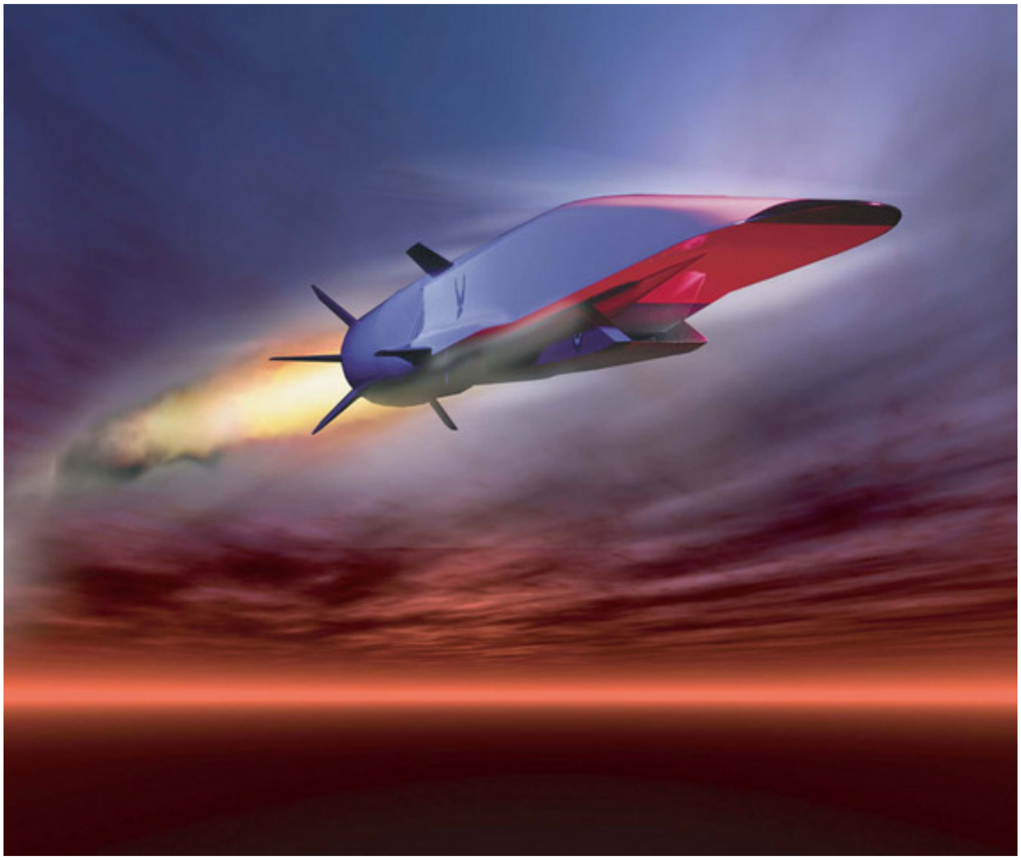
The flight of X-37 was exciting because in many ways it was a return to the future we were supposed to have. X-37 was a relatively traditional hypersonic vehicle in the sense that it had blunt leading edges, built very much along the same lines as the Space Shuttle orbiters. In other words, X-37 wasn't a sharp leading edge accelerating vehicle. It was a spacecraft, but it captured an idea from the 1960s, which I think has tremendous merit, and that is the idea of the small winged orbital vehicle. Having wings gives you operational flexibility. It lets the vehicle land on a conventional runway, taxi, and be refurbished to fly again. X-37 is thus similar to the space shuttle, except the space shuttle is much larger. Also, X-37 was unmanned.

The Space Shuttle has a huge cargo bay, which is good for some things, but not for all payloads. Flying the Space Shuttle every time you want to launch a payload into space is like flying a C-5 every time you want to deliver a package, no matter how small that package might be. The X-37 points the way to much smaller spacecraft that can do much more flexible missions into space at lower cost. But really, from a technology standpoint, it didn't quite push the envelope, except perhaps for its autonomous control.

The next flight, HTV-2 was a DARPA-led effort. HTV-2 was a very slender, sharp-leading-edged, maneuvering re-entry vehicle, Though a research craft, it points the way towards global long-range strike systems. HTV-2 was launched on a conventional rocket. If made operational, it could boost and glide to almost anywhere on the globe, very effective as a conventional strike system.

HTV-2 was not powered, so it didn't really push the state of the art in propulsion. It did push the frontiers of aerodynamics and material. To be honest, the first HTV-2 flight also was really a failure: it was lost half way through its fight. That is in part because DARPA initially didn't make enough of an investment in understanding the aerodynamics.

So from the standpoint of its being a flight experiment, HTV-2 was a failure, but as a teaching moment, it was also a success, because it reminded us the things that we don't know about flying at high speed.



And to DARPA's great credit, as soon as that flight occurred and the vehicle was lost, they began a significant investment in wind tunnel tests and computational studies to try to understand what went wrong.

Figure 4 The USAF illustration above depicts the X-51A Waverider scramjet vehicle during hypersonic flight during its May 26, 2010 test. Powered by a Pratt and Whitney Rocketdyne SJY61 scramjet engine, it is designed to ride on its own shockwave and accelerate to about Mach 6

http://www.space.com/8617-air-force-sees-hypersonic-weapons-spaceships-future.html

The third vehicle, and frankly the one that I'm most excited about, is the X-51. I am also especially proud of X-51 because it came right out of the Air Force Research Laboratory. X-51 was a flight test vehicle dropped off the wing of a B-52, designed to represent a vehicle such as a hypersonic cruise missile, with a corresponding mission of flying several hundreds of nautical miles in under a few minutes.

But the most important thing about X-51 is that it was a flight test bed for propulsion technology, propulsion that could power a vehicle operating in the atmosphere at hypersonic speeds. The type of engine that powered X-51 is something called a supersonic combustion ramjet or scramjet.

Let me explain what a scramjet is - in some ways it is the simplest engine you could imagine operating the atmosphere. It's got a hole in the front; air comes in, fuel squirts in, mixes, burns, and the hot gases accelerate out the back. However, building a scramjet that can operate at hypersonic speeds is a considerable challenge. At those speeds, there is very little time for the fuel to mix and burn- on the order of thousandths of a second. And temperatures are so hot that they push material limits.

The X-51 vehicle included tremendous developments in the technology associated with scramjet engines. Although its first flight in May was not 100% successful, it did teach us the things we needed to learn about flying at those speeds.

Figure 5 HTV-2
http://www.parabolicarc.com/2010/04/18/darpa-falcon-htv2-hypersonic-vehicle-launch-vandenberg-tuesday/

SLD: You were talking about ubiquitous presence, speed of light, and again we want to go as quickly as you can, different kinds of approaches to how you use the assets.

I think one of the most important things that gets lost when you're talking about a new technology, like potentially hypersonics can deliver, is when we describe it as game changing, which it certainly is, but it means also that it's a tool that you're adding to the toolbox which is iterative. It interacts with all the other things in your toolbox to make them more effective.

And our expectation is for rapid success or if we don't get rapid success, we think we have failed. What I've been concerned about is our tolerance for testing's low. Our budgeting for testing's low. Our willingness to allow new systems to have their place to get inserted, whether they be CH-53Ks or Ospreys or whatever. So that's one problem.

The second problem that I see is that if we make this transition in air power towards distributed ops, as you add long-range strike capabilities, it really allows you to use that grid very, very differently because now if I'm laying the grid on a region because I need to be there, then I can direct a hypersonic strike, or I can lead with a hypersonic strike because I think at the heart of the problem that I see is that it's not a 1991 scenario.

We know that a lot of what we want to affect is mobile, fleeting, and a hard to find and kill, so just so if I can get there with quick speed to affect something that's fleeting or moved with strike, I would have failed.

But the issue is because I'm addressing through stealth my ability to manage areas where there's going to be fleeting targets, if I now have stealth plus speed I have a very flexible set of assets to manage threat environments.

Lewis: Absolutely. I could not agree more. If I can, let me pick up on your first point. I could not agree more about your comments about testing. We're unwilling to make the proper investment in testing. We're unwilling to accept risks in testing. And we are short-sighted in funding our valuable testing infrastructure, such as wind tunnels and test cells.

Figure 6 X-37 Video from NASA http://www.youtube.com/watch?v=SPKGGkKoQsQ

I mentioned the X-15 program earlier. They took risks. Remember, they did 199 flights with three vehicles, and even towards the end of the program, when they tragically lost an X-15 and a pilot was killed, it didn't end the program.

Today, when we have a small failure on even an unmanned flight test, we spend sometimes years studying our navel to figure out what could possibly have gone wrong before we've got enough the nerve to fly again.

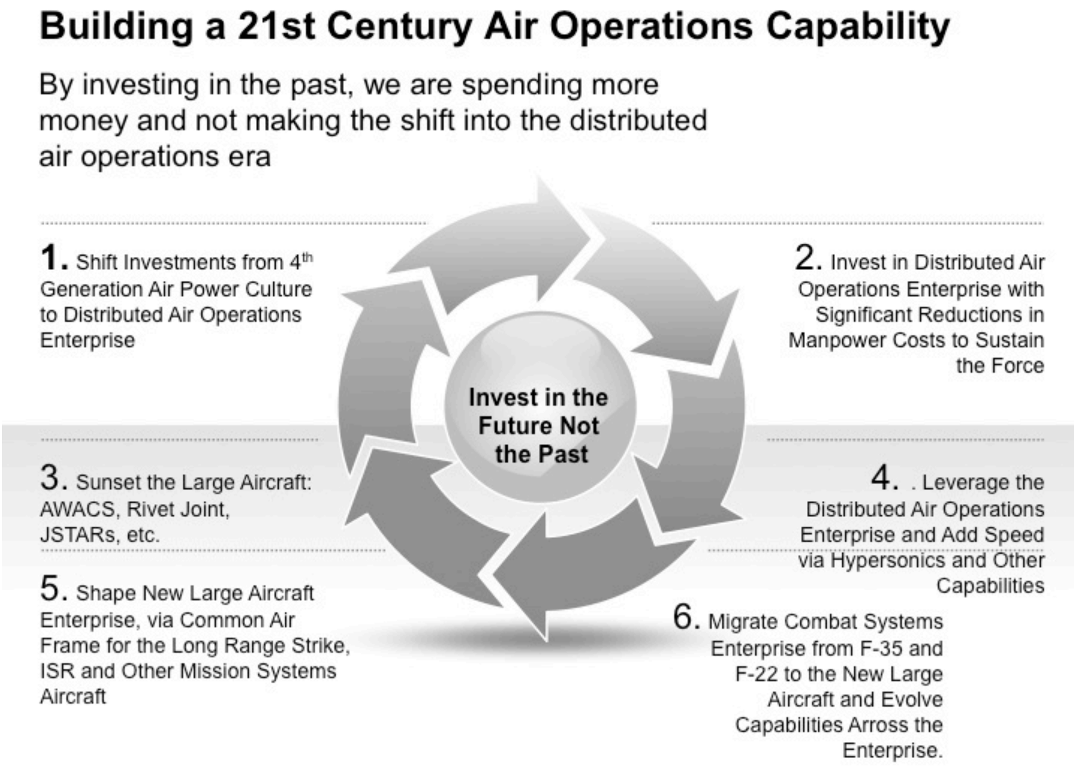
When I was Chief Scientist we started an Air Force program called HiFire. It was also under Mike Wynne's watch. HiFire is a joint effort between the United States Air Force and the Australian Defence Science and Technology Organization, with additional support form NASA and industry. The program is doing a series of hypersonic flight tests in the Australian Outback. That's using relatively small rockets flying modest experiments, but the going-in mantra was "we're willing to fail" - if the rocket blows up and we deliver the payload to the sands of the outback, then we're going to fly again, and we're not going to spend two years trying to figure out what went wrong. So you're absolutely right.

I see across the board an unwillingness to make the investment in testing infrastructure, in some cases, a lack of commitment to continue the investments in infrastructure that we've already paid for. And it's not only the facilities, it's also the people who run the facilities.

I mention the HTV-2 as my favorite example of the importance of testing infrastructure. The Air Force and DARPA led the development effort in that program. The Air Force was co-funding it, but DARPA had program management oversight. When it started we actually had a pretty big battle over that program because the original DARPA program manager insisted he didn't need to do any testing. He was just going to fly that thing without any ground test whatsoever. Fortunately, we had some smart people in the Air Force Research Lab who said, "You know, you really need to put the darn thing in a wind tunnel." Finally, DARPA gave in, though the Air Force actually wound up footing the bill for those wind tunnel tests.

The first thing we discovered when HTV-2 was tested on the ground was that the models that predicted behavior were wrong, and the vehicle was redesigned. The Air Force wanted to do more testing. DARPA pushed back., claiming there was no point to further testing. They thought they had the performance fully characterized. They flew it, and it didn't work. Now again, to their credit, DARPA, after it didn't work, after the flight, DARPA did turn around and say, "All right, now let's do the ground test." In part, that was because there was a new program manager, and that program manager came out of the Air Force Research Lab, so he understood why we needed to do more ground tests.

To my mind, that's a perfect example of why we need test facilities. I further point to the fact that you can make the investment up front in the test facility, or frankly, you can pay for it in a failed flight, but one way or another, you're going to pay for testing. It's just a matter of when you pay for that testing.



SLD: There's another aspect that I find very interesting which is when folks focus on how good our simulation capability is or our models to predict behavior, and they are extraordinary, but the problem with mathematics is that it can be hypothetical. It can be based on predictive behavior. It depends on how you do your models, but at the end of the day when you're pushing the envelope in an operational sense, you don't know fully the outcome in advance.

And when you've seen the test you now are trying to build a predictive model on, well what would happen if I changed this composite technology or whatever. The other thing that's lost in this current conversation, and you see this especially with things like ABLs and F-35s, is the ability to manufacture something is arguably as important as your ability to design something.

It's the front end of the cycle, and we've just lost any understanding that if I've gotten to the point where I can actually manufacture a stealth aircraft, I've achieved something historically significant, but it's just not perceived as important.

And it's at the end of the day if you can figure out your hypersonic cruise missile and you can replicate that missile in a manufacturing process, but to do that you need folks who actually have experience in manufacturing advanced materials, composites and all this sort of stuff. So that I think that testing to me is part of the pre-manufacturing process if we could call it that.

Lewis: Once again, I agree with you completely, on your comments on modeling and simulation. As a researcher, most of the research that I've done has been analytical and computational modeling of high speed flow, and yet I'll be the first to tell you that the best computational models that we have don't perfectly predict flow properties.

And the reason is, we don't fully understand the physics, but even if we did, we have to remember that any computational model never quite gets the solution correctly. That's fundamental to the way we solve the governing equations of aerodynamics on a computer. Let me explain that - a digital computer solves equation on discrete numerical grids, but real flow doesn't work that way. When we solve a problem on a computer, we're always making approximations. Even worse, the equations that we solve, those governing equations of aerodynamics, are really a simplification of ever-more complex equations that govern how molecules move around the vehicle.

So we know we never quite get it right, and I can give you example after example of fundamental problems that we really don't know how to simulate. Now, if I were to give you some data and also give you a computer code, you can probably do a nice job of matching the code results to the data, as long as you know the right answer before you start.

It's when we don't know the answer before we start that the numerical simulations are most uncertain, and that's why we frankly need experiments; and also, by the way, even experiments don't always quite get it right.

For example, the conditions inside a wind tunnel are not exactly the same conditions that a vehicle experiences in flight. That's especially true at hypersonic speeds, by the way. And that's why flight test, actually putting things in the air, is absolutely critical. You can simulate all you want, you can wind tunnel test all you want - and rest assured, they're both important - but until you actually put the vehicle in the air and light off a real engine and fly at the correct speed, you really won't understand fully and completely how that system is going to behave.

SLD: There's another aspect. If we go to the operational modality, one of the things that folks have really not taken onboard is the revolution in mobility, the revolution in defense, is so fundamental in terms of identifying the targets you want to affect. And one of the things I find interesting is if you think about stealth as a hovering asset and you're either directing strike, or as Mike Wynne says, you really want to use the best sensor on the battlefield last, which I think is a very good proposition, but there's also the point that when you have a kinetic effect on a mobile anything and you're looking interactively at the defenses and offensive capability of your opponent, you're essentially creating fractural results.

That is unpredictable results that essentially then recreate very quickly a different kind of target set, so for us to use these hypersonic assets effectively, they can be leading elements against things that you just know you've got to get out of the way, or they can be part of this interactive control of a dynamic battlefield.

And for that to work, you're going to have to have forward deployed assets of some sort whether they be space based or whatever. They could be aircraft. They could be RPAs.

Lewis: I agree with you completely, and that was actually a theme that I kept striking with the Air Force Research Lab folks who were working in hypersonics.

You need to think about how the hypersonic capability factors in with the other capabilities you bring to bear.

I'll give you my favorite example of that. There are some folks in the hypersonics community who envision very large hypersonic cruisers, including airplanes that might take off from anywhere in the continental United States and fly to anywhere on the globe in less than two hours to perform some missions. Sounds great, but when you actually work through the basic physics, you discover that it's almost impossible to do. Such a global cruiser is the wrong use of hypersonics. That type of vehicle would be too expensive and too hard to build, and simply wouldn't have sufficient range to do the envisioned mission anyway.

Now let's step back and ask, "all right, how do we combine hypersonics with other systems?" For example, a long-range next-generation bomber might fly to a loiter point at low speed, but when it has to launch a missile, it launches that missile at hypersonic speed. It peels off a hypersonic cruise missile for example. That's really a winning combination.

In a system like that, each of the technologies is doing what they do best, and combine to form a package that really, truly is game changing. So I take your point exactly.

(pictured above and found at the following site X-51 http://www.11news.us/05/speed-of-soundx-51a-waverider.html)

There's another aspect to all of this, and that's frankly the cost factor, the economics. People often say that hypersonic systems will be so expensive that they'll simply be cost prohibitive, but to that I answer that if hypersonics brings so much of the capability that I think it will, it will buy its way onto the platform.

We might be able to do more with one hypersonic system than what might have taken many, many lower speed systems. There's a capability multiplication there that I think actually makes hypersonic systems quite cost effective.

SLD: Let us go back to your discussion of the various tests in 2010. Could you discuss a bit more the X-51 ?

Lewis: X-51 is not the first air breathing hypersonic vehicle that's been flown. NASA flew a vehicle called X-43, which had a lot of similarities to X-51, and even our partners in Australia flew a small sounding rocket that used some of the same technology in a program called HyShot.

HyShot (pictured above and found at the following site **HY Shot Rocket Launch Video** **http://www.youtube.com/watch?v=SPKGGkKoQsQ**) was the first flight of one of these engines that I mentioned, these scramjet engines, supersonic combustion ramjet engines. The catch is that when the Australian's did it in 2002, they did so for only a few seconds, and they didn't produce net positive thrust; in other words, the engine produced thrust, but it had more drag than thrust. In order to accelerate a vehicle, thrust must be greater than drag.

Two years later, NASA flew the X-43 off the wing of a B-52. In fact, they used the same B-52, nick-named "Balls 8", that had been used to fly the X-15. X-43 was boosted to high speed on a Pegasus rocket for a total of three flights. The first flight was not successful –

the Peagsus booster lost a fin. NASA spent two years trying to figure out what went wrong, and they finally flew it again. When they flew it a second time, it hit Mach 7. They flew a vehicle a third time and it hit a record-setting Mach 10. Each one of those flights lasted for about ten seconds under power, and they burned hydrogen fuel. That's an important distinction from X-51, which used jet fuel, because hydrogen is not a very practical fuel, certainly not from a battlefield standpoint.

The engines on X-43 only ran for about ten seconds because they were limited by the fuel supply, but also because the design of the engine was such that if they had powered it for much longer than ten seconds, the engine walls would have melted.
Now let's jump to X-51. Why was X-51 a significant leap? I always argue that X-51 actually built on much of the legacy of the HyShot flight and more importantly, the X-43 flights. And by the way, one of the true success stories of X-51 is that we established a wonderful partnership between NASA and the Air Force on X-51, and again, Mike Wynne gets a lot of credit for this. A lot of the NASA guys and gals that worked on X-43 brought their expertise to our X-51.

X-51 looked like a missile. That's in contrast to X-43, which was kind of a sub-scale model of an airplane. Also of note, X-51 burned relatively traditional jet fuel. It burned JP-7, the same jet fuel that the SR-71 uses. That's a hydrocarbon fuel, which is a more practical fuel than hydrogen. JP-7 is something that we know how to handle operationally.

Perhaps most importantly, X-51's big advance was that its engine was thermally balanced. That means that the fuel circulated through the walls of the engine and kept the engine from melting. In principle, that engine could operate for as long as you could supply it with fuel.

It's very clear how you go from something that looks and operates like an X-51, and by the way, just like X-43, X-51 flew off the wing of a B-52. So there again, you see the marriage of a Legacy airplane with this high-speed system.

When that first flight of X-51 occurred it was supposed to fly for 300 seconds. Unfortunately, it wound up flying for only about 200 seconds. Of those 200 seconds, about 150 seconds or so were under power of the air breathing system, that scramjet engine, but that amount of test time increased by almost a factor of ten the total amount of flight time that we have had with an air breathing hypersonic engine.

As it turns out that, there seems to have been a seal failure in the nozzle. The nozzle has a seal between the end of the engine and the rest of the airframe that came loose early in the flight. Despite that, lots of things worked as well as, or better than expected.

Clearly X-51 wasn't an operational system. One obvious question is "what comes next?" and the thing that comes to my mind first is making a vehicle based on X-51 that is much more of an operational weapon. The seal that failed on the first flight shouldn't even be present in an actual operational system. Of course, X-51 didn't have a warhead of any sort.

It didn't have the sort of guidance and navigation package that you'd want to put on a real missile, so there's lots left to do if we continue marching down a path towards an operational system.

SLD: So what are the downsides of the test results?

Lewis: Let me offer a little bit of tough love. I've talked about the great successes for X-51 despite its seal failure. Let me tell you some of the problems.

Problem number one, and it kind of gets back to an earlier theme, the program has too few flights. The whole X-51 program right now is set for three more flights, for a total of four. Four flights is not a viable flight test program. X-15 did 199 flights. In today's constrained environment, I'm not expecting 199 flights, but if we only have four flights it makes it very, very difficult to do the real sorts of flight tests that we need, to really push out the envelope. To take risks.

SLD: If you don't invest in the test flights, you're not going to have the capability.

Lewis: Exactly. One of the things I saw firsthand is that flight testing has gotten incredibly difficult in part because we are so risk averse.

I'll give you an example of this: X-51 flew on May 26th. It was originally supposed to fly on May 25th, but just before the flight, a cargo ship sailed into the splash zone in the Pacific Ocean. I should mention that X-51 was launched out of Edwards Air Force Base and flew off Point Mugu, and just before they're getting ready to fly, this ship sails into the splash zone and the flight gets scrubbed.

Now think about that, your flight test efforts are at the mercy of some international tanker sailing into this vast area in the Pacific Ocean, that's kind of what we've done to ourselves. The chances of X-51 actually hitting that tanker were astronomically small, even if we had tried (and some of us thought we should)! The second flight attempt was May 26th. The ground crew at Edwards just did a phenomenal job, and their success was amazing considering that they basically had an ancient B-52 being used as the carrier aircraft. They had to start all eight engines three times, twice the first day and once the second day, in order to make that flight happen, and everyone was kind of holding their breath and crossing their fingers as those engines were starting up.

This is not a reliable way to do successful flight tests. It is this level of risk aversion, where we're terrified to fly because several hundred miles off the coast a tanker has sailed into a splash zone, that is hurting our ability to test.