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Statement of

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Mr. Chairman and Members of the Subcommittee:

In late May or early June of this year, a B-52 that was designed in the early 1950's will take-off from Edwards Air Force Base in Southern California and head to a test range over the Pacific Ocean. Mounted underneath the starboard wing will be a Pegasus rocket that was designed in the 1980's. Fitted onto the Pegasus in place of the nosecone will be the X-43, a small experimental scramjet (supersonic combustible ramjet)-powered vehicle designed at the Langley Research Center in the mid-1990's. Over the test range, the B-52 will drop the Pegasus, which will fire its rocket engine and accelerate to Mach 7. At that point, if all goes well, explosive bolts will fire and a ram will push the X-43 into free flight. Shortly thereafter, its scramjet will ignite and we will receive combustion data for ten seconds. When its fuel is spent, the X-43 will continue on its flight path before plunging into the Pacific Ocean.

Flight of the X-43 vehicles will be the culmination of over 20 years of scramjet research and the first time a non-rocket engine has powered a vehicle at hypersonic speeds. And while the concept of a scramjet engine has been around for decades – nearly as long as the B-52 that is carrying it to the test range – it has not been technically feasible until now. The talent and vision of the people at our NASA Research Centers are making it feasible, turning visionary possibilities into incredible realities. NASA's job is to envision the future and make it a reality. This is our history and it is our future.

I am confident, even excited about the future we can create. It is incredible and I will describe it to you. Dr. Creedon and I will explain how these exciting possibilities can be made reality through revolutionary technologies we are working on today. But let me be very clear, the aerospace industry is facing serious challenges, our air and space transportation systems are constrained and not meeting the needs of our society, and NASA must transform itself to lead the transition to this new future by managing within the resources provided to us by the American people.

The Importance of Aerospace

First, let me discuss why aerospace is so important. Aerospace is critical to National security, transportation mobility and freedom, and quality of life. Air superiority and the ability to globally deploy our forces are vital to the National interest. The role of air power in winning the Gulf War is a clear reminder of the importance of aircraft in major conflicts. Aviation is a unique, indispensable part of our Nation's transportation system, providing unequaled speed and distance, mobility and freedom of movement for our Nation. Air carriers enplane over 600 million passengers and fly over 600 billion passenger miles, accounting for 25 percent of all individual trips over 500 miles, 50 percent over 1000 miles and 75 percent over 2000 miles. Air freight carries 27 percent of the value of the Nation's exports and imports and is growing at over ten percent annually. Global communications, commerce and tourism have driven international growth in aviation to five to six percent annually, well beyond annual Gross Domestic Product (GDP) growth.

Aviation employs 800,000 Americans in high quality jobs, second only to trucking in the transportation sector. Driven by technology, annual growth in aviation labor productivity over the past 40 years has averaged 4.6 percent, compared to two percent for U.S. industry as a whole. For example, technological advances over the past 40 years, many of them first pioneered by NASA, have enabled a ten-fold improvement in aviation safety, a doubling of fuel efficiency with reductions in emissions per operation, a 50 percent reduction in cost and an order of magnitude reduction in noise.

Aviation manufacturing is a consistent net exporter, adding tens of billions of dollars annually to the Nation's balance of trade. Aviation produces and uses a broad base of technologies—from computing and simulation to advanced materials—supporting the high technology industrial base of the country. Defense aviation provides fast, flexible force projection for the U.S. Our military aircraft are unparalleled globally because they employ the most advanced technology.

Aviation is central to personal freedom, security of the citizenry and the global movement of people and goods in the new economy. Mobility is a prerequisite for freedom. The ability to move freely and efficiently from place to place is a right highly valued by U.S. citizens. Mobility requires transportation that is inherently safe, available on-demand, and affordable. National security and the economic health of the country are heavily dependent on aerospace systems.

The U.S. is the global leader in aviation. From every aspect—technology, products, services, aviation standards and procedures, and National defense—the U.S. sets the mark.

The Aerospace Environment Today

Sustaining our leadership and the National benefits we derive from it is far from assured. Both military aerospace research and development (R&D) and procurement have declined, reducing the "technology pull" from the military sector. In past decades, the primary motivation for advances in aerospace technologies was dominated by military needs. The partnership among NASA, Department of Defense (DoD) and industry rapidly advanced, matured and integrated aerospace technologies. These technologies were then appropriated for commercial use, with great success. Examples of this process abound. The turbine engine introduced on the B-707 was originally designed for military aircraft. The Pratt & Whitney J-57 and the General Electric J-79 engines were also originally developed for military use before leading to commercial derivatives. Beyond this, Boeing's Model 367-80, the "Dash 80," was the prototype for both the KC-135 military tanker and the Boeing 707. In the mid-1960's, the U.S. Air Force initiated work that led to the C-5A military transport. Shortly thereafter, the companies in competition to develop the transport all introduced wide body civil transports – the Boeing 747, McDonnell Douglas DC-10 and the Lockheed L-1011. In an additional significant development, revolutionary fly-by-wire flight controls were developed and first adopted for U.S. military aircraft and the Space Shuttle, and Boeing is now incorporating fly-by-wire into its newest commercial aircraft.

Although the increasingly competitive marketplace demands an accelerating pace of technological innovation, the opportunity for commercial industry to draw on defense-related R&D is decreasing. The military aerospace sector is a much smaller share of the overall aerospace market. Furthermore, recent military spending has been focused more on sustaining the current fleet and less on research and technology. According to the Aerospace Industries Association, in 1971, the military accounted for 55 percent of the overall market and by 1998 it was down to 31 percent. For turbojet engines, the decline is even more dramatic. For example, General Electric Aircraft Engines shifted from 70 percent of their business being military to about 20 percent. And for Pratt & Whitney the situation is very similar.

Furthermore, during the 1950's there were 45 aircraft development programs—during the 1990's there were only six. Far fewer developments with protracted design and acquisition schedules—an 80 percent increase in the development time for major DoD systems from 5.2 years during 1965-69 to 9.3 years during 1990-94—are the result of increasing system complexity and inefficiencies in design, development and manufacturing. With fewer aircraft developments, there are fewer opportunities for the Nation's declining engineering workforce and experience base to develop design and production skills, crucial in light of the increasing system complexity. A sharp decline in the enrollment in our universities' aerospace engineering departments has paralleled this decline in aircraft development programs. The National Science Foundation reported that between 1992 and 1997 enrollment dropped by 25 percent, and while there has been a slight upturn since, this decline further exacerbated the loss of engineering talent.

The market shift from the military to the commercial sector as the major buyer of aerospace products dictates a corresponding shift in R&D strategy. Industry consolidation—from 25 aerospace corporations two decades ago to four today—has contributed to the substantial reduction in the infrastructure that supports aerospace research and technology. R&D in the aerospace industry is typically in the range of three to five percent of sales. Much is focused on evolutionary product development. This contrasts with other industries. For example, in 1999, the pharmaceutical industry invested 10.5 percent of its sales in R&D and the computer industry invested 26.3 percent of sales. Therefore, at NASA, we shifted our technology development toward revolutionary long-term, high-risk civil needs, while maintaining strong partnerships with DoD and industry to ensure the sharing and application of technologies across military and commercial requirements.

Commercial markets are projected to be extremely large over the next decade. These projections are based on the assumption that the current aviation system can support unconstrained growth. But, just as the Nation (and the world) becomes more dependent on moving people and goods faster and more efficiently via air, important obstacles have emerged. The air traffic and airport systems in both the U.S. and overseas are reaching full capacity. Delays are increasing. Experts agree that the congestion and delay problems experienced throughout the U.S. last summer will only get worse unless drastic action is taken. Each year, airlines must add more "padding" to their schedules to maintain on-time performance and the integrity of their scheduling systems, while facing more congestion in the system. At the same time, legitimate concerns over environmental issues (e.g., noise and emissions) are preventing additions to physical capacity. In 1998, airline delays in the U.S. cost industry and passengers $4.5 billion—the equivalent of a 7 percent tax on every dollar collected by all the domestic airlines combined. With demand projected to double over the next decade, NASA estimates, based on a computer model of operations at the Nation's top 64 airports (80 percent of enplanements), that in the absence of change, annual delay costs will grow to $13.8 billion by 2007 and $47.9 billion by 2017. But growth in airport infrastructure that might offset this problem is not likely in the foreseeable future. Several key airports are unable to gain approval for projects to expand infrastructure because they are in non-attainment areas, where National objectives to reduce emissions have not been met. Therefore, we are seeing constraints to growth that could threaten the commercial prospects of our aerospace industry as well as impact the integrity of our transportation system.

Beyond these numbers lies another serious problem. Because of the networked nature of air transportation, as the system gets closer to its capacity limits, it has less flexibility to deal with unexpected but inevitable events. When the system is operating at its limits, an isolated problem within the system, such as a thunderstorm, creates missed connections, severe delays and canceled flights that ripple throughout the system. This loss of flexibility to deal with unexpected events cuts to the heart of the National imperative to have a dependable transportation system.

Today, these problems are even more acute than in the past. Shortfalls in capacity (i.e., airports, air traffic control and vehicle capability) and problems with the environment are not easily addressed in the private sector. The resulting delays, and noise and emissions pollution are not priced in the market place. These problems are termed "externalities" since, unlike other costs, no market participant pays directly for them. As a result, the private sector has inadequate incentives to address the very real problems imposed by aviation on third parties. NASA is making progress in a number of programs, including Aviation Safety and Aviation Systems Capacity that directly address these externalities.

As the long-haul jet transport has in effect become a commodity in the marketplace, commercial operating margins have become razor-thin. And, although the dollar value of the U.S. share of the world aerospace market has been increasing, from $84 billion in the mid-1980's to $114 billion in the late-1990's, the U.S. share of the total market has been markedly declining. From about 70 percent in the mid-1980's, it is about 50 percent today, in part because of the development of new programs overseas. Future market share could decline even further as European competition becomes more aggressive. The Aerospace Industries Association recently announced that the aerospace trade balance is down $14.8 billion, or almost 35 percent from the record high in 1998 of $41 billion. This includes a drop of $6 billion in civil transport exports and a $2 billion increase in the imports of civil transports.

America should not be lulled into the false security that the U.S. will continue to be the leader in aerospace. The Europeans have reached parity in civil transports, and have laid out a potential path to forge ahead of the U.S. The Japanese have shown significant interest in supersonic transports. If we lack the vision, we run the risk of: constraining our ability to meet the demands on our Nation's aviation system, losing the premier position of our civil industry, fighting battles with out-dated technology, and relying on foreign transports for our personal and business travel.

Anyone who doubts this should read the European plan for aeronautics. The following is an excerpt from "European Aeronautics: A Vision for 2020":

> "In 2020, European aeronautics is the world's number one. Its companies are celebrated brands, renowned for the quality of products that are winning more than 50% shares of world markets for aircraft, engines and equipment. They enjoy the considerable benefits flowing from Europe's fully integrated single market, especially the access to efficient capital markets and the ability to recruit from Europe's pool of well educated and trained professionals….For the European aeronautics industry, gradual realization of our ambitious vision must be facilitated by an increase in public funding. European aeronautics has grown and prospered with the support of public funds and this support must continue if we are to achieve our objective of global leadership. Although it is a preliminary estimate, total funding required from all public and private sources over the next 20 years could go beyond 100 billion Euro."

A Vision and Strategy for the Future

Evolutionary technology is not the solution to these problems. The manufacturers and airlines that do not grasp the impact of constrained markets and revolutionary technologies will not survive. This is not meant to be a harsh criticism; it is simply reality. When markets are large and develop constraints, opportunities arise for new companies or companies that can reinvent themselves to utilize new, revolutionary technologies to breakthrough the market barriers and create a new playing field. This is the history of innovation in the United States. It happened when semiconductors replaced vacuum tubes. It happened when airlines replaced railroads. And it will happen in aerospace.

In this environment, NASA's job is not to perpetuate the past and help industry better compete within a constrained market that does not meet National needs. NASA's job is to focus on the National good and enable a future that can continue to meet the needs of our Nation – for transportation, mobility, and security. That means pioneering revolutionary technologies that break through today's market barriers.

But NASA has its own challenges. Like any Government agency, we are responsible to the taxpayer and seek the highest return with the resources we have available. For the past several years, NASA has had to live within a relatively flat budget. This has required hard decisions about research priorities. Since the mid-1990's, the hard decisions we made resulted in the cancellation of the High Speed Research Program, the Advanced Subsonics Technology Program, and, most recently, the Rotorcraft Program.

In the case of High Speed Research, the program was cancelled on its merits. Our largest industrial partner, The Boeing Corporation, concluded that the program was not going to lead to a market-viable design and essentially canceled its investment. The facts are that the program was not addressing one of the most critical issues – supersonic flight over land. Without the technology to reduce the overpressure of the sonic boom, the vehicle would be limited to over water operation, restricting the market and limiting the viability of the aircraft.

Additionally, jet noise reduction for take-off and landing operations was not going to meet the likely Stage 4 noise limits. While the vehicle would beat current Stage 3 limits by a reasonable margin, the vehicle would have to meet the ever more stringent noise rules. Moreover, to achieve the Stage 3 noise levels required large "box car" nozzles to diffuse the jet noise. These nozzles added weight and cost, further limiting the viability of the vehicle.

So, while we were rightfully proud of the progress the program was making, we had to agree with Boeings conclusions. We made the hard decision to cancel the program.

In the case of the Advanced Subsonics Technology Program, we took the program apart, cancelled the nearer-term elements and transitioned the longer-term, public good elements to other programs. In this way, we maintained our efforts in noise reduction, emissions reduction and aviation system capacity improvements.

Most recently we canceled the Rotorcraft Program. It was cancelled because it was too near-term and not sufficiently focused on the advanced concepts that might allow vertical flight to play a critical role in our future air transportation system.

I do not want anyone to conclude from this that these vehicle-classes are not important or that NASA is not pursuing some research in these areas. For example, in the area of supersonics, we have developed a new partnership with DARPA to aggressively address the most significant challenges to sustained supersonic flight over land. Rather than a big, point-design program that characterized the High Speed Research Program, this is a pre-competitive study to address the core issues – efficiency, engine jet noise, sonic boom overpressure, and emissions. The approach is to consider revolutionary technologies that address the fundamental physics of these issues. Once we have a sufficiently explored a broad range of promising technologies, we'll work to develop and fund a more substantial industrial partnership.

There are those that for the health of the industry want us to fund a multi-billion dollar initiative now. This may provide short-term gain to the industry, but that is not NASA's role. And I will not agree to that approach.

Let me be crystal clear – we aren't going to look out the back window of the bus dreaming fond memories of the way things were. Fond memories do not get us to the future. Instead, we will be driving the bus – looking forward, making tough decisions and determining our future.

So, let me describe our strategy for moving forward. First, we will focus on aerospace. We must solve the most critical problems across the board in aerospace – but do it once. We are not going to maintain separate technology efforts, in structures and materials for example, for both aeronautics and space.

Second, we are focusing on the public good – not the maintenance of yesterday's industrial base. When we do this we create new opportunities. For example, NASA is focusing on the mobility of the U.S. people in our Small Aircraft Transportation System (SATS) program. Let me describe SATS. Over 90 percent of the U.S. population lives within 30 miles of an airport. However, most of the airports are small, non-towered and without radar surveillance. We also do not have a very small, smart, safe and efficient fleet of aircraft to use this network of airports. In other words, most of the U.S. airport infrastructure falls outside the modern air transportation system. But this does not have to be the case. Utilizing GPS, a relatively inexpensive suite of electronics and sophisticated software we can turn these "dumb" airports into "smart" airports that would allow them to actually leapfrog into a new era of intelligent, flexible airport facilities. It is also possible to enable a new generation of aircraft that can support this network of intelligent small airports. The first steps down this path are being made by new companies like Eclipse Aviation using NASA technologies to produce inexpensive, safe small jets that will provide air taxi service point-to-point to small airports. The SATS program is focused on enabling this future. So, in focusing and innovating on mobility NASA is creating new opportunities for U.S. industry and we are already seeing new companies being formed. The future is unfolding before us if we choose to look.

Third, we are focusing on revolutionary "leap-frog" technologies – this means integrating radical new technologies such as information technology, nano-technology and biologically-inspired technologies into the traditional aerospace sciences to open up new pathways for innovation. For example, we can now envision a wing that "morphs" its shape, a structure that heals itself, and a control system that senses and controls its own operation down to the molecular level.

Fourth, we will develop a new era of engineering tools and processes. Assured safety, high mission confidence, fast development times, and efficiency in developing revolutionary aerospace systems must become the benchmarks of our future engineering culture. To meet these needs, NASA will develop the tools and system architecture to provide an intuitive, high-confidence, highly-networked engineering design environment. This interactive network will unleash the creative power of teams. Engineers and technologists, in collaboration with all mission or product team members, will redefine the way new vehicles or systems are developed. Designing from atoms into aerospace vehicles, engineering teams will have the ability to accurately understand all key aspects of its systems, its operating environment, and its mission before committing to a single piece of hardware or software. We will drive the design cycle time back down from the nine plus years it takes today to three to four years while increasing the quality of design.

Fifth, we must train the next generation of scientists and engineers. If we are to truly develop an entirely new approach to aerospace engineering and our aerospace transportation systems, we must motivate our students by focusing on the incredible range of innovation and opportunity that is possible and educate them so they can make it reality.

So, let me reiterate – we're not interested in yesterday, we are here to create tomorrow. This is not your father's or your mother's NASA. So, even with a tight budget, we are reinvesting for the future. We have a vision for a 21st Century Aerospace Vehicle to focus our investments on the new functionality and performance enabled by the revolutionary technologies I described. We have augmented our Aviation Capacity Program to focus on new aviation system architectures and the sophisticated modeling and simulation required to support it. And we have consolidated efforts to create a new Computing, Information and Communication Technology Program to focus on more revolutionary information and nano-technologies and their application to aerospace systems.

So, let me now describe what is possible when you focus on the issues of mobility and transportation and apply this new technology paradigm.

Improving and Ultimately Revolutionizing Air Traffic Management – While the addition of new airport infrastructure will be limited and costly, the existing system can be improved by leveraging technology advances in digital communications, precision navigation, and computers. Currently the FAA is replacing aging computer, display and navigation equipment in an effort to modernize the infrastructure upon which the ATC architecture operates. Within that architecture, air traffic controllers need improved computer aids to help them plan and manage air traffic more efficiently. As an example, through the FAA Free Flight Program, the FAA implemented the NASA developed Center-TRACON Automation System (CTAS) at the world's busiest airport, Dallas-Fort Worth, to support daily operations in all weather conditions, 24 hours a day, 7 days a week. CTAS provides computer intelligence and graphical user interfaces to assist air traffic controllers in the efficient management and control of air traffic. The system has allowed a 10 percent increase in landing rate during critical traffic rushes. These improvements have translated into an estimated annual savings of $9M in operations cost.

In fact, NASA and the FAA have a long-standing partnership on air traffic management systems. NASA uses its unique technical expertise and facilities to develop advanced air traffic decision support tools, improve training efficiency and cockpit safety through human factors research, and develop advanced communications, navigation and surveillance systems. The FAA defines system requirements and applies its operational expertise to ensure that the technically advanced airborne and ground equipment, software and procedures developed by NASA are operationally useful, efficient, safe and cost effective. The FAA performs complementary research in the application of new technologies in addressing airborne and ground-based communications, navigation, and surveillance needs and in new decision support tools for strategic management of the system.

Overall, NASA is currently working on a suite of 16 technologies, of which CTAS is a subset, to improve gate-to-gate air traffic management to increase capacity and flexibility and to overcome airport capacity constraints due to weather. Most of these are Decision Support Tools that increase the efficiency of operations within the current infrastructure. And while these tools will add critical capacity and improved flexibility over the next several years, the capacity increases they provide will soon be outstripped by increasing demand. They will not fundamentally solve the capacity crisis, reverse the rise in delays or prevent the disruptive, chaotic behavior of the system.

The remaining technologies that NASA is working on add new capability beyond the current system for the worst delay problem: airport delay in adverse weather. These technologies rely on transitioning to satellite-based surveillance and navigation utilizing the National Airspace System (NAS) implementation of DoD's Global Positioning System (GPS). This implementation is under development but has not yet been achieved for full system operation. A critical element of this deployment is implementing a Wide Area Augmentation System (WAAS) to ensure reliable signal availability over the entire U.S. Realistically, however, it will be several more years before the current issues associated with FAA's required WAAS can be solved. Therefore, this suite of tools will not be available until GPS / WAAS is available.

NASA models indicate that these technologies fully implemented across the system would increase operational capacity by about 30 percent and reduce future predicted delays by about 50 percent. However, we should note that full implementation of the entire suite of technologies is not within the scope of the FAA Free Flight Program.

It is absolutely critical to aggressively pursue this approach in the near term. However, we must go beyond the near-term and achieve transition to a new system that is revolutionary in its scope and capacity. The current system structure, where most passengers and cargo are carried by tens of air carriers through tens of airports, must be revised to permit the continued long-term growth of the system. The thousands of airports distributed across this country are a true National asset that can be tapped with the right technology and the right Air Traffic Management (ATM) system. Also, "airspace," one of the nation's most valuable national resources, is significantly underutilized due to the way it is managed and allocated. Therefore, the airspace architecture of the future must increase the capacity of the Nation's major airports, fully tie together all of our Nation's airports into a more distributed system, and create the freedom to fly in a safe, controlled environment throughout all of the airspace.

One thing that will remain constant is that free market forces will drive the air transportation system. Therefore, the future system architecture must be flexible to respond to various transportation system possibilities, not constrain them. The airline industry must have the flexibility to move and expand operations to be responsive to transportation demands. This is the highest level guiding principle for the future ATM system. The next tier of system requirements are robustness (a system that can safely tolerate equipment failures and events such as severe weather) and scalability (the ATM system automatically scales with the traffic volume). One possibility for achieving scalability would be achieved by building the ATM system into the aircraft, so that as you add aircraft to the fleet the ATM system would automatically scale to accommodate them.

The system will be built on global systems, such as GPS, to allow precision approach to every runway in the Nation without reliance on installing expensive ground-based equipment, such as Instrument Landing Systems at every airport. However, the robustness of the global communication, navigation and surveillance (CNS) systems must be such that the system can tolerate multiple failures and still be safe. This is a significant challenge upon which the new architecture depends.

If we are successful at meeting the challenge of a robust global CNS, then with precise knowledge of position and trajectory known for every aircraft, it will no longer be necessary to restrict flying along predetermined "corridors". Optimal flight paths will be determined in advance and adjusted along the way for weather and other aircraft traffic. This fundamental shift will allow entirely new transportation models to occur. For example, with precision approach to every airport in the U.S. and a new generation of smart, efficient small aircraft, the current trend of small jet aircraft serving small communities in a point-to-point mode could be greatly extended.

Airborne self-separation will become the dominant method of operation. Each aircraft will become capable of coordinating and avoiding traffic. They will have full knowledge of all aircraft in their area and will be able to coordinate through direct digital communication with other aircraft. The pilot will be able to look at his flight path at different scales – from a strategic view of the entire origin to destination route showing other aircraft and weather systems, to a tactical view showing the immediate surroundings and flight path over the next few minutes. Aircraft will employ synthetic vision – which uses advanced sensors, digital terrain databases, accurate geo-positioning, and digital processing – to provide a perfectly clear three dimensional picture of terrain, obstacles, runway, and traffic.

By empowering the pilots to control their own flight paths, the system can operate at maximum efficiency and will change the role of the air traffic controller to more of an airspace manager who will manage the traffic flows and system demand. The air traffic "manager" will have a full three dimensional picture of all aspects of the airspace system. The highly compartmentalized "sectorization" of the airspace would be largely eliminated. Through direct interaction with the three dimensional, high-fidelity representation of the system, they will dynamically reconfigure the airspace based on weather systems, equipment failures, runway outages, or other real-time problems. Intelligent systems will provide expert support to such decision making. This real-time airspace redesign will be uplinked to aircraft to recompute flight trajectories. They will also manage the allocation of scarce resources, such as runways when there are conflicts that cannot be resolved between aircraft directly.

Eventually, the entire system will be fully monitored for faults and other risks. The system will move from a paradigm of being "statistically safe" to real-time knowledge of risk and safety. In addition, with pilots and air traffic managers having full data and situational awareness of the system, a new level of collaboration can occur allowing them to work in close partnership to correct anomalous situations.

The future system will truly be "revolutionary" in scope and performance, but it must also be implemented in a mode that allows continuous safe operations to occur, even in the face of unpredicted events. In designing the future airspace system, a systems engineering approach must be used to define requirements, formulate total operational concepts, evaluate these operational concepts, and then launch goal-oriented technology activities to meet requirements and support the operational concept.

This is an extremely complex problem. The system is dynamic and real-time. At the same time, system integrity is absolutely essential. It can not be turned off and it is highly interconnected. At the present time, we believe it will take a substantial public-private partnership to tackle such a large and difficult problem. And yet the payoff from a capacity, efficiency and safety perspective is absolutely enormous.

A Revolution for Aerospace Vehicles – Revolutionizing the airspace system alone is not enough. An entirely new level of vehicle efficiency, functionality and environmental compatibility must be achieved to meet the challenges of safety, noise, emissions and performance required in this new aviation system. The aircraft of the future will not be built from multiple, mechanically connected parts. The aircraft will have "smart" materials with embedded sensors and actuators. Sensors—like the "nerves" of a bird—will measure the pressure over the entire surface of the wing and direct the response of the actuators—the "muscles." These actuators will smoothly change the shape of the wing for optimal flying conditions. The control surface will be integrated with, instead of an appendage of, the wing, as they are today. Intelligent systems made of these smart sensors, micro processors, and adaptive control systems will enable vehicles to monitor their own performance, their environment, and their human operators in order to avoid crashes, mishaps, and incidents. Distributed as a network throughout the structure they will provide the means for embedding a "nervous system" in the structure and stimulating it to create physical response and even change shape. They will also serve as the means for sensing any damage or impending failure long before it becomes a problem.

These future structures rely on an emerging technology that builds the systems from the molecular, or nano-scale—known as nanotechnology. Revolutionary carbon nanotubes have the promise to be 100 times stronger than steel and only 1/6 the weight. We are at the leading-edge of this technology, transitioning from fundamental physics to building actual macroscopic materials. Much work remains to be accomplished. If we are successful, an aircraft made from this material could weigh as little as half a conventional aircraft manufactured with today's materials and be extremely flexible allowing the wing to re-form to optimal shapes, remain extremely resistant to damage, and potentially "self-heal." The high strength-to-weight ratio of these nano-materials could enable new vehicle designs that can withstand crashes and protect the passengers against injury.

The application of high temperature nano-scale materials to aircraft engines may be equally dramatic. Through successful application of these advanced lightweight materials in combination with intelligent flow control and active cooling, thrust-to-weight ratio increases of up to 50 percent and fuel savings of 25 percent are possible for conventional engines. Further advances in integrating these technologies might result in novel engine concepts that simplify the highly, complex rotating turbomachinery. Other future concepts include alternative combustion approaches and the potential to move toward hybrid engines. Combined with intelligent engine control capability, such approaches may enable integrated internal flow management and combustion control. It also has the potential to integrate both the airframe and engine systems for unprecedented efficiency and directional control capability.

To take full advantage of nano-materials, new computational tools using advances in information technology are required. Tools that take advantage of high-speed computing will enable us to develop large-scale models and simulations for the next generation of vehicles. High-fidelity, collaborative, engineering environments with human interfaces will enable industry to accurately simulate an entire product life cycle, dramatically cutting development costs and schedules. The increasing performance demands and system complexity require new tools to adequately predict the risk and life cycle costs of new aircraft. New computing techniques and capabilities can be exploited to develop robust designs by capturing knowledge and identifying trends to anticipate problems and develop solutions during design rather than after development. These simulations require tools that deal with the increasing complexity of future systems and could offset the diminishing design team experience base in this country. No longer will we design the engine and airframe independently, but rather the computational tools could allow fully integrated vehicle-engine design, integrated health management, and management of the total vehicle air flow both inside the engine and outside the aircraft. These new integrated propulsion and vehicle technology advancements could not only optimize subsonic flight regimes, with twice the thrust-to-weight ratios, but also enable sustained supersonic flight with minimal impact due to sonic booms or other environmental concerns for both civilian and military applications.

In the very long term, comparable advances in electrical energy storage and generation technology, such as fuel cells, could completely change the manner in which we propel aircraft. Future aircraft might be powered entirely electrically. In one concept, thrust may be produced by a fan driven by highly efficient, compact electric motors powered by advanced hydrogen-oxygen fuel cells. However, several significant technological issues must still be resolved to use hydrogen as a fuel, such as efficient generation and storage of hydrogen fuel and an adequate infrastructure necessary for delivering the fuel to vehicles. Success in this effort could end the Nation's dependence on foreign sources of energy for transportation. Revolutionary technologies such as these are prime areas for significant university involvement.

If we are successful, what will the vehicle of the 21st Century look like? It will be radically different from the commercial transport of today whose basic configuration has not changed since the introduction of the Boeing 707 and turbojet engines in the late 1950's. The design flexibility that the revolution in materials and computing technologies provides could enable aircraft whose shape could change to meet a range of performance requirements, for example, range, maneuverability and radar cross-section. With new fuel cell power systems, zero emissions may be possible, and the only noise would be that generated by the air flowing over the vehicle. The wing shape may be changed during flight to control the vehicle, eliminating the need for flaps and conventional control surfaces and their associated drag, weight and complexity. These aircraft could be flown in an air transportation system with unparalleled safety that allows hassle-free, on-demand travel to any location. The beneficial variations are potentially limitless—truly revolutionizing air vehicles, not only commercial and military aircraft, but also personal air vehicles and the utilization of more of the 5400 airports thus providing service to small communities and rural regions that today do not have easy access to air travel.

The NASA Challenge

So, now I return to where I started. NASA's job is to envision the future and make it a reality – that is, to make the possible feasible. This is our history and our mission. It is about America's future. The vision I described is possible and we at NASA are focusing our technology program on it.

We take this very seriously – we believe it is our responsibility and will do everything within the resources we are allocated to make it happen. I'm not here to claim this is easy or without risk. But the American people expect NASA to take that risk and be pioneers.

We are taking the following actions. **We must partner with the FAA and the Department of Transportation to improve and ultimately revolutionize air traffic management –** NASA is a key partner with the FAA in the future of the air transportation system. Through the unique talents and history of the Agency, we have become the National leader for research and technology for air traffic management. NASA is prepared to continue this leadership and to be a catalyst for positive change. We will also ensure a smooth hand-off through product development and certification. We will work with the FAA to get the maximum capacity out of the current system. We believe it is absolutely essential that the Nation take a long-term perspective and begin now to enable the high capacity, distributed system we need for the future. Within the next few weeks, FAA Administrator Jane Garvey and I will reaffirm this partnership in a joint letter to Secretary of Transportation Norm Mineta, who is providing bold leadership in addressing the challenge.

We must invest our available resources in the revolutionary technologies that will enable this vision for aerospace vehicles – The government's role is not to subsidize industry. However, it is unreasonable to expect the private sector to make the necessary high-risk, long-term, decadal, investments to achieve the vision. Government will need to reinvest existing evolutionary aeronautics research and technology resources in the basic research necessary to enable a 21st Century aerospace vehicle. Government aerospace research will focus on public good and leap-frog technologies.

We must strengthen our public-private partnership – The reinvestment of evolutionary technologies to revolutionary technologies results in significant changes in NASA and will cause disruptions in our current partnerships. Therefore, we must restructure our partnerships to ensure appropriate cooperation and technology transfer. This is imperative if we are solve the problems, remove the constraints to growth and break through current market barriers.

We must form partnerships with academia and the entrepreneurial sector to reverse the decline in expertise – There is a looming crisis in U.S. expertise—from relatively inexperienced design teams to reductions in research and development to reduced enrollments at universities. Leadership is required to reverse this trend. We, in partnership with the academic community, must begin developing a new generation of scientists and engineers that blend traditional competencies, such as aerodynamics, material and structures, and guidance and controls, with the emerging competencies in nanotechnology, biotechnology and information technology. We must also develop the design tools and environments that will allow us to integrate fewer and more specialized scientists and engineers into effective teams capable of designing highly complex integrated aerospace systems. Very soon, we will establish several university engineering research centers to provide the environment and learning required for this next generation to be ready.

We must identify the National facilities that support this vision and eliminate the rest – Over the past several years many reviews have been performed relative to our National aeronautical facilities. There have been closures and changes. However, more needs to be done to avoid the perpetuation of marginal facilities through small, evolutionary change. We are optimistic that looking to the future and a revolutionary vision will provide the framework necessary to define the facilities, new and existing, integrated together with computational tools in virtual space will enable a new era in aerospace.

Thank you, Mr. Chairman and members of the Subcommittee. I commend you for taking on this issue, and appreciate the opportunity to testify today and describe our vision and the actions we are taking for the future of this Nation in aerospace technology.