Remarks by
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New Directions in Mechanical and Aerospace Engineering
Princeton University
April 20, 2001

Good afternoon. Thank you Professor Jahn…

As we celebrate 50 years of Graduate Education in Aerospace Studies here at Princeton, I'm reminded of a prediction made by Neil McElroy, who was Secretary of Defense in 1958 – the year NASA was founded.

Secretary McElroy said, "In the space age, man will be able to go around the world in two hours. One hour for flying, and the other to get to the airport."

It does seem as if our airports today have become three big parking lots. One for the planes, one for the cars, and one for the passengers trying to get to the planes and the cars.

Today, I want to talk about two subjects: technology and education. To those of you here today, these subjects are likely thought of as one in-in-the-same. But today, too few people in this country think that way, and that is a major problem.

Anyone who knows me – or has listened to me before – can tell you, I am a technology zealot. I believe technology is at the root of our country's economic prominence. We enjoy the world's highest quality of life, largely due to our technological achievements. And I strongly believe our future prosperity, security and assurance of a long, fulfilling life will be built on our country's future technological achievements.

That said, I now want to talk to you about a technology challenge very near and dear to my heart as the NASA Administrator... the future of aeronautics in the country.

Aeronautics is a key to National security, transportation mobility and freedom, and quality of life. Air superiority and the ability to globally deploy our forces are vital to our 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 more than 500 million passengers each year and fly over 500 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 more than 10-percent annually. Global communications, commerce and tourism have driven international growth in aviation to 5 to 6 percent annually, well beyond annual Gross Domestic Product (GDP) growth.

Today, 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 2 percent for U.S. industry as a whole.

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 is central to our personal freedom, security and the global movement of people and goods in the new economy.

For Americans, mobility is synonymous with 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.

Likewise, the national security and the economic health of our country are heavily dependent on aerospace systems. Defense aviation provides a fast, flexible force projection for America. It is unparalleled globally because it employs the most advanced technology.

We are approaching the 100th anniversary of the Wright brothers historic first flight. And, during the past century the world has been dramatically changed by air travel. It is not nearly as big as it used to be. Also, during the past century we have seen the disappearance of sailing ships and the emergence of rocket ships.

However, if we standby and do nothing, early in this century we may witness the demise of the U.S. aircraft industry and the legacy of Kitty Hawk.

Since 1985 the U.S. share of the world commercial transport market has decreased from about 70-percent to about 50-percent today ...

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.... as a result of strong foreign competition, backed by strong support of foreign governments.

According to the Aerospace Industries Association, the U.S. aerospace industry's international trade surplus plunged, last year, by $10.7 billion to $26.7 billion – a decline of 29 percent from the previous year.

Civil transports – a traditional mainstay of the American aerospace industry – accounted for the bulk of the decline with exports falling by $6 billion, while imports rose by $2 billion.

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I don't know about you but this sends chills up my spine. Do you want to fly planes with foreign labels?

Until the end of the Cold War major advances in aircraft technology were driven by military needs. Performance is the key to "safety" in a combat environment, while the commercial world demands reliability first. As such, major technological leaps generally came out of military programs and worked their way into civilian aircraft.

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, the B-707 airframe was developed jointly for a commercial transport and for a military tanker.

The DC-10, L-1011, and B-747 were developed from research into wide-body aircraft, intended for the C-5A military transport.

In an additional significant development, revolutionary fly-by-wire flight controls were developed and first adopted for U.S. military aircraft, and Boeing is now incorporating fly-by-wire into its newest commercial aircraft.

However, the military market is becoming a smaller portion of the total market.

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In 1971, the military accounted for 55 percent of the overall market and by 1997 it was down to 34 percent.

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For turbojet engines, the decline is even more dramatic.

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The sale of engines and parts has dropped from 56-percent of the total market in 1984 to 22 percent by 1998 with a projected decline to 11 percent this decade.

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.

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As we move into the 2nd century of flight, civil aviation will have to carry more of the load for developing and introducing new technology to keep us secure and economically strong.

We need to recreate the spirit of innovation and excitement of the early days of aviation. And NASA intends to lead the way.

But a new revolution in air travel is far from assured. Unless we act decisively to overcome major barriers, the future can be one of disintegration and decline.

Future aircraft envisioned by NASA will be far different from today. And they will use far different technology. Aircraft will be much "smarter", more adaptive and self-reliant.

At NASA we are beginning to look to birds for inspiration to develop the next generation of aircraft. Clearly, not as a "blueprint" but as an operational model. Consider our national bird, the eagle.

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The eagle can morph and rotate its wings in three dimensions.

It has the talent to control the air flow over its wings by moving the feathers on its wingtips.

They are much more efficient than airplanes that have separate flaps and rigid, pivoting tail surfaces.

The eagle also has a fully integrated aerodynamic and propulsion systems.

The eagle is made from self-sensing, and self-healing materials.

Its skin, muscle and organs have a nervous system that detects fatigue, injury or damage and signal the brain.

The eagle is designed to survive.

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We want future aircraft to be more like eagles than conventional aircraft.

They will have continuously deformable wings for optimal shape control during take-off, cruise and landing.

The surface of the entire vehicle may be covered with tiny sensors and actuators to control the air flow for minimal drag.

And, the total air flow over the vehicle and through the propulsion systems will be integrated and managed for maximum efficiency, agility and control.

The wings and the body will be integrated for exceptional strength and light weight.

And, the wings, body and tail will work in perfect harmony to control aerodynamic lift and thrust and balance it against the force of gravity. It will instantly adapt to variable loads.

The materials we make them from will have embedded sensors networked into a vehicle "health management" system -- like the eagles nervous system -- to detect any damage before it becomes serious; and the materials will be self-healing.

Such an aircraft would be very safe -- designed to survive.

Clearly we are not ready to build such a vehicle, but we do have a clear vision........

(Play "morphing" video with voice over)

The key to building the aerospace vehicles of the future is not to in today's technology. It lies in emerging technology: information technology, biotechnology and nanotechnology.

Today NASA is working on revolutionary new composite materials that will use fibers made from carbon nanotubes.

Nanotubes are a molecular form of carbon that looks like a long, slender "chicken-wire" tube. They are 100 times stronger than steel and only 1/6 the weight -- it is the strongest material known.

NASA studies predict that an aircraft or reusable launch vehicle made from this material would weigh less than half of a vehicle made from the best available composite material today, if we are successful.

Further, this material should be able to bend 10 times more than any current aerospace material without damage. They should, hopefully, enable wings and control surfaces to deform to aerodynamically optimal shape during take-off, landing and cruise.

High temperature nano-scale materials should similarly reduce the weight of engines to as little as half their current weight, and also provide for an integral "health management" system.

Temperatures, pressures, vibrations could be continuously monitored and analyzed. Unique performance characteristics could then be automatically developed for each engine to continually operate it as efficiently as possible, and very safely.

Long before a part failed, the problem would be detected and protective maintenance scheduled.

The airflow over the airframe would also be integrated with distributed, vectored thrust from the engines for optimal stability, control and safety.

Self-sensing, self repairing...is it fantasy?

It may be closer than you think. Recently, a front-page newspaper article appeared featuring self-repairing materials.

Researchers embedded microscopic capsules containing material that interacts with air. When the capsules are broken they initiate a reaction that repairs damage. It is a polymeric reaction capable of stopping cuts or cracks before they become serious.

We anticipate within 10-to-15-years, we should be able to build self-sensing, self-repairing, self-adaptive systems.

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.

Inside the cockpit compartment, the pilot will see everything around the aircraft on a 3D display that displays local weather, accentuates obstacles, shows all near-by aircraft and identifies the safest flight path.

On-board, a clear air turbulence sensor will use lasers to detect unsteady air well ahead of the aircraft to assure a smooth ride.

When approaching a major airport the lingering vortices that were shed from the wingtips of larger aircraft and which can upset a smaller one, will be easily avoided.

To achieve this level of intelligence in an aircraft we will again look to nature. What if we could mimic biology as one alternative to traditional technology?

As President John F. Kennedy said in 1963, "… man is still the most extraordinary computer of all."

It is difficult to precisely compare the performance of today's human brain with that of today's silicon-based computers, but it is estimated that the human brain operates 100-to-1,000-times faster than the fastest silicon-based computers. However, rather than consuming a gigawatt of electricity for this breathtaking speed, the human brain consumes only watts.

The brain works so well because of the way it is constructed. Each neuron in the brain is about 1 million times slower than the fastest transistor, but we have about 10-billion neurons in the brain.

We "learn" by connecting intricate networks among these neurons. Each neuron can be connected to as many as 10-thousand other neurons, and these connections can change as the brain develops and learns.

Also, information is not confined to a single network but distributed among the brain's vast "network of networks".

That is why a damaged brain can still function at near full capacity. It is "damage tolerant" -- information can be reconstructed from other undamaged "networks".

This is the technology that will enable us to build the aerospace vehicles – and the spacecraft – of the future. This why NASA has significantly increased our strategic investment in nanotechnology, biotechnology and information technology.

This is the future I see for aviation in America. It is the one we need to keep us economically strong, secure and assure we lead the second century of aviation just as dominantly as we did the first.

But, leadership is not built out of technology. Leadership means people -- well educated, highly motivated scientists and engineers, who see the future before them and are committed to make it a reality.

For the past two decades, the U.S. college-age population declined by more than 21 percent – from 21.6 million in 1980 to 17 million in the year 2000. This has been paralleled by a corresponding decade-long decline in enrollment and degrees in several fields of natural science and engineering – all critical to our country's future.

<u>I want to get you fired up. The country is depending on you to produce our future aerospace leaders.</u>

To be a bit more specific, the number of students enrolling in <u>undergraduate</u> engineering decreased by 16 percent, and enrollment in science <u>graduate</u> programs fell by 6 percent between 1993 and 1997, while engineering graduate enrollment fell by 2 percent. These have traditionally been areas of growth.

Let me give you another statistic: In 1986, we produced 25,000 thousand electrical engineers and I believe about 10,000 thousand people got a degree in parks, recreation and fitness.

By 1996, we had a crossover point. We produced an equal number of degrees in parks, recreation and fitness to electrical engineers.

I don't know how much recreation we're going to have, or want. But, I do know we won't have it if everything continues to go the way it's going. Everybody's happy today, but what's going to happen?

This is occurring in the face of an expected 50 percent increase in demand for scientists and engineers over the next decade. <u>It's only about the American economy.</u>

Though American universities are still producing the world's best scientists and engineers, the trend is not encouraging. While the number of graduating foreign-born doctoral students has decreased by 15 percent since 1997 – reversing a decade long increase – this is not necessarily a good sign.

It is a sign that foreign schools are improving and that foreign opportunities for undergraduates are improving as well. For a long time, foreign students came to the United States because they did not see an exciting future in their home countries.

So they came to graduate school in the United States in hopes of eventually staying. They are not coming as frequently. And, more of those that do come here are returning home with the expertise gained here. So, we are becoming a diploma factory for countries that are going to compete with us in the future.

I am not telling you this to criticize foreign students for exploiting the great opportunities offered by America. However, I am worried that our own citizens are not exploiting their own opportunities.

One thing we can do to help reverse this trend is to work harder to use the full potential of our total population. What is our workforce made up of....

Although women make up nearly 50 percent of the total workforce, they comprise only 23 percent of the science and engineering workforce. The situation is worse in some specific areas.

Only 9 percent of engineers are women and only 6 percent of aerospace engineers are women. So one simple thing we could do is to convince young girls over the next decade to become engineers -- comparable to their representation in society – and we have almost half the problem solved.

African-Americans, Hispanics, and American Indians comprise less than 3 percent of the workforce in physical and life sciences and in engineering.

And, the trends are also getting worse. Between 1996 and 1997, the number of first-year graduate enrollments of African-Americans in science and engineering fields dropped more than 20 percent. The number of Hispanics entering graduate school in science and engineering declined 18.2 percent during the same period.

Do you realize that only 20 African-American women have received doctorates in physics in the entire history of the United States?

We must make a concerted, national effort to attract more young women and minorities into the S&E pipeline. But, not to just come in, we want the best and the brightest. Merit has to reign. This is not a social problem, this is an economic problem that everyone in the country needs to worry about. This is a national resource yet to be mined.

Technology represents about 50 percent of U.S. economic growth but our production of scientists and engineers is not keeping pace.

Between now and 2009, the United States is expected to create nearly 2 million new jobs in science & engineering fields. This is good.

We also expect to graduate about 2 million students with BS, MS, or PhD degrees in Engineering, Physical Sciences, and Biology/Life Sciences during that same time period. This, too, is good.

However, what is not good... 2-million S&E degreed workers will retire between now and 2009.

Therefore, based on these statistics, the number of new S&E graduates *won't* be adequate to fill new jobs *and* cover anticipated retirements. We will fall short by about 2 million graduates -- the same as the number we will produce.

The shortage of technically skilled workers is a fundamental threat to economic growth of the United States. It hurts "high tech" companies and also hampers the growth of the entire economy by lowering the productivity increases available with latest technology products.

<u>But, the solution to our impending shortage of "high tech" men and women, also lies in today's "high tech" world.</u>

I am sure that most of you in this room that went to college did so on campus -- whether as full-time or part time students. This was the only way to learn.

Today is different. The age of the internet is upon us and every kid in school today is "wired." The teenager of today is on the computer like the teenager of my time was on the telephone. Not just "talking" but surfing for information.

More and more colleges and universities are offering internet based courses – some entire degrees. And, all this less than a decade after the internet was "invented." Actually, it was invented in the 1970s, but the technology only caught up to its potential in the last several years.

And, this is where I believe the big change is going to take place. Today, our interaction over the internet is strictly a 2D monitor. A decade from now it could be an immersive 3D room. The student could be at home at work or just about any place and have the full educational experience of being in the classroom.

Teachers will not be limited to academics, but will include experienced professionals across the country. The traditional university will be expanded to include a "virtual" dimension. They will not be limited to their own on-campus faculty. There may not even be a campus as we know it.

One thing this will do is make graduate education more available to everyone. Education will be a life-long adventure, not merely a episode of our life.

We all must be concerned with education. This is the President's number one priority and he backed it up with a proposed 11 percent increase in the Administration's education budget.

The pace of technology development is moving too fast to be complacent. To stay ahead industry, academia and government need to stay on top of the latest breakthroughs.

Albert Einstein, who had an office here on the Princeton campus, once said, "Imagination is more important than knowledge." I believe we have to bring them together to be successful.

Our future will depend more on advanced technology, not less. And the countries that learn the fastest will economically dominate those that don't.

This is my pact with you. You accept the challenge of educating a new generation of scientists and engineers – young and old – that the country needs…

.... and NASA will accept the challenge of creating great new opportunities in aerospace to spur their imagination and inspired missions to focus their talents.

Together we will make the second century of aviation and space exploration even greater than the first.

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