Mitchell Institute for Airpower Studies

Presentation: Hypersonic Power Projection
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Dr. Rebecca Grant, Director, Mitchell Institute
Dr. Richard Hallion, Former Historian of the Air Force
Dr. Mark Lewis, Former Air Force Chief Scientist

Mitchell Paper: Hypersonic Power Projection

Grant: I'm Rebecca Grant. I am the Director of the Mitchell Institute which is a research arm of the Air Force Association. The institute is named after General William Mitchell who was the first joint air component commander, pulling together over 1100 aircraft for combined air/ground operations at the Battle of San Mihiel in 1918. San Mihiel is not important in military history really, except for one reason, and that it was the first action of an all-US Army on foreign soil and in a way a great turning point in this country's evolution as a military power.

General Mitchell I think is well known to all of you. After World War I he earned his star for his work at San Mihiel and at the Muse Argonne offensive. He then came to Washington as an advocate for air power. He also spent a great deal of time in the development of the physical aspects of new aircraft and new bombs and tests of both, the most famous of which of course were those carried out on the captured German battleships including the *Ostfriesland* in the early 1920s, down in the waters off Langley Air Force Base.

As we know, General Mitchell was court marshaled and resigned from the Air Force. He died about ten years later. I always like to point out that among the pall bearers at his funeral was a man that he'd met back in World War I, a rather obscure colonel named George Marshall, who was a good friend of his and a colleague in planning the San Mihiel Offensive.

The Mitchell Institute was established partly to honor his legacy in two ways—one, his advocacy of pushing the edge in air power technologies; and second, his leadership which in his case was a direct contribution to America's success in World War II. He influenced the likes of Arnold, Spots and many others who created the generation that spawned the Air Force that we have today.

That's the Mitchell Institute. I am delighted to have two absolutely outstanding speakers here this morning. The first is Dr. Dick Hallion who I think probably most of you know very well from his extensive writings. He is a retired Chief Historian of the Air Force and a long-time expert in the application of air power and in Air Force programs. He will be speaking about a topic that has long been near and dear to his heart. Any of you who know his email address will know that for certain. That is hypersonics.

Commenting on the presentation and presenting a few slides of his own then will be Dr. Mark Lewis. Dr. Lewis was the former Chief Scientist of the Air Force and is now a professor—I should read the whole thing—the Willis Young Professor of Engineering at the University of Maryland, i.e. very very high up in the Engineering School at the University of Maryland.

We could not have two more superb experts to talk about this subject. So without further ado, Dr. Hallion.

Hallion: First of all, anybody here from Rolling Stone? [Laughter].

It is a very great pleasure to be here, and especially with Rebecca Grant who of course Rebecca Grant is one of the leading aerospace power analysts in the world today. I would say "the" leading, but that's my own personal bias. And it's always a pleasure to share a podium with Mark who is the President this year of the American Institute of Aeronautics and Astronautics, and I apologize, Mark, for my playing engineer this morning in front of the audience.

I have been very interested in hypersonics my entire life, literally from the earliest days of the X-15 program and its formulation in the late 1950s, and my email gives this away. If any of you wish to get in touch with me it's DrHypersonic@aol.com.

Well, hypersonics I think offers us an opportunity at a time when we're facing some unique defense challenges to really perhaps take advantage of technology to compensate for some of the problems we have with aging platforms, with reduced force structure, things of this sort.

What is it we're really talking bout here? We're talking about something which isn't really fanciful. We're talking about the art of the possible. We're talking about things that can be accomplished, they can be accomplished very very quickly, and they can give us, I think, timely and rapidly applicable combat power.

Hypersonics, for those of you that are perhaps not completely technically cognizant of what it means, hypersonics refers to flight at five times the speed of sound and above. It can be accomplished by systems that either have rocket propulsion, or nowadays air-breathing propulsion typified of what we call supersonic combustion ram jets.

If you take a look at the development of hypersonics as a technology field and the application of it, I think it's very consistent with the steady evolution of Air Force capabilities. Much like we saw the advent of the machine gun equipped airplane, and other precision munition applied to the airplane in the 1940s, and then the air-to-air and air-to-surface munitions and sensor developments and things of this sort. This is very much consistent in that same way.

It does, I think, address the future roles environment that we're facing today where we have to be very flexible, deployable, expeditionary, and deal with rapid threats. And I think we're less than ten years away from IOC. If not us, certainly somebody else.

So what it isn't basically is this. We're not dealing here with huge, large inhabited systems that require some radical breakthrough that we can speculate upon but can't define precisely, with some exotic material, the unobtainium issue, and it doesn't require, I think, a break the bank investment.

Now if we take a look, and I'll just review this very quickly, if we take a look at the history of aircraft, we can look at the old classic way in which people look at speed over time, and we see that basically by the 1970s we had reached some plateaus. Your rocket research aircraft had taken us up to the point where we were developing the technology to develop shuttle craft to go into space. We had about a Mach 2, 2.2 plateau for fighter aircraft. A high transonic plateau for commercial aircraft and bombers. At this point on the plateau, we basically sort of stayed there, but if you take a look at what's happened, we've of course refined dramatically the capabilities of aircraft and power projection capabilities using technology by such things as sensors, fly-by-wire flight control systems. Compare a Mach 2 F-104 and a Mach 2 F-22, if you will, and you sort of get the impression of it.

So what's next? Well, I would argue that what's next out here is hypersonics.

To give you some idea of the roots of this, we see that actually we have about 75 years of effort here. It goes all the way back to the late 1930s in terms of technical conceptualization and then we've seen a whole steady progression of programs from the air and space side that have represented a confluence of these two branches of aerospace technology culminating in the X-51 as the most recent effort that we have today.

But having said all this, it's also been 75 years of real discouragement and frustration, because actually if you look at this, we've had multiple fits and starts. We've had programs begun, programs dropped. We've had very fanciful ideas pushed by enthusiasts, many of whom were quite [inaudible] individuals, but what they came up with was unrelated to actual military requirements, military need. A lot of this was related to some vague idea of space access or exploitation of space, space-based ISR, space-based combat operations where you'd actually be doing space-based strike. And the vehicle concepts, and when you took a look at them the vehicle concepts were extraordinary. Most of these were around one million pounds gross liftoff weight, they had all sorts of exotic propulsion, single stage to orbit, two stage to orbit, whatever it was we were looking at, and there was very little attempt by the science and technology community to relate these to actual warfighting needs.

The example I'd give you would be a program from the early 1960s called the Aerospace Plane. Now here's this glowing monstrosity racing across the sky. The United States pursued Aerospace Plane for quite a while and then the Scientific Advisory Board did an assessment in 1963, and I think it's really quite interesting to read this quote. Erratic history, clearly infeasible factors, ridiculed, no new program achieved such difficult position. This kind of, if you will, throws some cold water, so to speak on the issue.

Even so, this enthusiasm persisted. We saw just within about two to three years of that time we saw once again people talking about these very large, very complex vehicles blending a whole lot of technologies to try to achieve some sort of reusable space lift function, 750,000 pound gross lift-off weight to this vehicle that's 350 feet long, taking off horizontally.

Then we had this in the 1980s. You had Tony DuPont come up with this concept for a 50,000 pound single stage to orbit, hypersonic dart, you know, very neat little vehicle. By the time we actually had grown that and made it somewhat feasible we had a 450,000 pound vehicle and we still had a 3,000 foot per second deficit in performance to actually getting to orbit.

So you take a look at this and you say what about hypersonics in the United States Air Force, and the answer is basically, hypersonics is controversial.

At this point, why are we here? It's because actually, if you take a look at the community that the Air Force has relied upon for analysis and assessment of where the Air Force needs to put its science and technology investment in the future to build reliable and useful combat power, you find that for years, all the way back to Theodore von Karman, in the 1940s, you find that hypersonics has received consistent endorsement. Particularly I think when people start to look at practical applications, and I think there were three moments here over the last 15 years that were very important. One of these was the New World Vista Study in 1996, the revitalization of the Scientific Advisory Board and its prognostications of where to take technology. The Scientific Advisory Board [Why and Whither] Study in 2000 which was basically a make or break for hypersonics in the Air Force, whether we would continue to robustly invest in it. Finally the NRC's Future Air Force Survivability Needs Study. These strongly endorsed the notion.

Why is this? It's because if you take a look at the field of hypersonics itself, the technical capabilities that we have achieved in hypersonics, we've actually done a number of things. We know the design approaches, we know the region, and we've achieved some notable milestones.

For example, we understand very well the requirements for both lifting vehicles such as the prime lifting body on the left and winged vehicles, winged lifting vehicles such as this asset vehicle on the right. We understand the materials issues. We understand the aero-thermodynamic structural issues. We understand the flow issues. We understand the controllability issues.

If you take a look at the region itself, well before the flight of the shuttle we had been there, done that. We had actually flown hypersonic reentries down to precision recoveries from orbit, all the way back through the hypersonic lifting corridor back down to sea level. And we had actually developed some notable vehicles. For all the challenges that it had, if you take a look at the shuttle, the shuttle gave the United States since 1981 an extraordinary capability to place large payloads into orbit and to undertake relatively routine access to orbit when we needed to do so, to do some pretty significant things in terms of working in space.

But I think even more than that, the vehicle that I like to highlight, and I know Mark does as well, is the X-15. Here's a vehicle with over 199 flights, went out to Mach 6.7 at a very early stage in the whole hypersonic revolution, reached 354,200 feet demonstrating redundancy, reliability and routine operation.

The result is, we understand now, better than at any previous time, the hypersonics arena. But so do a lot of other people. These other people are a mix of friends, potential perhaps not friends, and some people that maybe sort of fall in the middle, depending on who brings the bucks. To show you how achievable this is, and I'm delighted that we have our Australian colleagues here who have been very helpful to the United States in the hypersonics field, we have the Center for Hypersonics at the University of Queensland which in 2002 flew a scram jet test vehicle, and they did it for $1.4 million. This is not a technology that is necessarily beyond the ability of small players to play in.

I'm fond of saying that on December 17, 2003 we had two very different commemorations that day. We tried and failed to fly a replica of a 100 year old airplane. The Australians tried to—[Laughter]—Australian hypersonic—[Laughter]—that's a little cruel, and I apologize. But anyway, there we go.

So the bottom line is, whether we recognize it or not, we're in a global hypersonic race and this is something we need to keep in mind.

Now the applicability of this in terms of our military capabilities I think is kind of intriguing because we face, as many of you well know, this idea of [tyranny] of distance. If you take a look at where we're liable to have to intervene and place combat power at a distance, you find that 30 knot solutions and .85 Mach number solutions don't really meet the need any more. When you're dealing with actors that increasingly have very robust forces.

This shows the West Pac scenario. Here's the Southwest Asian scenario. You see it's pretty much the same thing, looking at something operating from Diego Garcia.

This also leads to another problem and that is the power projection capabilities we actually are able to exercise. We talk about closing the sensor to shooter loop. I'm convinced that equally important and often ignored is the fact that we have to close the shooter to target loop. What I mean by that is if we take a look at [tyranny] of time we get into one of these "are we there yet" scenarios. You take a look at targets that you'd like to hit, and the fly-out time of weapons going to those targets, and you realize that from the time you get weapons clear and you release that weapon off the vehicle or out of the tube or off a sub or whatever it is you're doing, by the time that weapon actually gets to the target area, things have changed dramatically. In fact the intelligence that you get very often is historical intelligence. It's nice to know. Gee, it's interesting, there was a meeting. Too bad we weren't able to have been in that meeting. You know?

One of the things that hypersonics I think offers is the chance, and I'll get to this a little bit later, of taking intelligence that's fleeting intelligence and turning it into actionable intelligence.

Now what adds some urgency to this is that we are in a very dangerous world. We're in a world in which the nature of communications technology, the nature of the surface-to-air missile threat, the widespread availability of proliferation of sophisticated arms has built a circumstance in which nations that may not have very good intent can build relatively robust integrated air defense networks that actually can cause a super power some problems in intervening.

The example I give you is the Falklands War. If you take a look at the Falklands War in the early 1980s, Britain had air superiority, but not enough. They had early warning, but not enough. They had fleet air defense, but not enough. The ability to project power sure, but not enough. The enemy saw this. They got into an attritional slugfest and if you take a look at it, came very very close to having to withdraw their fleet.

If you think about a super power, a super power has to be able to intervene perhaps simultaneously in multiple crisis regions and win decisively against opponents who only have to look out for their own backyard. That's the challenge that is posed by this new technology building robust IADS and networks that are very tough to crack. It becomes even more acute when you think that we have a very aging force structure, and I chose this deliberately. We have aging surface combatants, we have aging Air Force combatants and naval aviation combatants, and these are increasingly constrained in their ability to undertake combat operations.

Put this all together and we have a synergy of things here that really present a very very great challenge to us. You have the distances, the time, the age of the force structure, the strength of the defenses, and that's why I think we have an advantage if we pursue hypersonics, because hypersonics removes that zone of "are we there yet". You can reach out very very rapidly across distance, within eight to ten minutes, and turn those capabilities to achieve some sort of decisive effect.

So what does hypersonics offer? I would offer that it counters all these tyrannies. By the very nature of hypersonics, you're covering a great deal of distance. You've moving at about a mile a second, at the minimum, the lowest level of hypersonic velocity. So you have inherent graphic reach.

If you think about air power, the air power has always been built around height and reach and speed, and with hypersonics you really have all of those operating very very effectively to you. It fulfills the dictum that Major General JFC Fuller, one of the great theorists in military affairs said in the middle of the last century, and that is that at any particular time if you take a look at the capabilities of the weapon around which you have to build the fulcrum of combined tactics. You have to look to the weapon with the greatest reach. So it furnishes, just by the nature of the speed, it furnishes that theater commander the option of using force across the whole range of the theater that he has, and for that matter it even gives us the opportunity to project power over global distances as well.

Because of the nature of its ability to intervene against an opponent who does not possess that capability or who may be operating an older force structure, you start to get those fourth dimension effects. You start to operate within the enemy's [OODA loop]. You start to be able to offset their ability to reach you and therefore to affect your taking time away from them. It's a little bit like the effect that air attack had in the Italian campaign in the 1940s when a German general named Frido von Senger stated that he felt like a chess player who could only make one move to his opponent's three. That advantage of air attack had taken time away from him. Finally, and I think this is very important for all of us, it revitalizes our aging platforms. Those aging platforms that may have to operate very close to a high threat double digit SAM fifth generation fighter arena, now they don't have to. Now they can loiter further off and they can let the weapon achieve the penetration and operate through that distance very very quickly.

This has been recognized for quite a while. We had a Scientific Advisory Board study, and I was on one of the panels, in the year 2000 fly [inaudible] hypersonics in the United States Air Force. It's available as a web document from the Scientific Advisory Board. We took a look at what a hypersonic missile would do if you had a ballistic missile operating, and looking at the architectures we had for detection, we found that we actually could intervene, if we had a hypersonic missile available we could intervene from the 2000 time period on against the launch of these and catch them very quickly before they actually got to the launch point.

Since that time further studies have actually pushed it even further back, so I think this is a powerful example, just a single example but nevertheless a powerful example of what hypersonics can offer.

So it closes, as I said, the shooter-to-target loop. Therefore it inherently addresses the time sensitive target issue which is one of great concern. It redefines what we see is actionable intelligence because what was fleeting intelligence or intelligence that was just nice to know, good to have, background only, now becomes actionable intelligence. It enables you to seize these fleeting opportunities. Finally, it increases the commander's ability to find, fix, track, target, engage on those targets. And it also enables him to be more reflective in his or her decision-making. Is that a column of terrorists or is that a column of nuns? Now you can afford to take the time because the speed of the weapon can make up in many ways for the deficiencies that you might otherwise have if you're using something that's moving at a slower velocity.

It ranges across the whole kind of target sets that we would be concerned about. Whether we're looking at using these for suppression of enemy air defenses to kick the door down so that you can allow legacy aircraft. By legacy aircraft I'm even including our first and second generation stealth aircraft in that now, to get into a crisis region. It enables you to go after very high leverage targets—command, control, communications, leadership, key infrastructure. It enables you to go after targets that might pose a unique threat—weapons of mass destruction, directed energy, something that's threatening the satellite systems. And it enables you to go after hardened targets. And because of this, because of the range of things that it addresses, then I see it as something that is uniquely valuable in terms of enhancing our joint operations and our joint capabilities. Because what it does is it enables us to operate as these threat lanes are expanding, as the nature of the air defense threat within these new IS constructs is getting more and more robust, it enables us to operate still from the periphery, from outside, with poise, if you will, with the ability to then intervene using the speed of these systems. This is particularly valuable I think to defend sea lines of communications and air lines of communications and particularly I think to enhance the joint force commander's options if he's using, for example, littoral naval power. If you're taking a look at the power of carrier battle groups.

It's very interesting to me to take a look at naval combat operations in the last century. You find that even at the time of those battles being fought—Jutland, whatever it is you're looking at—with one or two exceptions that are very small exceptions, the Battle of Komandorski Islands, for example, every single naval action fought in World War II was fought at that time within the range of available land-based air power. You had Zeppelins operating, for example, during the Battle of Jutland.

The point being that air power and sea power and land-based air power have always worked in synergistic fashion together as complementary operational strengths. We tend I think sometimes in roles and missions today and we tend sometimes in the Washington environment and other environment where we're hacking and hewing resources to get that. But the linkage of the air and sea power, the land-based air and sea-based air has worked very very effectively and that's why I think this works very very well for us in the future.

I'm about to wash this off to Mark, but before I do, let me just throw a couple of technical thoughts out to you.

I think we have passed a very important baseline step just within the last few weeks with the first successful flight demonstration of the X-51 which is a vehicle that Mark will have much more to say about. It demonstrated acceleration at the launch, it was a missile type configuration. And more importantly, it was not something that used some exotic fuel like Xylene that has sand as a by-product or something like this. It used plain old JP hydrocarbon.

We have the X-51 in flight tests right now. If you take a look at this, it uses a modified JDAM launcher off a B-52. You think, you know, that's basically what one would look like. A weaponized scram jet Mach 6 to 8 vehicle would look like. You can operate 6 of these off a buff right now.

If you take a look at what, I call it a gen one hypersonic scram jet missile might look like, I would see for air launch a vehicle that basically gave you an impact velocity of Mach 4, I'll get to that in a minute. Max mach out around Mach 7, strap on boosters so it will enable you to use a rotary launcher in something like a B-1 of a B-52 or a B-2. Surface sub-launch, you're less concerned about the strap-on. You can actually use a fairly large interstate. Of course you're climbing then from sea level so you have some performance penalties in the top end. And another vehicle just in sort of generic terms, once again, this won't really surprise anybody. It looks like sort of like this. A nose cap, a very high temperature nose cap, probably tungsten, guidance flight control system, warhead, fuel, very slender profile, air-breathing engine module.

The thing about hypersonics, it's interesting, when you get into hypersonic design you find that the integration of the engine into the vehicle becomes critical because actually the whole [inaudible] of the vehicle acts as part of the induction system, if you will, for the engine.

Gen one employment, air-launched, 35,000-40,000 feet, rocket boost 65,000-75,000 feet, do your transition from rocket boost to scram jet ignition, then you climb out. One of the aspects of hypersonic scram jet vehicles is as they accelerate they tend to naturally climb. You do a pitch over in the target area, maybe because of some of the defenses we're seeing you might want to do some sort of terminal maneuvering. That wouldn't necessarily have to be too much, just maybe a mild pitching maneuver. And you impact it around Mach 4. Why? Well one of the things we studied in the [Why and Whither] Study in 2000 with the Air Force Scientific Advisory Board was how fast do you have to be going to cause serious destruction to a target, particularly a heavily embedded bunker target or something like that. Everybody was thinking we'll hit them at Mach 8. We'll hit them at Mach 9, 12, whatever.

We found there are some interesting properties of materials and that is when you get above 4, all of a sudden that very dense warhead you have might start to behave in a sort of a plastic or liquid mode and you might just go splat. So actually Mach 4 turns out to be just about what you're looking at.

What can carry these things? Anything. And I deliberate picked here what might not be thought of as necessarily your typical aircraft. Yeah, we can certainly think of a buff or a B-2 operating them. An F-15E, I think that may surprise some that we could actually do this with an F-15E. But remember, the F-15E was carrying two larger weapons, GBU-28s, when we were going after Saddam, and that was way back in Gulf 1. You can even take them off a 130 or certainly a transport-sized vehicle and there would be an ideal weapon for use by something like the Navy's maritime patrol aircraft, the P-8. The applications, you can think of anti-piracy applications, vessel threatened by a pirate vessel. You hit that vessel at something like Mach 4, that pirate vessel, it's not going to be doing too well.

Basically that's my brief. I'll just leave you with one final thought, and that is if we take a look at rates of mobility we find that we entered the 19th Century at about six miles an hour, the speed of an animal-drawn vehicle; we ended the 20th Century at about 60 miles an hour with the speed of a steam locomotive; the 21st at about 600 miles an hour, the speed of an intercontinental get airliner, a normative form of transportation; and I think we're on track to enter the next century at about 6,000 miles per hour, the speed of an air-breathing hypersonic vehicle. I think that's fantastic. I will just remind you that we're very very close to where the Wright Brothers made their first flight in 1908, and at that time they were called into the President's office and the President said what do you think's going to happen with your vehicle? They said, you know, if you invest in all sorts of technologies we don't have now, let's call one gas turbines, and we'll call something else radar, and we make shapes like things called swept wings, and we move trillions and trillions of cubic feet of earth and spend trillions and trillions of dollars and create all sorts of occupations we don't know, we might be able to move 600 million people through the air in the United States by the year 2000. Had they said that, they'd have probably been sent across to St. Elizabeth's.

So these things all begin with little steps and I think with the X-51 we have taken a little step but a very important one, an exquisite one. So at this point I'll turn it over to Mark. Thank you very much.

[Applause].

Lewis: W.C. Fields said never share a stage with animals or children. I'm going to add to that, never share a stage with Dick Hallion, because no one will ever notice you were there.

But I'm going to do my best. When I was asked to do this, we've done this joint presentation several times in the past, and I'm always tempted to just stand up and say what he said, and sit down.

What I hope to do is take you through some of the research issues, some of the basic science/technology issues that we face in the realm of hypersonics. And also maybe circle back to some of the points that Dick just made in his presentation.

First, as Dick mentioned, hypersonics usually refers to flight in excess of about Mach 5. When you talk about the scientific challenges it's important to remember there actually is no firm definition of hypersonics. In the Russian language, for example, there's no word that corresponds to hypersonics. The Russians refer to higher speed supersonics. So in fact what hypersonics really refers to is a series of physical effects that begin to occur as an air vehicle flies faster and faster through the atmosphere. These include the importance of chemistry. As you fly at high speeds through the atmosphere temperatures become high and you change the atmosphere and chemistry.

At supersonic speeds, of course, a supersonic aircraft produces a shock wave. Hypersonic speeds are high supersonic speeds at which those shock waves start being pressed very very close to the body and that changes some of the physics of the flow around the vehicle.

Heating becomes an absolutely critical issue, and that's especially important for the sorts of hypersonic vehicles that Dick was just talking about, those that would accelerate through the air, perhaps as missiles, because they have to be very efficient aerodynamic shapes. And that leads to configurations that have very very high heating rates.

When we talk about hypersonics, we really, the term actually flies across the board to anything flying at high speeds, including a space shuttle reentering from orbit, an Apollo capsule coming in from the moon. But in modern parlance, hypersonics has most recently been applied to slender configurations that accelerate through the atmosphere either using rocket power as gliders or I think most excitingly as air-breathing systems, using oxygen from the atmosphere to power their propulsion systems.

Dick talked about some of the applications of hypersonic systems. This is kind of my laundry list that sort of fills in. At the top you see a list of weapons. Weapons applications include what we might almost call traditional hypersonic vehicles, traditional blunt body reentry systems, the slender cruise missiles, the type that Dick was just referring to. There are some aircraft applications that can build on some of the things we learn based on our exploration of weapon systems.

Finally, very long term, access to space applications. There you run the risk of getting into those big sorts of vehicles that Dick was just talking about. I think there are lessons that we can learn from weapons and the associated technologies that we apply downstream to some exciting space applications.

In a range of global missions, how would you apply these? Dick talked about missiles, in the lower left hand side you see an X-51, referring to the sorts of derivative missile configurations that might come out of a system. Above the X-51 you see another notional missile, somewhat longer range missile, that was part of an analysis of alternatives that was done by Space Command about two years ago, created as a very

very favorable means for reaching out at large distances.

In the center of that viewgraph you see a notional concept for a hypersonic aircraft. Those become very very interesting. There's a lot of talk about hypersonic aircraft. People talk about these notional hypersonic cruisers that can travel anywhere in the world in under two hours, perform some mission, return to launch point. I'll show you in a few moments, most of those global cruiser concepts really don't make a lot of sense, especially for the United States Air Force. However, there are some shorter range missions, some recce strike missions, where hypersonic aircraft might be a very attractive option.

Finally, far right side, the sort of notional hypersonic vehicle, a launcher that can fly up to orbit but use air-breathing engines. I'm very fond of future, building in some of the technology that might be developed in the left hand side of the viewgraph, but if you could do that it might give you some intriguing capabilities for access to space.

Also in that mix should be considered the unpowered systems. Upper right hand side you see hypersonic reentry systems. They're the conventional cruisers that can be lofted on a rocket but reenter and do a maneuverable reentry as part of a Prompt Global Strike mission. In fact we just had an attempted flight of a system that would use this sort of technology. DARPA's HTV-2 which was not successful, but has some intriguing features for a future Prompt Global Strike system.

Dick mentioned some of the failures in the past. Some of those failures are continuing, although not all for the same reasons. There are three recent failures that I'll highlight. The first, the one in the back is actually a program that I'm rather fond of. It's a Navy program called High Fly. In fact we've got some Navy folks in the audience. High Fly is a program very much like X-51 in its sense of taking the hypersonic technology and applying it to a very practical weapon system. A High Fly uses a different flow path than the X-51 that Dick showed, but I think captures many of the same issues, many of the same applications of relevant hypersonics.

High Fly has had two flights so far, both of which were not successful, but not for reasons relating to the hypersonic system. Basically the flights failed before we ever got to the point of hypersonic flight. I think perhaps the most important take-away that comes from that is that hypersonics requires a significant investment in the flight test infrastructure. That means you can't just fly twice. You've got to build on what I would argue is the X-15 model of multiple flights and accept failure because the ultimate payoff is worth the investment.

The middle of that screen, you see a reference to a program called Black Swift. That was a DARPA program which failed for entirely different reasons than High Fly. Black Swift I would argue failed to learn some of the lessons of the [inaudible]. Reaching too far with some fuzzy goals; unrealistic budgeting; and at the end it was canceled by the US Congress and probably for good reasons.

Finally on the far right side you see DARPA's HTV-2, the Hypersonic Technology Vehicle. That was not a powered system. It was a slender, high lift glider launched on a Minotaur rocket and then brought in to do a simulated Prompt Global Strike mission. That seems to have failed for technical reasons. Data is still being analyzed. It's supposed to fly for 20 minutes in the atmosphere. It got to about 9 minutes and then seemed to break apart in flight.

I would argue that that failure was most likely caused by a failure to invest in sufficient ground testing. HTV-2 was not tested adequately. They did a few runs down at NASA Langley. DARPA did some runs in an Air Force facility, but didn't test out the full flight test envelope. Although the data hasn't been analyzed, we don't know the final reason for the failure, I've been offering to bet a lunch or a dinner to anyone that it almost certainly failed because of a failure of its thermal protection system, due to some fairly complicated flow physics.

But failure aside, we've had some notable successes.

This is the cover of Aviation Week from about nine months ago. I love the title. "Making Scram Jets Practical." The scram jet is the engine that we believe is the secret to air-breathing flight of hypersonic speeds. A scram jet is in some ways the simplest engine you could ever imagine; in some ways the most complicated engine you could ever imagine. It's an open duct. Air comes in, fuel is injected, mixes, burns, accelerates out the back of the nozzle. Very few moving parts in its main flow path. What's so challenging about a scram jet is it has to operate at incredibly high temperatures with flows moving in through the flow passage in literally milliseconds. So you've got milliseconds to squirt your fuel in, mix it, burn it efficiently, and shoot it out the back of the nozzle. That makes it very challenging.

Scram jets have been envisioned for many years, and I'll show you, a few viewgraphs down I'll show you what I think of as the first reference to a scram jet engine. But it's only in the past couple of years that scram jets have flown; and more importantly, in the past year that we've shown that scram jets can be built as a practical engine. By practical I mean something that can operate for more than a few seconds, that we see leading us to a pathway to a practical missile application.

Dick mentioned the X-51, and I think that's also a very exciting success and a very recent success at that. May 26th was the first flight of X-51. Let me tell you why I think X-51 was so important. A couple of things were captured. First, 200 seconds of powered flight. How important is that? It's important because at that point the engine operating X-51 was thermally balanced. That meant that the heat that was being deposited into the walls of the engine was being taken out of the walls by the fuel and circulated back into the combustion system. That means that that engine effectively was operating in steady state. It could have operated for as long as the fuel could be supplied to the engine. That's an important milestone.

Number two, as Dick pointed out, X-51 flew on a very practical fuel. JP-7. The same fuel that powered the SR-71. And it was initially ignited by ethylene. Previous flight tests had used some fairly exotic chemicals to ignite their engines. Dick mentioned Xylene. It was the ignition system used for NASA's X-43 that I'll mention in a few minutes. A very dangerous chemical to work with. Ethylene is a much more practical ignition system.

But perhaps most importantly, X-51 accelerated at hypersonic speeds going uphill. Previous to X-51 there had always been this question, can an air-breathing hypersonic engine truly produce more thrust than drag? Even after NASA's flight of X-43, they did two flights for ten seconds each, there were some doubters that said well, it only flew for ten seconds, we don't really know for sure. X-51 removed any doubt, any future doubt that a scram jet engine can power a vehicle at hypersonic speeds and accelerate it through the atmosphere.

Like any good flight test, X-51 was successful but also raised some questions. That 200 second flight wasn't the full expected flight duration. It was supposed to fly for 300 seconds. It didn't reach that. X-51 was supposed to reach Mach 6. It seems to have hit about Mach 5, and then there were some on-board problems.

Within about 30 seconds of that flight the engineers working X-51 had a pretty good sense of what had gone wrong. It looks like they lost a nozzle seal. The nozzle seal basically, and this is by the way all preliminary. And anyone in the press don't quote me on this as a definitive answer, but the facts seem to match the data that they saw. There's what's called a rope seal that connects the nozzle to the main fuselage of X-51. It looks like that gave out very early on in the flight which means there was flow leaking out the side of the nozzle. That produced a bit of a yaw, excess drag, excess drag meant it didn't quite accelerate, they were losing some thrust along the way. They also had some internal leakage of the flow passage inside the vehicle. If they watched the temperatures, they could see high temperature creeping in towards the front of the vehicle, probably led to the failure at 200 seconds.

So not entirely success. I've been giving them an A- because they demonstrated the important things. We got a lot of good data. And frankly, they're all set for the next flight.

But here was the really exciting thing about that failure. You're saying why would a failure be exciting? The engine actually worked better in flight than it did on the ground.

Remember that cover of Aviation Week? That was a photograph taken in a NASA Langley wind tunnel where the engine of X-51 was tested. It worked better in the air. In fact if it hadn't worked better in the air than it did on the ground it most likely would have been a complete failure. Engine pressures were about 15 percent higher than was measured on the ground. So not only did the engine work, it worked better than expected, and that's always a good thing to see.

I pointed out X-51 was a milestone, but it wasn't the first time we had flown the scram jet engine. The idea for a scram jet engine dates back to the late 1950s. Two researchers at the precursor of NACA, the old National Advisory Committee, wrote a paper that I think of as the first paper that kind of maps out where everything high speed propulsion can go. They were called Webber and McKay. In 1958 they wrote a paper which essentially looked at what happens when you try to fly a conventional ram jet engine at higher, supersonic speeds. Conventional ram jets will run up to about 4.5 times the speed of sound before they stop working. They actually worked out the basic physics, Webber and McKay worked out the basic physics of high speed air breathing flight, and they really got it all right.

Jump ahead. 1968 as part of the X-15 program, there were actually plans to fly a hypersonic engine, a scram jet engine, ten years after Webber and McKay's concept. We know today that that scram jet engine would not have worked. We know it wouldn't have worked because NASA actually about ten years ago funded some Russians to fly a scram jet engine off of a missile in Siberia. That Russian engine looked amusingly and amazingly like the engine that was going to fly on X-15 and it didn't work. There was a lot of fun speculation about where the Russians got the design for their engine, by the way, but it was almost an exact match to the thing we were going to fly underneath the X-15. However those X-15 flights, they never actually flew a working engine but they did fly some dummy engines and we learned some really neat shock physics from those dummy engine flights.

On one of those flights the shock wave off the nose of the X-15 actually interacted with a pylon that was holding the dummy engine, burned right through the pylon. From that we learned a lot about what happens when shock waves hit other shock waves and the intense heating that can result.

Upper right hand corner, you see that the High Shot program from Australia that Dick had mentioned, that I think was a phenomenal accomplishment. This was a small university group working on a shoestring budget and by some arguments they were the first to actually fly a supersonic combustion ram jet.

A lot of folks will tell you that it wasn't a real supersonic combustion ram jet. It wasn't a real scram jet because they didn't produce thrust greater than drag. Well that wasn't in their design because of the way they operated their engine. What they were trying to show was that they could have supersonic combustion inside an engine at hypersonic speeds, and by that criteria they succeeded incredibly well.

Lower right hand side is NASA's X-43. X-43 is also a milestone. They flew at first Mach 7 and later at Mach 10, two hypersonic flights. They had a fully engine airframe integrated configuration, a little bit different than High Shot. High Shot was basically flying an engine all by itself on top of a missile. On X-43 you had the makings of a hypersonic vehicle. It was powered by hydrogen fuel. In each of those two flights they ran their engine for a total of about ten seconds each.

Why ten seconds? For two reasons. Because of the way they stored their hydrogen they only had about ten seconds worth of fuel on board the vehicle. But more importantly, those engines, the engines on X-43 were not thermally balanced. In other words, they didn't have active cooling.

So if they'd run the engines for much longer than ten seconds, the engines would have melted and basically used a lot of copper to absorb the heat from the combustion system. And because they were only running it for ten seconds, the copper was able to absorb the heat. If they had run it any longer, the copper would have melted.

So that X-43 was a very very significant contribution. I argue it leads directly into the X-51 program, and X-51 takes that same notion of hypersonic flight, integrated system, but now does so with a more practical military fuel and does it with a thermally balanced engine that can run for much longer periods of time.

I just want to emphasize, a lot of the debate that we have in hypersonics is the choice of fuel. This is a plot of the various fuels that you might consider using in a high speed system. The very top of the plot is liquid hydrogen and slush hydrogen which is a combination of liquid and solid hydrogen that was envisioned for the National Aerospace Plan Program that Dick mentioned.

Hydrogen was often seen as the fuel of choice for high speed flight because it burns very very rapidly. And hydrogen has lots of energy per unit mass. So if I give you a kilogram of hydrogen it has about three times the energy available as kilogram of a traditional jet fuel. But there's a problem with hydrogen. It's not very dense. The storage density of hydrogen is about one-quarter the storage density of a hydrocarbon fuel like a jet fuel. So if you want to build a vehicle that runs on hydrogen fuel, you need a really big tank in order to store that fuel. Hydrogen has to be stored as a very very cold liquid so it gives you a lot of handling problems. So from a military standpoint a hydrocarbon fuel is a much more attractive fuel and that's what X-51 did for us.

Dick talked about the tyranny of distance and what hypersonic does for you. One of the interesting features of a hypersonic vehicle is it can combine some of the benefits of speed and range. This is a plot of range versus cruise Mach number. It's very well known if you want to fly a long distance the way to do it is at very very low speed. Burt Rutan has built two airplanes now that have circled the world without refueling, and he did so at very very low speed. The first was his Voyager airplane that's hanging in the Air and Space Museum. Then he did his high speed version which was a jet version, and that flew at a slightly higher speed but still a very very low speed airplane.

As you crank up your Mach number, your range will always decrease for a vehicle. But an interesting thing happens at high speed. When you start entering the hypersonic range you start to pick up some propulsion efficiencies which means that a hypersonic, the range of a hypersonic vehicle might be comparable to the range of a supersonic vehicle. And yet it gets you there much faster.

So if your sole goal is maximum range, I'd be the first to tell you that a hypersonic option is not the option you want to go with. If I want to circle the planet, I want to do it at low speed. But if I want a combination of reasonable range but very very high speed for short flights, then hypersonics is a very very attractive solution.

Let me talk about some of the results we get when we put those together. If you do your best estimate for the range of a hypersonic vehicle, you make your best assumption about the aerodynamic performance of a hypersonic aircraft, make your most optimistic assumption about how its engine will operate, make your most optimistic assumption about the structural efficiency of that vehicle, you come to the conclusion that the maximum distance you can fly at hypersonic speeds is about halfway around the planet.

Now you might say hey, that sounds great. Well, folks who talk about hypersonic cruisers and cruisers that would reach all the way around the planet usually say they need to go all the way around the world. If I want to perform some mission, an ISR mission, deliver a payload at some point that's completely around the world, then what I really need to do is fly all the way around the world, I need to do my mission and turn around and come on home. You can't do that with a hypersonic system. You don't have enough range.

The advocates of these sorts of systems will tell you there's an easy solution. You perform your mission, then you refuel and you come home. That raises a lot of problems.

Problem number one is, a vehicle that's designed to fly at Mach 10 or even Mach 6 or Mach 7 isn't going to handle really well at Mach .7 when you try to refuel it. It's going to be very very difficult to do that refueling.

Question: You have a global network of bases and launch it from there.

Lewis: That's the other option, which is you've got a global network. I always pose the question, great, if I've got a global network of tankers, why do I need the hypersonic system that takes off from CONUS to get there? Why don't I just—

Question: Not tankers. Bases.

Lewis: And that's the answer. You preposition the hypersonic system. Exactly right. You don't try to do the global reach. You don't try to take off from CONUS to reach around the world. For some reason whenever we do these studies people want to fly to Australia. I'm not sure what you Australians have done to us. [Laughter]. But you're exactly right. These vehicles make a lot of sense for reconnaissance and strike in theater. If you try to push it to global reach, they don't make a lot of sense. That's my second bullet.

Let me jump a little bit to air-breathing launchers and why they're so attractive. If I can build a technology for hypersonic systems from the weapons applications, I can take that same technology eventually and apply it to access to space. That gives us some interesting capabilities. To explain that, let me step back and talk about the way we reach space today. Think about a space shuttle on the launch pad. About 80 percent of the mass of a space shuttle launch pad is attributable to oxidizer or the tanks that hold that oxidizer. The space shuttle has a big external tank in the center of its stack. Most of the mass in that external tank is oxidizer.

Why are you carrying oxidizer with you on your way up to orbit? We're swimming in a sea of oxygen. That's what a hypersonic system might enable, the ability to swallow oxygen as you're flying up into space so you don't have to carry it with you.

That results in a vehicle that will probably have a heavier unfueled weight but a much lighter fueled weight which gives you ultimately a better system. It also can lead to a launch vehicle that operates more like an airplane and less like a rocket.

Now there's some important traits. Hypersonic vehicles operating longer in the atmosphere than a traditional rocket. That means you've got draft, so you're losing energy. But it can use lift to help itself get up to orbit which means you lose less energy to gravity, and there's an interesting trade there that in most cases benefits the air-breathing system.

Here's a simple plot that shows you, and these are two different plots that show you two different concepts for air-breathing systems. The Y axis is the weight of the vehicle and the X axis is the fraction of orbital speed.

The important point here is that for the slid lines that refer to air-breathing systems, in most cases up to a given speed the air-breathing solution gets you much more weight to get in speed than the rocket solution. And imply because you're not carrying oxygen with you for most of the flight, so you save on the weight of the oxygen and you save on the tanks that would carry that oxygen.

Let me close up with a little technology evaluation. This is hypersonics according to Lewis. Where are we today?

I'd argue weapons class, very very promising. We've got some exciting programs. X-51, HiFly, that are taking us directly to products that we can see transitioning into practical weapon systems.

Access to space, very long term. We've got to develop the science and the technology based on our weapons, but still very promising.

Prompt Global Strike, also within the realm of the possible. Unpowered lifting systems like HTV-2 have a lot of operational intelligence behind them.

Aircraft. In some cases aircraft are some of the most difficult issues of all because they can operate the longest in the atmosphere, and has to deal with the hypersonic regime longer than even a launch vehicle.

Recce strike is possible and again very attractive. I always cite the old V-21 drone example of a high speed unmanned reconnaissance system that you might envision ramping up the Mach scale.

Transatmospheric flight for global reach, frankly, less attractive for the reasons that I mentioned.

Where do we stand on the research? Here's a laundry list. It's intended as an eye chart to show you all the unsolved problems that we have in hypersonics. There are a lot of them. There are some very basic questions about the flow around a hypersonic vehicle that we still can't answer today. Things we've learned, things we understand, but still some big questions. I'll give you one of my favorite questions.

We don't understand fully the state of the air right in the vicinity of the vehicle as it's moving quickly over the vehicle. The boundary line that defines the region where viscous forces dominate on the surface of a vehicle is still very poorly understood at high speed flight.

So where do we go from here?

I would propose that we need to follow a logical progression. The first step, we need to be expanding the hypersonic envelope with minutes-long flights. Things like X-51 and High Fly as well. Building on the experiences that we've had with the first flight, but continuing that sort of progression. Keeping in mind the notion of flight test. The X-51 is still a flight test vehicle which means we have to be able to fail. We have to be able to fly things and break them and fail them.

Step two. Bring in some of the platform elements to make things more practical. Translate these directly into practical weapon systems, for example. Practical recce strike aircraft.

Step three. Looking at more propulsion options. Right now what we've flown are scram jet systems that have been powered, that have gotten up to their speed with rocket boosters. Dick mentioned the X-51 used a solid rocket motor to get up to its air-breathing speed. Well, obviously for some of the airplane applications that's not the best way to do it. We need to be exploring some of those.

Right now in the hypersonic community you can almost say that there's a religious fervor that relates to the types of combined engines that might get us up to speed. There is one school of thought that says you want to use a turbine engine to get up to hypersonic speeds and transition to a scram jet. And then there's a school of thought that says you want to use a rocket system that gets you up to speed. I bill myself as an agnostic. I don't know what the best engine is, but I know we need to explore that.

In parallel, there are still fundamental questions that must be answered. And I'm glad to tell you we've got some programs in place today that are exploring these fundamental problems. The Air Force Office of Scientific Research, for example, has a very robust program exploring some of the basic physics of high speed flight. They just kicked of a program with universities just last year that identifies some of those issues.

I program that I'll get to in a second called High Fire, I'm very proud of. It's a joint US-Australian program, again, looking at some of the fundamental issues.

But to do all of this, there are a couple of key points. One is we need to have adaptive recoverable flight platforms to do these tests. We need to protect ground T&E infrastructure. Right now we're at risk of losing some of our most vital hypersonic test facilities because we've got folks who say well there are no requirements, there are no acquisition programs. Why do we need these high speed tunnels? Well we need them because we need to make the investments today in the basic research and in defining the physics that will lead us to the weapons systems of tomorrow.

I mentioned the High Fire program. This is an example of how international cooperation works best. This is a program that we put in place. It's joint between the United States Air Force and the Australian DSTO which is their Defense Science Technology Office. A collaborative effort where we basically go out to the outback of Woomera, which is one of the neatest places in the world to do flight testing, and we launch a series of flight tests. The first High Fire flights have already flown. The idea is basic research, basic science, launch early, launch often. If it breaks, you fly again. And we've got buy-in. NASA Aeronautics is investing in the program. We've got several companies that are actually instead of getting paid, investing their own dollars to do this sort of work. And it's got off-ramps that ties directly into some of the weapons programs that we talked about earlier.

Now let me close on a down note. Dick mentioned interest in other countries. Well what about interest from the basic research standpoint? In October, the AIAA sponsored the International Hypersonics Meeting. Let me tell you some interesting facts about that meeting.

Half of the papers that were submitted to that conference came from mainland China. That should be a sobering thought.

Now of those half, only about half of the presenters actually showed up when the conference finally kicked off. That was kind of irritating. But 18 months previously, the previous time we had the hypersonics meeting, only about a third of the papers were from mainland China and none of the presenters showed up. More importantly, almost all those presenters at that hypersonics meeting from mainland China were intimately familiar with the literature from the West. They knew all of our papers. They had read all our publications.

The previous viewgraph was a couple of emails that I get in my daily job as a university professor. There are three emails from Iran, students in Iran who wanted to come to the United States and study hypersonics. I get about one of those a month. Last month I actually got a telephone call. It was a fellow, at a university in Tehran. He wanted to come and study and he had this great idea for a hypersonic engine which was stolen directly out of the Russian literature. He obviously thought I was stupid and didn't read the Russian literature. But he was presenting this idea and he wanted to come work with me on this.

I pose to you the following question. Why is there such a strong interest in a country like Iran in sending their students to the United States to study basic hypersonic flight?

Summing up, my last viewgraph. Actually my penultimate viewgraph.

I agree with Dick Hallion, that hypersonic flight has been a realistic concept for more than 60 years. Weapons hold a tremendous amount of promise, and we've seen some very important first steps including the first X-51 flight.

We've had some missteps. I think a lot of them relate to the idea of global hypersonic cruisers. They don't make a lot of sense but they shouldn't be, the concept defines the field. Weapons do make sense and ultimately access to space makes sense. In fact access to space might be our ultimately solution to orbit.

Let me close with two quotes. The first is one of my favorites from the UK Air Chief Sir Jock Stirrup. In 2005 at a meeting at the Royal United Services Institute that both Dick and I attended, Sir Jock Stirrup stood up and declared that in modern warfare speed is the critical issue. I submit to you that hypersonics is one of the solutions that gets us the speed.

Let me also close with another quote and this comes from Randy Bolen. Randy was the Chief Engineers in the X-43A and actually he's worked very extensively on the X-51, bringing the expertise from that X-43 program and translating it directly into our Air Force program.

After the second flight of X-43 when they hit almost Mach 10, Randy was at a post-flight press conference and a reporter stood up and asked him what was the most important thing he learned from X-43? He had what I thought was a very profound quote. He said, "We learned it's not that hard." After 50 years of research in the field we know a lot of the things that are required to get us into the hypersonic flight, everything in the hypersonic flight regime. We know how to do this, and I think X-51 also demonstrates that. It's not that hard.

If it's not that hard for us, it's probably not that hard for other folks as well.

With that, let me open the floor.

Grant: Thank you both. Great job.

[Applause].

Grant: Tremendous. I'd like to just go directly to questions from the floor.

John Tirpak: Gentlemen, I'd like you to assess the climate for pursuing hypersonic vehicles right now, given that the Air Force seems to have ruled out a hypersonic approach to the long range strike system, and that there seems to be a lot of infatuation using Minuteman or Trident as the prompt conventional strike system. Is there really a market for this right now, or are we going to have wait?

Hallion: My feeling is that there is very little enthusiasm for, and I can understand why, there is very little enthusiasm for very large, complex, hypersonic, high risk systems that might be inhabited systems or complex remotely piloted vehicle systems of one sort or another.

I believe, however, that, and the example I would give was a briefing that Mark and I presented down at ACC. I believe that when you show people what can be achieved with weapon approaches, something coming off a pylon or out of a tube, that all of a sudden the scales drop from the eyes.

We went into a meeting with Air Combat Command several years ago and in conversations with their people they were very very concerned about a particular kind of technology they needed to get their mission accomplished. There was not really a weapons technology. And they could not understand why hypersonics might be important to them, when we presented basically a variation almost of this briefing. There was kind of a stunned silence at the end of the presentation and then they realized that this was applicable across the range of missions that they had to undertake, particularly things like SEAD or strike at a distance. So I think actually there is an opportunity here if we pursue this from the achievable and make certain that we are rigorous in stripping out the fanciful.

There was not much enthusiasm in military services for the initial precision munitions and for the initial air-to-air missiles and surface-to-air missiles. When people suddenly realized what could be done with these, and then they had the dramatic impact of the Powers shootdown in 1960, the climate changed.

What I fear here is that this is a technology that's achievable and it's almost of more value to our opponents in terms of cutting our sea lines and air lines of communication, and I would fear a Powers effect here where this is used first against us and then you find yourselves in a terrible catch-up situation, akin to say what happened after the sinking of the Israeli destroyer Eilat, from an anti-shipping missile in 1967.

Lewis: I agree. And John, a couple of elements of your question. Something like an ATV-2, a slender, hypersonic configuration, is actually an interesting alternative to the conventional warhead on an ICBM. It applies a very very different trajectory. The big issue with putting a conventional warhead on an ICBM is how do you convince everyone else that it's conventional and not nuclear? I've always joked, well maybe you paint the missile pink and they believe you. [Laughter].

But if it's an ACV-2 type configuration, it would fly a very very different trajectory, be able to avoid over-flight, it would be maneuverable.

So I think it gives you a politically more tenable solution.

But there's a deeper and I think more profound aspect of the question that you've posed, and I'd say to a certain extent it's a tolerance for investment across the board in advanced science and technology. And there I'll tell you, I think the climate is not as good as it was just a few years ago.

How much attribution is there in this talk?

Grant: I'm afraid we're on the record.

Lewis: Okay. I'll put this in the positive.

I was on the Air Staff of Mike Wynne and Buzz Moseley. They loved this technology. They understood it. Recently I got a phone call from a reporter who had called up Mike Wynne and asked him a profound question. He said, if there was one area of technology he wished he'd invested in more when he was Secretary of the Air Force, what was that? Without skipping a beat he said hypersonics and gave the reporter my name. [Laughter].

General Moseley especially loved the idea of being able to put a high speed weapon on the rail of an existing conventional platform. He got the notion of having a relatively low speed conventional aircraft kind of in the orbit, but when you need it, could shoot the Mach 6, Mach 7, Mach 8 round long distance.

But on that climate, a comment was made to me, someone in the Air Staff recently observed that the Air Force Research Lab shouldn't be investing in any technologies that can't be transitioned within five years. When I hear things like that I basically want to curl up. Hypersonics represents a long term investment. It's one of many technologies that I believe represent a long term investment. And there's no better example of that than the viewgraph that I showed you, that gave you the example of the paper that was first written in 1958. Webber and McKay over 50 years ago basically mapped out the basic physics and it's taken us how many decades before we've ever flown this? Research is an investment. It's a long term investment. We've seen that across the board. I think hypersonics clearly falls in that category. We need to keep fighting for that sort of investment.

Question: Dr. Hallion, I didn't really hear your take on the DARPA HTP program. What was your assessment?

Hallion: My assessment would be similar to Mark's. I think it was a concept that had a great deal of promise. Hopefully we will see this played out and continued. But there was inadequate test and evaluation that went into it before flight. That actually raises a couple of issues. One thing is we have a dreadful term that has gained prominence over the last quarter a century in the test community and that is this term technology demonstrator.

Technology demonstration is something you do in a high school science class. You know exactly what the outcome is going to be. You're teaching a class, and basically there's nothing really coming out of this. We have taken risk out of tests to such an incredible degree that we are afraid to extend ourselves and we look to flight tests as validation, and we have flight test programs now that are based upon three or four or five demonstrations of something.

The example I'll give you was X-43. The first flight of the X-43 failed because a fin came off a booster. It had nothing whatsoever to do with the purposes of the vehicle itself. The second flight worked okay. We almost did not get the third flight. There was the sense that well, we've gotten to this point, we can check that off and move on to something else. It took tremendous pressure from the Air Force, and frankly it took tremendous pressure from Mark Lewis and others to get that third flight which was actually a very significant flight.

This notion of pushing technology forward, we're only going to push technology forward if we have robust and repeatable tests. The example that I give is in the 1950s we had a missile program called the X-7. It was a ram jet powered air-launched vehicle. There was some incredible number of these vehicles flown, I think at least 70, maybe up over 100. But the vehicle gave us a capability to undertake many different kinds of tests, many different kinds of developments.

Under the kind of test environment we have today, I don't see how we would have pursued air-to-air missile systems like Sidewinder or Sparrow or even AMRAAM, which all evinced difficulties during their own programs.

Let's take the most recent flight of the X-51. We had several flight attempts before the X-51 got off on its first flight. Several of those attempts had to be canceled. Not a single one related to the X-51. They related to the B-52 launch aircraft, they related to chase aircraft, they related to range impingement issues, they related to range control issues. All these things in an environment where you have constrained funding and constrained support for programs can work to really hinder and hurt tests. This is not the kind of things we need to have dominant within the test community.

Getting back to the first question, I did have a comment to follow Mark's. The overall environment, I think people, hypersonics among other technology fields, hypersonics has gotten so tarred with this brush of big, complex, unworkable, rat hole investment because people think in terms of these very large vehicles that have relatively little relationship to real world needs. It really worked, I think, to discredit the field.

In the year 2000 when we understood the Scientific Advisory Board's [Why and Whither] study, I remember very well that our going in position on that, and I was one of the panelists, was that it was, as I said in my presentation, it was a make or break moment for hypersonics. We had two very fine officials at that time running the Air Force. We had Secretary Whit Peters, an extraordinary Secretary; and we had the Chief of Staff, Mike Ryan. Mike Ryan was a superb Chief. They basically said okay, what is it? What's really going to happen here with this technology? Is this something we need to invest in? That's why it had the title it did. [Why and Whither] Hypersonics? For the first time the Scientific Advisory Board put a built-in red team on that panel.

When we met we had to test every one of our assumptions and our conclusions against a read team who pushed back and fought us at every stage. Very very rigorously and very responsively. And yet after all that it withstood the challenge. The report that came out strongly endorsed hypersonics and had the unanimous endorsement of all the participants, including the Red Team. And to their very great credit, Whit Peters and Mike Ryan, who I think their previous inclination would probably have been to shut it down pressed on and continued investment.

But that's the kind of mindset that I think to a degree still tends to associate itself. So when you have programs that are ill thought out like Black Swift or which are not executed properly like we saw with HTV, that can only be a bad things because what that does is it furthers this impression that somehow this is not a technology that is worth pursuing or in a time of scarce resources one that we should not precede.

Question: If I can pile on, one of the big frustrations with HTV, when that program first started there were lots of smart folks in the Air Force telling DARPA you need to do more ground testing. Actually there was a big battle and it almost came to the Air Force pulling out of the program because DARPA wasn't going to put in enough ground testing. Finally we convinced them to do ground testing. When they did they found that the computational codes that had been used to design the vehicle missed it entirely. They filled in some data points, did redesign, but they didn't do enough testing, and we don't know the reason the SUV-2 failed it. There are many different possibilities, but I wouldn't be surprised if it turns out that if we had done more ground testing we would have learned more, and that would have been a successful flight.

I'm very happy to report DARPA's got a new program started called Arc Light, and the program manager's a very very smart guy. He's figured out from day one he needs to put it in a wind tunnel and do testing before he flies it.

Question: Is that also hypersonic?

Voice: Actually very similar to HV2 with shorter range, with a Navy application, but some of the same technologies.

Grant: We're going to conclude the formal portion here in just a minute since we've run a little bit over our time. I'll invite some of you if our panelists can stay aft wards to answer questions.

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