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SHUTTLE SAFETY

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

SEPTEMBER 6, 2001

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ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

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SHUTTLE SAFETY

THURSDAY, SEPTEMBER 6, 2001

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Subcommittee met, pursuant to notice, at 2:33 p.m. in room SR–253, Russell Senate Office Building, Hon. Ron Wyden, Chairman of the Subcommittee, presiding.

OPENING STATEMENT OF HON. RON WYDEN, U.S. SENATOR FROM OREGON

Senator WYDEN. The Subcommittee will come to order. Today, the Subcommittee is going to examine the issue of Space Shuttle safety. It is a vital issue, and certainly a timely one, as the U.S. Congress and, indeed, our country has an appropriate and important debate about our future budget priorities. I especially want to thank our colleague, Senator Bill Nelson of Florida. He has spoken repeatedly to me about the importance of this hearing. We have scheduled it specifically at his request, and I want to thank him for his leadership on these issues and tell him how pleased I am that he is a Member of our Subcommittee.

I am of the view that Space Shuttle safety is not a luxury that is prioritized only when there is a budget surplus. This is a critical issue for our country. Reasonable people can have differences of opinion with respect to the best way to achieve the safety requirements that are necessary for these space flights, but let it be understood that this Subcommittee is not going to let anything compromise the critical safety needs for this and other programs that are so important to the development of space flight in our country.

Beyond safety, there are a variety of questions that we are going to look at in the months ahead with respect to the future of NASA. These problems include the financial management issues that dog not only the Space Shuttle program but also the International Space Station. In fact, there is a $500 million shortfall in the Station's budget. The mission of the Station has gone from an eight-person crew performing all manner of scientific experiments to a three-person crew whose work is severely limited by the cancellation of several of the Station's planned modules. Clearly, the agency needs to focus on an integrated vision to address these concerns and move forward.

Certainly, when I was a young man, when I had a full head of hair and rugged good looks, I used to watch space flights and think about how these dreams become reality. Crude rockets derived

from war machines sent men into space and to the moon. The idea of a reusable spacecraft that landed on a runway was a dream as well. The original vision for the Shuttle was to serve as a so-called space truck to service a space station such as the one that exists today.

When the Shuttle program took off successfully, almost 2 decades before the Space Station did, NASA did an admirable job of adapting the Shuttle to new purposes. Now, however, the Shuttle does what it was intended to do, deliver components, cargo, and crews to the Station. It is clear that we are going to have to look beyond the technology of today and look at the creative possibilities of tomorrow. In light of that, we have to view every investment made in Shuttle upgrades and operations with a critical eye. Does it enhance the prospects and benefits of our long-term presence in space? We are going to hear today from witnesses who can very capably testify to the need for additional investment in the Shuttle.

I want to especially commend our witnesses for their service to this country. As I was looking over materials that have been prepared by a number of them, I was particularly struck by a comment that was made by Richard Blomberg, who chairs the ASAP, the Aerospace Safety Advisory Panel. He said, and I want to conclude my remarks with this, and I quote here, "Everyone is completely aware that safety is the top priority. Nobody is going to cross the line intentionally. The problem, of course, is that you can get fairly close to the line without knowing it. What price will be paid down the road is not clear, and I don't mean the dollar price." I think that is a very appropriate comment to make.

This Committee is committed to ensuring that this program and the other space programs clearly are on the line that ensures that our citizens who are involved in this work have every possible safety precaution in place. With that, I would like to yield to my friend and colleague, Senator Allen, our Ranking Minority Member.

STATEMENT OF HON. GEORGE ALLEN,
U.S. SENATOR FROM VIRGINIA

Senator ALLEN. Thank you, Mr. Chairman, and thank you for calling this hearing today. I very much appreciate your leadership and that of Senator Nelson and Senator Hutchison as well on this matter that I know is of great concern to all Americans, and particularly in this Subcommittee.

I would also like to welcome our guests here today. This is a very distinguished panel. I look forward to hearing the testimony of a variety of great insights into this issue. Mr. Readdy; Mr. McCulley, a genuine hero; Mr. Blomberg; Mr. Li; and Mr. O'Connor. Your insights will be very helpful to us.

The reason we care about this is that the Space Shuttle is a very unique and, indeed, it is a national asset, and we do have to take good care of it, but also not just be happy with the way things are, the way things have been, but where it can go into the future. I think some are very correct when they say the Space Shuttle is an example of some of the very best, if not the best, that the United States has to offer in our ability not just the technical, but the ability to achieve our dreams, and to reach for the stars, and live in the stars, so to speak, into reality.

Now, the Space Shuttle has been around for 20 years, and even today, everybody in the country stops and holds their breath whenever the Space Shuttle is being launched. Some of that is because of the tragedy back in 1986, but Americans are still in awe and, indeed the world is, and I think we all do recognize the risks that our American astronauts are taking each time that an orbiter is launched.

Each launch represents the coordination of so many highly technical, sophisticated systems that it is almost inconceivable that they all go right, which makes you wonder, you know, what if one goes wrong, and that is where I think some of the advancement and some of the ideas that you all have been talking about as far as using technology to address safety. So you are not relying just on human eye-balling and idea, but have a system that double or triple checks that, because there are so many systems that need to be coordinated for safety and also for the efficient operation of the particular mission.

And NASA has, through all of this, continued to make the Shuttle assembly safer and more reliable after many years of operation, but again we need to not only applaud those efforts, but also look forward to the implementation of additional developmental efforts in this area.

I am disappointed, as was also reflected by Senator Wyden, our Chairman of the Subcommittee, that the budget for fiscal year 2002 has a shortfall. A shortage of over $200 million, combined with the cost overruns of the International Space Station of over $4 billion, has made for a very tough situation—I will use that phraseology—a very tough situation in Human Space Flight right now in NASA. We should be, I think, concerned with these budgetary problems, but as unfortunate as all this is, it does not mean that this should be something you say, "Well, we cannot be ambitious any longer." I think we have to have some very important technological problems solved. The programs that are being addressed I do think make some sense. Some—in my view as a layman trying to be a juror so to speak, listening to you all as experts—some make more sense than others. Some you scratch your head and just wonder, well, how can you be so far off on some of these estimates, and maybe some of your testimony will reflect on that. But we still have to advance the state of human space flight and advance the state of research. This is absolutely essential.

Mr. Chairman, as you know, and we all know very well, our economy and, indeed, the success of the United States is based on a continuous flow of technological advancements and, indeed, on a spirit of our continual innovation and improvement, which have been and always must be part of our nature, our culture as Americans. Whether it is questing or pioneering or advancing better improvements, technological advancements have always been what has made America great, and it has to continue in the future.

Now, we know that space is considered to be one of the next growth areas for major economic development. The reality is that NASA is responsible for much of the technological underpinning of this growth, and we must recognize that the space-based problems that we are discussing and will be discussing here today and in the

months to come could have very valuable impacts on the quality of life and in the future here on earth.

Furthermore, I am concerned about the effects that these cost overruns will have on the other programs at NASA, such as Aeronautics. I have major concerns for this area of research in Aeronautics, given the problems we are now experiencing in the aviation community. The Senate has spent a lot of time ensuring a balanced budget, so to speak, at NASA, and we should not let any one program become the total focus of the agency. Aeronautics and aviation have been neglected, I think to our nation's economic and security detriment, and all of these and more concerns were brought up in an earlier hearing we had on the subject of Aeronautics. Suffice it to say, as these concerns of funding come about, NASA should not be taking it out of the Aeronautics aspect of it. It will have to be handled some other way, other than raiding that pocket, or that aspect of NASA.

On a separate note, Mr. Chairman, you mentioned and alluded to it, and we seem to both be disturbed as much as anyone to learn from the recent GAO report that NASA has not been able to provide detailed transaction-based support amounts charged to the Space Station and Shuttle programs, as required by the cost limitation provisions contained in last year's authorization of NASA.

I know the cost limitation provision was something that—I was not here, but in researching for this hearing—I know that the then and current Chairman and Ranking Member, Senator McCain and Senator Hollings, spent a great deal of time on that issue, and I know that our GAO witness is not here to specifically address that report, but we all look forward to more discussions on this matter both with the GAO and also with NASA.

But the Space Shuttle program right now, with this budget situation, and the challenges you are facing, we know is in a very tough situation. There are shortfalls in the budget, there are infrastructure concerns, and there are work force issues. Many of the work force issues are not unique, I would say, to space. You hear that in aviation, you hear that in many technology areas, but many times in life, struggling becomes the pathway to success, and I think that this can happen if we acknowledge whatever problems exist now, deal with them honestly, and then I hope what we can accomplish here today with the insight and expertise of these five gentlemen here, we can at least find the pathway to move forward, because I think it is essential for our security, it is good for our economy, and it is also just the way Americans ought to be, always questing to do better, always improving, always innovating.

I thank you again, Mr. Chairman, for having this hearing, and thank all these gentlemen for sharing their time and expertise with us. Thank you.

Senator WYDEN. Thank you. Senator Nelson.

STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA

Senator NELSON. Mr. Chairman, I want to thank you for having this meeting. I want to thank Senator Daschle for putting me on this Committee. I want to thank Chairman Hollings and Senator

McCain for talking to Senator Daschle to put me on this Committee.

Senator WYDEN. That leaves only 96 Senators left.

[Laughter.]

Senator NELSON. Well, we have a lot at stake in this hearing. Senator Allen, I am grateful for your interest. Senator Hutchison, you have a great deal at stake in the subject matter of this hearing, and I am grateful for your interest and your support. I am grateful to the expertise that we are going to hear from today, which is going to be unvarnished testimony, and I am grateful to a lot of the people in this room today who share the passion with all of us that we want to continue to have a robust, Human Space Flight program. That is what we are talking about, ultimately, the bottom line: are we going to continue to have a successful manned space flight program?

We are not talking about dry numbers and ledgers today. Make no mistake about that. We are talking about the men and women who serve their country by exploring its frontiers. We are talking about an exploration program, since Alan Shepard first lifted off in 1961, that has provided the most valuable research available to people anywhere, because NASA technology has touched the lives of Americans every day in every way. More than 1,300 documented NASA technologies have gone beyond the space program, including freeze-dried foods, cordless power tools, and miraculous medical advancements such as CAT scans and kidney dialysis machines, and this Space Shuttle program alone has generated more than 100 technology spin-offs, including the artificial heart, developed through technology used in the Space Shuttle fuel pumps, and even the insulating materials in NASCAR race cars have come from Shuttle thermal technology.

So as we move forward in this hearing, this is the importance of the funding question before us. This is the importance of making certain that we build, maintain, and fly the safest vehicles possible, and it is against this backdrop, and this history of our space program, that we now delve into these very serious funding and safety questions that have been raised.

So Mr. Chairman, thanks to you and Senator Allen. I have asked for this panel of experts to speak to our Subcommittee today, because I fear that if we do not provide the Space Shuttle program with the resources it needs for safety upgrades in the future, our country is going to pay a price that we cannot bear. This proposed budget abandons some of the most critical safety upgrades of our aging fleet, and mind you, it is aging. It was developed in the seventies, starting in the early seventies. It first flew in 1981, and now, under increased budget pressures, we have got tough decisions to make about spending priorities.

But our budgetary decisions should not come at the risk of astronauts' lives and, in fact, whether or not—ultimately, the bottom line is whether or not we are going to have a Human Space Flight program. This budget fails to adequately protect these and future astronauts.

Most think that we are going to continue to fly the Shuttle for another 20 years. Now, mind you, let me repeat that. Most people in this room will agree that we are going to fly this existing fleet

of Space Shuttles for another two decades. That was not the plan. There was going to be a follow-on vehicle, and a lot of these budgetary decisions predicated in this budget were on the fact that we were going to have a new vehicle ready, and therefore these safety upgrades were not going to be necessary. So we are basing, if we do not watch out, our budgetary decisions on the long-lost premise that the Shuttle would be replaced in 2 or 3 years.

But this is not proper planning, and this is not putting safety first. This is putting the safety of our Shuttle fleet, the crews, the cargoes, as well as the people on the ground supporting the Shuttle, all at an unnecessarily high risk. In order to pay for continued operations of the Shuttle fleet at a flight rate of 6 per year. By the way, I compliment these folks, because they just had 8 very successful flights in 11 months.

But if we are just looking at a rate of only 6 per year in the face of these budget constraints, then NASA is abrogating its commitment to upgrade the Shuttle orbiters by canceling, by deferring, or by stretching out its previous upgrade plan. At the same time the agency has yet to request any funds to make improvements to the ground infrastructure, which is literally falling apart. You cannot have infrastructure at the Kennedy Space Center with all that salt air, and with hurricanes coming by every now and then, and not have those upgrades.

So safety improvements considered critical two years ago are now discretionary projects subject to available funding. All but one of the Shuttle's pending safety upgrades have been targeted for cancellation or deferral. That is unacceptable, when our motto is supposed to be safety first.

NASA has canceled continued work on the Electric Auxiliary Power Unit, even though this upgrade was previously considered to be one of the highest safety priorities of the agency. At Kennedy, in order to protect people from huge pieces of concrete falling from the ceiling of the vehicle assembly building, a net has been strung up to catch any falling items.

The Shuttle program part of NASA's budget is $218 million short in the next fiscal year, and in the absence of a permanent leader for the agency, and I say that in reality, because the new Administrator has not been named, decisions about NASA priorities are coming not from NASA, but from bean counters at the Office of Management and Budget.

I said I was going to talk unvarnished, but I am talking truth. We have got accountants making life and death technical decisions for our astronauts and our ground crews, instead of the engineers and the program managers who have dedicated themselves to keeping the United States in the forefront of space exploration. Now, we here have an opportunity to fix this problem, because this hearing is timely, because the VA–HUD conference committee meets next week, which includes NASA appropriations.

I have talked to Senator Mikulski, who chairs the VA–HUD Subcommittee, about this. They have the ability to increase the budget to pay for some of these safety improvements that are so critical to our Shuttle program, and I urge you all, as you hear the testimony today, and I have talked with Fritz Hollings, he is going to the floor with his Commerce-Justice Appropriations bill this after-

noon, so he cannot be here. I have talked to John McCain. Senator McCain is in the markup on the Armed Services Committee right now, but he is going to try to get in.

I urge all my colleagues to seek the reprioritization in the conference committee of the funding for this program, and as it stands, what we are doing, if we do not do anything, we are starving NASA's Space Shuttle budget, and thus greatly increasing the chance of a catastrophic loss. I wonder if the lessons of Challenger are fading.

So let me say that the witnesses here can speak the truth. We all have great respect for all of you. You are extremely accomplished. You all believe in NASA's future. You believe in our Human Space Flight program, and you believe in reducing the risk for our astronauts and ground crews to the lowest possible acceptable level, and I also believe, I personally believe that you all have had your hands tied, that in recent months—and I am not talking about just this Administration.

Please understand this has nothing to do with partisan politics. I am talking about the direction that this has taken over the last decade, that you all have had your hands tied over the years, but we are dealing with the now, because decisions have been taken out of your hands, and you are out of the decision loop, and I hope you can get back in it, but the witnesses here on this panel represent the wealth of wisdom that we in the Congress had better start listening to.

So Mr. Chairman, I thank you for the privilege of being here today.

Senator WYDEN. I thank my colleague for an excellent, excellent statement, and we are anxious to work with him on these matters.

Senator HUTCHISON.

STATEMENT OF HON. KAY BAILEY HUTCHISON,
U.S. SENATOR FROM TEXAS

Senator HUTCHISON. Thank you, Senator Wyden. I thank you for calling the hearing. Senator Nelson, you are certainly a welcome addition to the Committee. I did not know it was so hard for you to get here, but I am glad you are here, and certainly Senator Allen has been a long-time supporter of engineering and research and space, and I look forward to working with all of you.

The fact of the matter is, the NASA budget and the Senate Appropriations Committee final result is a disaster. It is a disaster for the International Space Station, and without the Space Station there would be no reason for a Shuttle. I led the fight in the appropriations process last time to upgrade the Shuttle and the safety that was necessary for the Shuttle, because we all lived through the Challenger disaster, and none of us want to see that happen again, ever—ever.

But to short-change the vehicle for the scientific research, which is the Space Station, would be just irresponsible. So I think we have all got to come together and try to work through the appropriations process to secure adequate funding for the Station, to make sure that we stop these overruns, which no one thinks is acceptable, and to go forward making safety our first priority and

making sure that we have the scientific basis for NASA, or we are going to see NASA careen into a nonfunctioning agency.

You cannot lose any part of NASA—as Senator Allen said, you have got to have your aeronautical research, you have got to have your engineering. All of the things that Senator Nelson mentioned that we have gotten from our space research—the CAT scans, the MRI's, all of these things—are so much a part of the investment we have made in NASA. But to all of a sudden start whittling away at the Space Station and keep all of the parts that would service the vehicle that we are whittling away is crazy. So we have got to have a plan that makes sense, that keeps a solid, research facility in the Space Station, and does the upgrades for the Shuttle that would make it not only safe, but also a good service tool for the space station. That is what I want to work for, and I hope all of us will be able to come together when we get to this appropriations bill and try to make sure that we are doing the right thing for our goal, which is the research capability.

Thank you, Mr. Chairman.

Senator WYDEN. Thank you.

Gentlemen, you have just heard four United States Senators say they want to work with you on this important issue, and suffice it to say it is going to be a challenge in this budgetary environment. We will make your prepared remarks a part of the hearing record in their entirety. We have asked each of you to try to keep within 5 minutes or thereabouts. Let us begin that end of the table with the NASA folks and we will go right down the line, Mr. McCulley, Mr. Blomberg, and let us proceed.

STATEMENT OF WILLIAM F. READDY, DEPUTY ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION HEADQUARTERS

Mr. READDY. Chairman Wyden, Senator Allen, members of the Subcommittee, thank you for the opportunity to testify before you today. First, though, I would like to compliment fellow astronaut Senator Bill Nelson on his timely editorial in this week's *Space News.* As proud as we are of the past 20 years of achievement and over 100 Space Shuttle missions, we must never allow our current successes to cause complacency to set in.

Today, just as in 1981, a safe and successful Space Shuttle launch is the only metric the world uses to judge the quality of NASA's Human Space Flight program.

Since Challenger, with your steadfast support we have continued our quest to improve the Space Shuttle safety. Our loss of vehicle rating has gone from one in 78, post Challenger, to one in 483, and while maybe that is acceptable to the general public, and they would label this quite an accomplishment, to us it is not sufficient. In the realm of human space flight, 95 percent is not an A, 99 percent is not an A. Anything less than 100 percent is an F.

Modern day fighters such as the F–22 are on the order of 1 in 10,000. Modern airliners like the Boeing 777 have a safety level of 1 in a million, or 2 million. These statistics show us that even though we have achieved significant improvements in the first gen-

eration of reusable human space flight, we have a long, long way to go, and we need upgrades to get there.

At present, the Shuttle is the safest, most capable and reliable vehicle in history. We have flown more than 80 successful missions since return to flight, and I have to applaud the NASA/contractor Shuttle team for its superb stewardship to date in continuing to fly safely and accomplishing the most complex of missions in assembling the International Space Station, servicing the space telescope, and doing space research against a background of a 40-percent reduction in budget purchasing power. This is nothing short of remarkable.

That said, beginning in fiscal year 2002, we have reached a point where simply accounting for inflation may eclipse future efficiencies and could foreclose our options to recapitalize this program. To be more specific, our Apollo era infrastructure is aging, obsolescence issues are arising more frequently, many of our vendors are going out of business, and the operating costs for our contractors are going up.

In 1997, NASA established a Space Shuttle Program Development Office at the Johnson Space Center for the purpose of systematically identifying, prioritizing the required upgrades that would maximize flight safety, mission success, and improve the end-to-end reliability of the total Space Shuttle system.

Since 1997, NASA has implemented many safety and performance upgrades, super lightweight tank, the new, improved Block II's Space Shuttle Main Engine (SSME), and the glass cockpit all come to mind, and because of the improvements in the Space Shuttle Main Engines, we have reduced the risk of launch failure by 80 percent. We have increased the launch probability to support International Space Station limited launch windows of 5 minutes or less, and we have increased the payload to orbit by 8 tons.

Two years ago, Congress took the leadership in providing a plus-up to start the Space Shuttle upgrades program. In the fiscal year 2000 budget, and subsequently, the Office of Management and Budget established a challenging goal of *implementing* all safety upgrades starting in 2005. Given the current budget environment, and all the reasons I mentioned above, it is now anticipated that *development* of these safety upgrades would not be completed until 2005, with implementation into the fleet actually beginning in 2007.

Although our upgrades program has been focused on vehicle improvement, the vehicle is only one part of a vehicle integrated system. Ground facilities that support training, processing, launch, landing operations are all equally critical to mission success and the safety of our astronauts. This infrastructure includes facilities located literally across the country, some in fact overseas, much of which was built during the early sixties in support of the Apollo program.

Current Space Shuttle infrastructure revitalization projects are predominantly focused at the Kennedy Space Center, where currently there are four major vertical assembly building projects, but to date the Space Shuttle program has only been able to address these projects on an emergent case-by-case basis.

In the mid-nineties, NASA underwent significant downsizing. At NASA headquarters, the Civil Service work force went from 2,200 to 1,000. Within the Office of Space Flight, where I work, we went from 240 to 80, and within the Space Shuttle Program Office the Civil Service count went from 4,000 to the current count of approximately 1,700.

In 1999, when the NASA centers were experiencing a shortfall of people with critical skills for the International Space Station, Space Shuttle, and advanced space transportation programs, Office of Space Flight received permission to discontinue the downsizing and commence rehiring, and with respect to the Space Shuttle, those hires focus on the increased flight rate for the International Space Station, and the safety upgrades program.

To conclude, I would like to reemphasize that safety maintainability obsolescence issues must not be allowed to threaten our nation's only human-rated access to space. Delaying the implementation of key improvements could expose future flight crews to higher levels of risk for longer than is necessary.

We accept the fact that human space flight and the quest to explore and develop space does not come without risk. We have accomplished much over the past decades. Our continued success in this undertaking depends on never overlooking the fact that, along with the astronauts on board those Space Shuttles, a little piece of all of us flies on each and every mission.

Thank you.

[The prepared statement of Mr. Readdy follows:]

PREPARED STATEMENT OF WILLIAM F. READDY, DEPUTY ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE FLIGHT, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION HEADQUARTERS

Mr. Chairman and Members of the Subcommittee:

Thank you for this opportunity to testify on the subject of Space Shuttle safety. There is no higher priority for NASA than the safe launch, operation and return of our Space Shuttle vehicles and their astronaut crews. The Space Shuttle represents assured human access to space for this nation for at least the next decade, and is indispensable to the success and viability of the International Space Station (ISS).

NASA's Space Shuttle program has been one of the agency's real success stories over the last several years. The program, working with their contractors, has made significant reductions in operations costs—by about a third even before accounting for inflation. At the same time as the operations costs have been coming down, the Space Shuttle has made dramatic improvements in the capabilities, operations and safety of the system. The payload-to-orbit performance of the Space Shuttle has been significantly improved—by over 70 percent to the Space Station. The safety of the Space Shuttle has also been dramatically improved by reducing risk by more than a factor of five. In addition, the operability of the system has been significantly improved, with five minute launch windows—which would not have been attempted a decade ago—now becoming routine. This record of success is a testament to the quality and dedication of the Space Shuttle management team and workforce, both civil servants and contractors.

The fact that the Space Shuttle is the safest, most capable, and reliable space transportation system in the world is due, in large part, to the commitment of NASA, the White House, and the Congress to make the necessary improvements across the system to ensure safety and mission success. Let me assure you, however, that this has not been an easy task. It has taken exceptional leadership and an unfailing commitment to safety to navigate through a prolonged period of steadily decreasing budgets, although the last 2 years have seen increases in the Shuttle request. We have delayed needed investments in support equipment and infrastructure that today present themselves as significant management challenges.

We find ourselves searching for innovative methods to achieve additional operational efficiencies while continuing to safely fly the Space Shuttle fleet through 2012. The truth is that most significant efficiencies have already been realized. Since submission of the President's FY 2002 budget request, the program has projected increased costs for Shuttle operations for FY 2002 and the outyears, some of which is driven by factors beyond the control of the Shuttle Program. These include contractor rate increases, core skill and business base erosion, supportability/obsolescence issues, and energy cost increases. Internal cost increases are largely driven by the cost of orbiter operations support, such as critical re-wiring on the mature orbiter fleet.

In the following testimony, I will address the subjects of Space Shuttle upgrades, infrastructure revitalization and the Space Shuttle workforce as they relate to Space Shuttle safety in FY 2002 and beyond. I will also address NASA's FY 2002 Budget Plan for the Space Shuttle and associated challenges related to these same subjects.

The primary objective of safety upgrades to Space Shuttle systems is to achieve major reductions in the operational risks associated with those systems, and to provide safer Space Shuttle operations through system safety upgrades. NASA's FY 2002 budget request provides a large increase to the Space Shuttle safety allocation, from $256 million in FY 2001 to $406 million in FY 2002. The total Space Shuttle budget in FY 2002 and the out-years is flat, and does not provide for adjustments due to inflation in anticipation of achieving incremental operational efficiencies. NASA has been conducting an external review to assess how the Safety Allocation funds can most effectively be used to improve the safety of the Space Shuttle, to include investments in hardware/software upgrades, personnel, facilities, or other safety-related areas. NASA will proceed with investment activities once Authority To Proceed (ATP) has been accomplished. Space Shuttle safety investments are an important element of NASA's strategy for an Integrated Space Transportation Plan (ISTP).

Cost challenges to the Space Shuttle Program and upgrade technical issues are presenting significant potential impacts to increasing Space Shuttle safety. Some individual safety upgrade projects are being evaluated for cancellation or deferral in FY 2002, due to either technical issues or to pay for increased costs that were not known at the time of the FY 2002 budget submission. These issues will be addressed as we work with the Administration in formulation of our FY 2003 budget. In our deliberations we will try to avoid near-term decisions at the expense of improved safety (current risk) in order to preserve a safe and viable six flight rate per year core Space Shuttle program. We will also seek to address facilities and infrastructure requirements in the program.

Space Shuttle Upgrades and Program Achievements

The Space Shuttle is a very mature system, remarkably reliable, very mission flexible, and a true testbed—not just for scientific inquiry, but also for forming international partnerships and goodwill. Wise investments in safety upgrades during the course of the program have kept the Space Shuttle viable and ready to meet the needs of our nation's space program.

High Launch Rate Reliability—Of 106 launch attempts, there have been 105 successful launches, equating to a launch reliability of greater than 0.99. Let me add to that, Mr. Chairman, that while we are proud of our accomplishments, anything less than 100 percent is still unacceptable in a Human Space Flight program.

Mission Diversity—The Space Shuttle has launched over 3 million pounds of cargo and over 600 humans from around the world. The Space Shuttle is the only launch system in the world that can deliver and return large payloads to and from orbit. Each Space Shuttle flight can support a diverse package of mission objectives. The Space Shuttle is very flexible in accommodating all types of missions, including those dealing with national security.

International Leadership—No other country has been able to integrate the technical, operations management, and financial resources to develop its own human-rated RLV system. At least 38 percent of the Space Shuttle flights so far have carried non-U.S. astronauts. This percentage will increase as we continue to assemble and operate the International Space Station.

Invaluable RLV Operating Experience—The Space Shuttle Program has provided over 20 years of invaluable experience in Reusable Launch Vehicle (RLV) Payload Integration and Flight and Ground Operations. It has produced a massive database of technical information from which future improvements will be made to next generation RLVs.

Privatization—The Space Flight Operations Contract has proven to be successful in finding efficiencies and reducing cost. Lessons learned with this effort will ul-

timately pave the way for further privatization of the Space Shuttle that is envisioned under the President's Blueprint.

Space Shuttle Technology Spin-offs—The trickle-down of benefits from the Space Shuttle Program continues to impact the development of new electronic devices, medicines, improved manufacturing procedures. The Space Shuttle Program in the U.S. private industry has created thousands of jobs.

Space Shuttle Upgrades Program—Objectives and Strategy

The Space Shuttle Upgrade program is intended as a proactive measure to keep the Space Shuttle flying safely and efficiently in support of the Agency's commitments and goals for human access to space. Shuttle Upgrades are intended to enhance the primary goals of the Space Shuttle Program:

Fly safely;
Meet the manifest;
Improve mission supportability; and,
Improve the system.

The two types of Space Shuttle upgrades are safety (high priority) and supportability. Safety upgrades are those upgrades that minimize ascent, descent, and critical operations risks. Supportability upgrades are those upgrades that maximize Flight Hardware Availability Assurance (FHAA), and Operational Improvements (OIs).

The following table illustrates the focus areas for Shuttle Upgrades over the last several years.

Main Focus	Examples
Shuttle Safety; Supporting the ISS	SSME Alternate turbo pump Super Lightweight Tank
Combating Obsolescence	Checkout and Launch Control system
Enhanced Capability (does not change the fundamental Shuttle configuration)	Avionics Extended Nose Landing Gear Long life Fuel Cell

Space Shuttle Upgrades Selection Process

Any Space Shuttle Program Element or Project Office may propose potential candidate projects to the Space Shuttle Program Development Office (SSPDO). The recommending organization is responsible for providing a technical description of the proposed upgrade concept, the rationale for the proposal in terms of benefit to the program, and a rough order-of-magnitude estimate of cost and schedule to implement.

The SSPDO scores and weighs the proposals with respect to how well they meet Program goals and objectives of flying safely, meeting the manifest, improving supportability, and improving the system. The primary goal of the selection process is to allocate resources, on a priority basis, to the significant safety improvement opportunities and significant supportability needs. Approval of upgrade candidates is an ongoing activity of the Upgrades Review Board.

NASA's upgrade investment strategy is to pursue high priority safety upgrades, supportability and obsolescence upgrades. The principal discriminators for the high-priority safety upgrades are the degree of safety improvement, and how quickly the associated benefits can be realized.

The upgrade portfolio consists of project proposals in various stages of definition and approval. These proposals include those undergoing initial definition and feasibility assessments, those that have received formal approval for further definition and implementation planning, and projects that have been approved for implementation and thus form the base lined Space Shuttle Safety Upgrades Program content. Addendum 1 shows the Shuttle Safety Upgrade Schedule Strategy and Addendum 2 depicts the organizational relationship of the SSPDO to the OSF.

High Priority Safety Upgrades List

The current Upgrades plan calls for High Priority Safety Upgrades which, all combined, have the potential to reduce the overall risk of a catastrophic loss of vehicle by a factor of two. All total funding figures listed below are in the President's FY 2002 Budget request.

The Cockpit Avionics Upgrade (CAU) Increments I & II, totaled $20 million in FY 2000 and $40 million in FY 2001. The total funding is estimated to be around $500 million. These upgrades will provide: 1) access to more systems data; 2) increased organization of data display and command capabilities; and, 3) improve human-to-machine interface, all of which reduces crew workload in the cockpit during all phases of the mission. Implementing the CAU into the Space Shuttle fleet in a timely manner with other Space Shuttle upgrades will: 1) reduce the cost of scheduling separate Orbiter Maintenance Modification periods, 2) increase the quality of the training of Shuttle astronauts, and 3) eventually begin to further lower the Loss of Vehicle (LoV) risk.

The Electric Auxiliary Power Unit (EAPU) would have replaced the Orbiter's three hydrazine power unit. Using battery-powered electric motors to replace the hydrazine system and high-speed turbines, this upgrade would have eliminated the potential of extremely toxic and hazardous conditions for processing and in flight. However, due to technical issues, this upgrade will not go forward and instead will be a technology development effort in FY 2002.

The Advanced Health Management System (AHMS) Phase I & II upgrades to the Space Shuttle main engines will provide improved real-time monitoring of engine performance and environmental data, will provide improved engine health advisories to the onboard crew and ground controllers, and will provide improved engine anomaly response capabilities. The AHMS will reduce the risk of catastrophic engine failure by up to 40 percent. This project has been allocated $13.8 million in FY 2000 and $17.7 million in FY 2001. The total funding is $155 million.

The Solid Rocket Booster (SRB) Advanced Thrust Vector Control (TVC) upgrade, if implemented, will replace the hydrazine power turbines currently used to drive the hydraulic pumps with helium. This eliminates hydrazine leakage/fire hazards, turbine over speed hazards, and reduces toxic materials processing hazards. This project was allocated $5 million in FY 2000 and $11 million for studies in FY 2001. The total funding is $207 million.

Safety Upgrade Studies

Studies are also being conducted in several areas of high risk. The completion of these studies is vital to successfully supporting our safety upgrade efforts and may result in the selection of additional upgrade candidates to be prioritized and reviewed within the proposed five-year period of safety upgrade development (FY 2001–FY 2005).

Crew Escape Engineering Design Trade Study—This is an in-depth engineering study of contingency crew survival options; extraction, ejection, crew module separation; determine feasibility, survival utility, cost, and technical impacts; increases probability of a successful crew bailout.

Thermal Protection System (TPS) Lower Surface Tile Study—This study will develop a more durable lower surface tile for the bottom of the Orbiter which would reduce the risk of tile burn-through, reduce post-landing repair, and may provide additional micro-meteoroid and orbital debris protection.

Self-Contained Apparatus Protective Ensemble (SCAPE) Suit Improvement Study—The objective of this study is to develop a safer and more efficient SCAPE suit used for hazardous operations during ground processing; the current suit is heavy, allows undesirable levels of carbon dioxide, and is not efficiently cooled.

Space Shuttle Abort Improvements Study—This study will investigate Space Shuttle hardware, software and procedural improvements to eliminate/decrease specific abort scenarios, reducing the areas of no coverage, eliminate abort scenarios, and increase probability of a successful abort.

Main Landing Gear (MLG) Tire Study—This study is investigating improved tire designs that allow for higher landing speeds, increase cross winds limits, increase the landing load limit, mitigate obsolescence issues, and improve margins for pressure leakage and colder temperature environments.

SSME Block III Study—This study would investigate the incorporation of an Extra Large Throat Combustion Chamber and a more robust channel wall constructed nozzle, increasing performance margins and abort thrust capability and eliminating main combustion chamber and nozzle failure modes. However, due to technical issues, this study is being discontinued.

The Industrial Engineering for Safety (IES) Study—This study is a significant and comprehensive effort to increase flight and ground safety through improved handling and inspections via changes in flight and ground hardware and ground procedures and processes. Within this study, several small projects are in formulation, and a few projects in this category have been authorized for implementation.

No candidate upgrades will be approved until NASA's overall safety investment strategy has undergone external independent review by the Office of Space Flight's (OSF) Space Flight Advisory Committee (SFAC) to assure that only technologically ready projects will be pursued. Moreover, NASA must complete its full management review process to ensure that the cost is fully defined, accurate, and has sufficient reserves to ensure that it can be completed within the overall safety allocation. Approved projects will be reviewed annually, and reprioritized if necessary, to make sure that they are managed within the plan.

Supportability/Infrastructure Revitalization

Another issue of concern for the Space Shuttle Program is maintenance of the ground infrastructure that is so vital to the continued success of the program. We recognize the importance to the Space Shuttle Program of the facility structures, systems and test support equipment. That importance extends across all stages of the program from manufacturing, assembly, testing, transportation, processing, and all the way through launch, SRB retrieval, and the final landing of the orbiters. We have identified the projects that are required to revitalize the Shuttle infrastructure over the next decade. There are over 200 projects that will eventually need to be completed. Many of these projects are required to revitalize a set of buildings, systems, and equipment that were developed for the Apollo program and then retrofitted to accommodate the Space Shuttle.

The Space Shuttle infrastructure revitalization projects are predominantly focused at the Kennedy Space Center (KSC), but there are also many important projects required at Marshall Space Flight Center (MSFC), Johnson Space Center (JSC), Stennis Space Center (SSC), White Sands Test Facility (WSTF), and the Michoud Assembly Facility (MAF). The highest priority projects are at the Launch Complex 39 (LC–39) area at KSC, including projects at both Pads A & B and the Vertical Assembly Building (VAB). There are four major VAB revitalization projects needed for the roof, siding, door openings, and the door mechanisms that need to be addressed in the near future. Other key KSC projects include refurbishment of the high-pressure gaseous nitrogen and helium pipelines, communications cabling replacement, power distribution systems, and refurbishment of the crawler/transporters that move the Orbiters from the VAB to the launch pads.

The Space Shuttle Program has addressed these projects to the best of its ability. This has been accomplished while at the same time flying an accelerated set of missions over the past two years in support of the ISS, and initiating the Space Shuttle Upgrades program that will enable the Space Shuttle to fly safely well into the second decade of the 21st century. Our Space Shuttle philosophy places the highest priority first and foremost on crew safety and then on mission success. These priorities, when coupled to the challenging budget realities facing the entire Federal government, requires us to place our funding priorities on meeting the operational requirements of the Space Shuttle and on the high priority need for safety upgrades. We have tackled the most urgent infrastructure projects, but we have had to defer action on a number of projects that we feel are very important to the program and, if not addressed in the near future, could at some point impact mission schedules. We would like to perform more infrastructure projects, and at the same time strike the difficult balance between ensuring the operational requirements of the Orbiter and maintaining an extensive ground infrastructure that is also critical for the successful long-term operation of the Space Shuttle Program.

Space Shuttle Upgrades Independent Assessments

Over the past three years, OSF has relied on several advisory organizations like the SFAC and the Aerospace Safety Advisory Panel (ASAP), to provide comprehensive review and feedback, assessing the definition and prioritization of Space Shuttle Upgrades. Both of these organizations played a key role in the definition and prioritization of the current Safety Upgrades plan.

The ASAP was established by Congress in the aftermath of the fatal Apollo1 fire in 1967 and provides NASA with an annual report outlining any findings and recommendations for improvements regarding its programs. In its latest annual report submitted last February, ASAP submitted important comments on Space Shuttle safety upgrades and infrastructure. Just last month, ASAP provided to OSF the results of the overall impact to Space Shuttle safety if Orbiter Maintenance Modifications (OMMs) are delayed until FY 2005 and 2006, and orbiter structural inspections (SIs) are retained at KSC, for orbiters Discovery and Endeavour.

In the last twelve months, SFAC, an internal committee of the NASA Advisory Council, has provided quarterly assessments of the Space Shuttle Program and upgrades. This past June, SFAC recommended to NASA that the Electric Auxiliary Power Unit (EAPU) upgrade project be redesignated as a technology project. The

primary reasons given were because the EAPU technology was not mature enough, project costs were increasing, and schedule slips were beginning to occur. NASA thanks these organizations for their valuable input and will continue to rely on them for various Space Shuttle upgrades assessments in the future.

Addendum 3 summarizes the results of the independent assessments.

SSP FY 2002 Cost Issues and Mitigation Strategy

During preliminary FY 2003 budget development this Spring, increased costs to FY 2002 baseline requirements were identified totaling as much as $218 million. This projected cost increase is due to the following:

1. Content changes and growth.
   - Orbiter OMM phasing/re-estimate
   - Space Shuttle main engine (SSME) alternate turbopump development support
   - SSME minor components
   - Orbiter operations support
2. Contractor rate increases that factored in normal inflationary labor cost growth, higher fringe benefits (driven by higher medical costs) and other non-labor escalation. Contractor rate increases have always been projected to grow at 4–5 percent per year vs. 3.5 percent assumed.
3. Core skills and business base erosion, particularly within the rocket propulsion sector of the aerospace industry.
4. Supportability/Obsolescence issues.
5. Recent price increases in natural gas and electricity are projected to continue. These increases are not limited to the aerospace sector nor to prime contractors but include industries nationwide.

NASA Headquarters has partnered with the SSP project offices and SFAC on a strategy to maintain safety while mitigating the identified cost challenge. In order to maintain a healthy content in the Safety Upgrades plan, the following upgrade initiatives have been retained in the FY 2002 budget to Congress:

1. CAU Increment I, this was just approved as a project last month.
2. AHMS Phase I
3. ET Friction Stir Weld
4. New Main Landing Gear Tires Study
5. Industrial Engineering for Safety
6. Program Integration/Studies

In addition to eliminating Program reserves, delaying infrastructure revitalization support, and the reductions due to the re-designation of the EAPU, OSF is in the process of analyzing budget decisions dealing with the following Upgrades-related initiatives for possible cancellation or deferral.

1. Advanced Health Management System (AHMS) Phase II for the SSME
2. SRB Thrust Vector Control (TVC)
3. RSRM Propellant Grain Geometry
4. Industrial Engineering for safety
5. Orbiter Maintenance Down Period (OMDP) timing and location

Safety and The Space Shuttle Work Force

At the end of FY 1999, OSF undertook an assessment of its staffing requirements at the field centers. While maintaining Space Shuttle safety as our highest priority, OSF began an intense phase of building, integrating and testing significant ISS flight elements. We were also continuing ISS Operations while planning to integrate assembly and logistics flights to the ISS. During this time we began development of High Priority Safety Upgrades to the Space Shuttle fleet.

Given this workload environment, our internal assessment of core civil service workforce requirements at four Space Flight Centers convinced us that full-time equivalent (FTE) targets would have to be adjusted upwards. In late December 1999, each Center was directed to address critical workforce shortfalls in the SSP, ISS, and Advanced Space Transportation Programs. With respect to the Space Shuttle Program, the objective was to hire employees to support the increased flight rate

and the Space Shuttle Upgrades program. Since January 2000, we have seen our Space Shuttle FTE levels grow from a FY 1999 base of 1819 to a planned FY 2001 level of 1968 FTEs.

Our new hires have addressed our need for additional support in the areas of Flight and Ground Operations, hardware, and software design. In addition, the new hires have also contributed to our ability to develop and train flight engineers for future flight operations activities. Beyond the new hires, we also transferred personnel from existing Center organizations to support on-going Shuttle Program requirements. As we move forward in maintaining our Space Shuttle flight rate and complete the construction of the International Space Station, our recent hires will increase our ability to safely and meet our program commitments.

The "Safety Culture" within our Human Space Flight program is robust and healthy. It is a culture that is led from the front—management demonstrates its commitment to safety by listening and rewarding, and by being willing to accept impacts to schedule in the interest of safety. Every single Space Shuttle employee is empowered to call a "time out" if they believe that there may be a potential threat to safety.

There is concern about the uncertainty facing the workforce towards the end of this decade, should a next generation RLV be ready to begin a transition with the Shuttle. NASA is very sensitive to the need to preserve a work environment that emphasizes safety, and is beginning to think about transition issues at a very early stage so that we can ensure safe operations through any transition. In addition, reducing the level and implementation frequency for upgrades could cause many of these experienced and uniquely skilled employees to seek aerospace job opportunities elsewhere. Replacing these workers could become very difficult. We will also have the same problem with vendors that provide the unique services and products NASA needs to maintain the flight elements. NASA will work with the Administration and the Congress to proactively address these issues and ensure that human space flight activities continue to have the level of safety needed.

Space Shuttle Upgrades Program and the Space Flight Operations Contract

The Space Flight Operations Contract (SFOC) is a cost-plus-award-fee performance-based contract. NASA works closely with the contractor, United Space Alliance (USA), to ensure that the "scope of work" adequately covers all technical and management activities necessary to support all ground, flight, and orbiter services required for space flight operations. These activities also include management of approved Space Shuttle Upgrades projects and the requirements for Orbiter Modification Down Periods (OMDPs), which are necessary to implement Orbiter Maintenance Modifications (OMMs) and Orbiter Structural Inspections (OSIs). Revisions to the SFOC are negotiated based on additions or deletions to the scope of work. The current SFOC contract expires in 2002, but we have two, non-priced two-year options and are in the process of starting the negotiations to exercise the first option.

Given NASA's cost issues as described in my previous remarks, NASA Headquarters, JSC, KSC, and United Space Alliance have commenced activities to develop long-range facility and staffing plans for OMDP activities. With this plan, NASA will be able to better ascertain what critical resources are required to keep the high priority safety upgrades on schedule. The plan will address the requirements for retention of critical skills in the Shuttle workforce to accomplish the necessary upgrades and sustaining engineering work.

Space Shuttle Upgrades Program and Assembly of the International Space Station

Improving Space Shuttle safety and reliability to support ISS assembly operations and utilization for at least the next decade is currently a top priority for NASA. While we may be able to alleviate the short-term SSP cost challenges by delaying OMMs and OSIs, this may also increase the long-term risk for the SSP and could impact the current schedule of assembly flights for ISS. Addendum 4 illustrates that NASA's ability to maintain the SSP is facing increasing cost challenges.

At projected funding levels we are confident that we will be able to maintain a flight rate of six flights per year until FY 2003. Beyond that point, unless cost challenges are met, the Space Shuttle may not be able to sustain the projected flight rate, seriously impacting the ISS assembly and operations (Addendum 4, Part II).

Space Shuttle Upgrades Program and the Integrated Space Transportation Plan

The President's FY 2002 Budget Blueprint reaffirms NASA's commitment to work with the aerospace industry to explore new space transportation systems that will dramatically increase safety and reliability, and reduce costs. NASA's Integrated Space Transportation Plan (ISTP) is the long-range investment strategy for the Gov-

ernment to accomplish its mission objectives by enabling its partners to develop a new, commercially-viable, reusable space transportation architecture, focused on NASA's priority needs.

The ISTP consists of the Space Shuttle Program, the Space Launch Initiative (SLI) also known as the 2nd Generation RLV Program and the Advanced Space Transportation Program (3rd Generation research and in-space transportation technology). Under the plan, the Space Shuttle will be maintained through investment in the safety upgrades. The Space Launch Initiative formulates and implements risk reduction activities and technologies to enable development of a 2nd Generation Reusable Launch Vehicle. Addendum 5 illustrates the ISTP concept.

The follow-on RLV to the Space Shuttle will be operating from the subsonic (Mach < 1) to the hypersonic range (Mach > 5) of the high-speed envelope. Currently, the Space Shuttle orbiter is the only reusable operational vehicle in the world that flies in the hypersonic regime. With 106 Space Shuttle flights completed, NASA has accumulated a total of 50–60 hours (ascent-descent) of hypersonic flight over twenty years. The Space Shuttle could play a valuable role in assisting SLI to evaluate promising 2nd RLV technologies if SLI provides the necessary funding for ground and/or flight tests during one or more Space Shuttle missions. An orbiter outfitted with SLI technology demonstrations for flight software, computers, internal vehicle health management system, and non-hazardous fluids could significantly reduce the development time and financial resources needed to flight-test these prototype systems. By acting as a technology pathfinder, SSP will be supporting SLI management and technical processes, to efficiently and accurately accumulate and analyze data that will improve/influence the various RLV concepts and designs. This type of effort would certainly minimize the operational transition problems from the SSP to an operational 2nd Generation RLV.

The two programs are working together to bring the Space Shuttle heritage and lessons learned to the SLI concepts and evaluating the benefit of key technologies. The large majority of technologies being pursued in SLI is relevant to the Space Shuttle and can be evaluated using the Space Shuttle as a reference point. The Space Shuttle and SLI programs are also investigating other areas of collaboration and synergy.

The following list summarizes some of the design features that the SSP could help to influence for SLI:

1. Number of toxic fluids
2. System margins
3. Number of systems with build-in-test (BIT) build-in-test equipment (BITE)
4. Number of confined spaces on vehicles
5. Hours for turnaround between launches
6. Number of different propulsion systems
7. Number of unique stages for flight and ground
8. Number of active ground systems required for servicing

Current plans call for the Space Shuttle to be maintained until the 2nd Generation RLV can achieve "Initial Operating Capability" (IOC). That milestone is projected to be the start of FY 2012. Under the ISTP, the transition from the Space Shuttle to the new vehicle could begin as early as FY 2009 and be completed by the end of FY 2011.

Concluding Remarks

Mr. Chairman, safety continues to be our top priority. The American taxpayers have every right to expect the Space Shuttle program they pay for to operate safely and efficiently. However, our ability to continue to perform to the highest safety standards in the long-term will require that we continue to address the critical needs of an aging Apollo era infrastructure.

Safety, maintainability and obsolescence issues will need continuing attention to ensure that the needs of our nation's Human Space Flight program can be met while next generation RLV technology is being developed. Safety investments must continue in order to ensure a safe program for as long as we are asked to fly.

Mr. Chairman, this concludes my remarks for the record. I would be happy to answer any questions you may have. Thank you very much for your attention.

Senator WYDEN. Very good. Mr. McCulley.

STATEMENT OF MICHAEL JAMES MCCULLEY, CHIEF OPERATING OFFICER, UNITED SPACE ALLIANCE

Mr. MCCULLEY. Chairman Wyden, Senator Allen, Senator Nelson, if I had a tape recorder, perhaps you could just punch Mr. Nelson's, put it on replay and run it, and then I would not have to say much.

I am Mike McCulley, Chief Operating Officer of United Space Alliance, which I will refer to as USA in the future, and we are responsible, as NASA's prime contractor, for the day-to-day operations of the Space Shuttle.

Our mission is safe operation of the Shuttle, our No. 1 mission. We plan flights, train astronauts, prepare all the hardware and software for launch, mission, landing of the Space Shuttle. As Senator Nelson mentioned, I am very proud of the fact that in the last 11 months we have had 8 highly successful missions, a flight rate of around 9 a year. Six of those went on-time the first time on 5-minute windows, one of them was delayed for weather, and one of them was delayed for an infrastructure issue for a couple of days.

We have done an outstanding job, as Mr. Readdy said, of continuing safe operations while reducing cost. When I left the Astronaut Corps in 1990, if I had known that today I was going to be an expert in how to execute lay-offs, I might have taken a different job. I am unfortunately an expert on the Warn Act, the Fair Labor Standards Act, the Service Contract Act, and how to get through these things, and whether you do them performance-based or seniority-based, but I have done enough of it.

At the time NASA and USA signed the space flight operations contract, the next generation RLV was expected to replace the Shuttle in 2004 or thereabouts. Of course, that resulted in nobody being interested in infrastructure upgrades or safety upgrades, and as Mr. Readdy said, and as Mr. Nelson said, we are still sitting there looking at those type of budgets today.

But now we are being asked to fly for at least another decade, safely, efficiently, and in order to do that we have got to do something different than this flat budget we are looking at.

At the direction of Congress in 2001, we were provided additional funding to initiate the safety upgrades, and NASA and its contractors, many of us, have been working very, very hard on a systematic approach to prioritize and work those upgrades. These upgrades would take the probability of a catastrophic failure during ascent from one in 483, as previously been mentioned, to around 1 in 1,000, or a 50-percent, half reduction in that risk, but now those high priority safety upgrades have become discretionary funding.

We believe that the proposed cancellations, or deferral of key spatial upgrades, are due to shortfalls in available budgets and not due to the project's lack of contribution to that safety improvement. USA believes that the NASA policy should be to dedicate the entire amount of funds provided by Congress for safety upgrades to the highest priority initiatives. If technological challenges make it impossible to move aggressively on one project, then we should revise the timetable for implementation or redirect to the next, rather than reprogram for other purposes.

We have mentioned the infrastructure. The ground facilities are essential. It is a tough environment for KSC. We have similar problems in Mississippi, in Alabama, and in Texas. You have to take care of these things, and we have not done as good a job in the past few years, in my 10 years in the management side of this, as we should have.

The hands-on work force, technicians, inspectors, and engineers is at the lowest level ever and yet, as we said earlier, we completed essentially a nine flight rate a year schedule in the last 11 months with near perfect vehicles, near perfect software, and near perfect performance on the part of the ground crews, flight controllers, and the astronauts.

This work force number has stabilized over the past 2 years. Morale is high. We have actually had some new hires, some fresh outs, or seed corn, as I call them, and they are excited. They like to be part of this program. But we need to be ever watchful that these folks are protected and augmented where necessary. They have very unique skills. For example, nobody in the world knows how to do proximity ops and rendezvous in space, except some of our folks. We helped DARPA, for example, in a program that they have got, because there is nobody else to do that, and we need to protect those skills.

In summary, I have had the incredible opportunity for the last 17 years to work on this program. I have had, depending on how you count, eight different jobs, from astronaut, to weather pilot, to deputy program manager, and now the chief operating officer of this fine company. We have made remarkable success in budget, in quality, in predictability of schedules. I am an optimist. My wife says I am an optimist to a fault, that I hide my head when the bad things come, but I will tell you that I am more pessimistic today than I have been in the 17 years that I have been doing this, and I worked through those years in the nineties that Bill talked about, downsizing, looking for efficiencies with my eyes wide open, and taking little, small steps, because the ice is getting thinner under our feet as we move out toward the middle of this lake, but as I look at the budget that is laid out for the next 5 or 6 years, it is a very disturbing budget that has got me more pessimistic, as I said, than I have been in 17 years.

Thank you, sirs, for having us.

[The prepared statement of Mr. McCulley follows:]

PREPARED STATEMENT OF MICHAEL JAMES MCCULLEY, CHIEF OPERATING OFFICER, UNITED SPACE ALLIANCE

Chairman Wyden, Senator Allen, Senator Nelson and Members of the Subcommittee: Thank you for the giving me the opportunity to testify before your Subcommittee on a subject that is very important to our nation—Space Shuttle safety.

Good afternoon, I am Mike McCulley, Chief Operating Officer of the United Space Alliance (USA). USA is responsible for the day-to-day management of NASA's Shuttle fleet under a single prime contract, the Space Flight Operations Contract (SFOC), awarded by NASA in 1996. The company employs over 10,000 people, primarily in Texas and Florida. USA's mission is safe operation of the Shuttle and the International Space Station (ISS). We plan the flights, train the astronauts, and prepare all of the hardware and software for launch, mission, and landing of the Space Shuttle as well as support the ISS on orbit.

Prior to joining USA, I managed the Lockheed Martin contract at Kennedy Space Center. I also had the opportunity to pilot the highly successful Galileo mission on STS–34 in 1989. I come before you today with seventeen years of experience on the

Shuttle program. Working over 80 Shuttle missions in 8 different jobs from weather pilot to astronaut to manager, I can state with certainty that the Shuttle program today is at the most robust and safest condition in its history.

Together with NASA, the USA Team works continuously to reinforce the "safety first" culture of the Shuttle program. I am very proud that in the past eleven months, the Shuttle team successfully launched and landed 8 missions, which represents the highest flight rate in several years. Those flights have contributed to the establishment of a permanent outpost in low earth orbit.

In order to continue supporting the nation's Human Space exploration goals, USA and NASA have implemented significant initiatives to further improve Shuttle operations as well as our performance. We have exceeded all of our industrial safety goals by substantial percentages and are performing significantly above the aerospace industry average. Having safely and successfully launched 29 Shuttle missions since the inception of SFOC in 1996, USA gained invaluable experience and is now working closely with NASA to implement upgrades to the flight hardware, improve our processes and recommend improvements to ground facilities. However, in my opinion, our drive toward efficiency has moved us below sufficient funding for the many years of Shuttle operation ahead of us.

Over the past decade, the Space Shuttle Program has done an outstanding job of continuing safe operations while reducing cost. Under the SFOC contract, USA and NASA have saved the American taxpayers $1.2B to date. USA has under-run the SFOC contract every year, and POP submissions to NASA reflect under-runs in GFY01 and GFY02. In addition to the savings realized under SFOC, NASA has reduced the Space Shuttle account by 40% since FY90. The Shuttle program succeeded in meeting reduced budget guidelines by achieving operational efficiencies, eliminating program reserves, and reducing its uncosted obligations to a level unacceptable for a program of this complexity. The budget limitations drove the Shuttle program to allow flight hardware upgrades and ground infrastructure projects to remain unfunded.

As you may recall, at the time NASA signed the USA SFOC contract, the agency expected to phase in a Reusable Launch Vehicle (RLV) to ultimately replace the Shuttle fleet in 2004. As a result, NASA's management plans for Shuttle out-year budgets were greatly reduced, and plans for orbiter fleet and ground infrastructure improvements were very limited. Now, the Shuttle program is being asked to fly for many more years, yet the current and out-year budget profiles remain unchanged.

USA believes that both the Congress and the American people support the continuation of the Federal Government's efforts to maintain human presence in space. If we are correct, the Space Shuttle Program is the link to all human space flight initiatives. The next generation launch vehicle is at least a decade away. The safety of our astronauts is paramount to USA and NASA, and it is obvious from the statements made on the Senate Floor by Members of this Committee, this objective is paramount to the Congress as well. USA strongly agrees with the emphasis of the Congress on the need to prioritize funding for the Shuttle program, in particular, the safety upgrades. Moreover, we believe that the long-term budget policy of the Federal Government should reflect a determination to refrain from reducing safety upgrade initiatives and ignoring ground infrastructure requirement. Prudent, timely and pre-planned modifications and upgrades of the Shuttle must be a national priority that transcends the budget limitations of any given year. Affordable upgrades are an essential investment in retaining the value of this indispensable national asset.

Today, I have been asked to focus my remarks on safety upgrades, infrastructure and the Shuttle workforce.

Safety Upgrades

The Space Shuttle is the foundation for our nation's continued human access to space in the 21st Century. It is uniquely capable of carrying humans into space while simultaneously providing the ability for heavy lift, rendezvous, docking, space walking, micro-gravity research, and new technology testing. These capabilities are unmatched elsewhere in the world.

At the direction of Congress, in the FY01 budget, NASA was provided additional funding to initiate the High Priority Safety Upgrades Program. NASA and its industry team have embarked on a systematic approach to upgrading and maintaining the Shuttle system.

Contrary to some perceptions, the Shuttle Upgrades program has done *exactly* what it was designed to do during project formulation: define requirements, establish project costs and schedules, and produce initial designs. I'd like to take this opportunity to provide the Committee with some information on the outstanding

progress that has been made on these projects and the need for their continued development.

New designs for Shuttle steering systems will eliminate the use of explosive and highly toxic hydrazine fuels. These new designs reduce hazards for both astronauts and ground crews. Complete integrated system prototypes of these designs, which could replace the current Auxiliary Power Units (APUs), have been built and tested. I am proud to say that this summer these prototypes have performed full mission simulations that meet and/or exceed current Shuttle capabilities on high fidelity test stands.

The Orbiter APU prototype, known as the Electric APU (EAPU), would eliminate the single largest risk to Orbiter flight safety. The EAPU reduces the APU's contribution to Orbiter flight risk from 30% to less than 5%. This project has advanced the state-of-the-art for spacecraft batteries and demonstrated that they have more than enough energy for their intended usage. Electric motors and pumps have also been built and tested that can provide the hydraulic power necessary to move Shuttle main engine actuators and aerodynamic surfaces. With requirement definition complete and many technical issues solved, the project is ready to produce detailed and cost-efficient designs.

The current APUs on the Solid Rocket Boosters use the same hazardous hydrazine fuel, and, similarly, represent a significant Shuttle safety risk. Multiple prototypes were created for this system, and each met mission requirements. A very simple, low-risk design was selected that uses safe helium gas in a blow-down configuration. The design not only has shown to be effective and efficient, but also has made use of composites technology from the X–34 program to reduce weight.

We have seen significant progress in the formulation and definition of the Cockpit Avionics Upgrade (CAU) over the last year and a half. The CAU is an important safety upgrade to the Orbiter that will greatly improve the situational awareness of the crew and reduce their workload, particularly in unexpected and critical emergency situations.

Prototyping activities for the CAU software and hardware have clearly proven the safety benefits of this upgrade as well as the major modification required to the heritage onboard computers. Display prototypes have been evaluated by flight crewmembers against established criteria and have improved the increased response and performance by the crew in life critical situations. A hardware prototype of the new direct access capability to the onboard computers has proven the ability for all parameters contained in those computers to be available for display to the crew, thereby further enhancing their ability to have full control and reaction capability. Not only do these prototypes demonstrate the feasibility of key architectural components of CAU, they also reduce the risk associated with the development of the system.

Designs for the Advanced Health Monitoring System (AHMS) for the Space Shuttle Main Engines continue to achieve greater definition, and a prototype is planned for a ground experiment in spring 2002. New engine controllers, new software and added computer power will "see" trouble coming a split second before it can do harm, thus allowing either a safe engine shut down or commanding a reduced utilization of the engine thereby increasing landing and/or orbit options.

A number of smaller improvements also add significantly to overall Shuttle safety. A new tire has been tested that will support higher landing speeds and provide greater safety margins. Likewise, new welding technology has been developed that can increase weld strength and fracture toughness on the External Tank. Finally, a modification to the Orbiter's radiators and wing leading edges that substantially reduces their susceptibility to orbital debris penetrations has nearly been completed across the Shuttle fleet.

There are other product-improvement efforts that can further enhance the safety and operability of the Space Shuttle, particularly if it is to fly for an additional 10 years or more. Delaying the implementation of these improvements will expose flight crews to higher levels of risk for longer than necessary.

Also under consideration is the slippage of scheduled Orbiter Major Modifications [OMM's]. This slippage may initiate a damaging trend, as budgets at NASA are not expected to improve. Delayed maintenance will delay incorporation of the upgrades creating detrimental fleet-wide implications. We prudently conduct scheduled OMM's, which we believe are essential to ensuring the integrity of the vehicle. Onschedule, fleet-wide modifications are necessary and prudent—consistency in configuration of the Orbiters is a must for training, safety, and reliability of operations.

USA believes that proposed cancellations or reductions in the Space Shuttle upgrades budget are due to shortfalls in available NASA budgets, and are not the result of the projects' lack of contribution to overall Shuttle safety improvements. USA believes that NASA policy should be to dedicate the entire amount of funds provided by the Congress for safety upgrades to the highest priority Space Shuttle safety up-

grades initiatives. If technological challenges make it impossible to move aggressively forward on one project, NASA should revise its timetable for implementation or redirect to the next project, rather than reprogramming the funds for other purposes.

The continued, safe operation of the Space Shuttle is paramount until its replacement vehicle is in place.

Infrastructure

Space Shuttle ground facilities are essential to safe and reliable operation of the Shuttle fleet. Crumbling equipment has already begun to adversely affect program performance and safety. Necessary upgrades to the infrastructure supporting the Shuttle program at the four Human Space Flight Centers (KSC, JSC, MFSC, SSC) can no longer be ignored.

NASA's own Space Flight Advisory Committee (SFAC), a Subcommittee of the NASA Advisory Council, recently reported that the Shuttle might be operational for at least a decade beyond its originally predicted 2012 lifetime. Two quotes from the 2000 SFAC Report are apropos at this point: *"For a system that will go well beyond the 2012 timeframe, attention must be given to this infrastructure. This should be a separate budget initiative";* and, *"Flight hardware upgrades alone won't keep Shuttles operating into the 2020's without ground upgrades also."*

Unfortunately, for years the NASA budget has not included funding for critical Shuttle infrastructure projects. Infrastructure revitalization appears to have become the "unwanted stepchild" of the budget process. The need to address infrastructure is a well-documented issue and represents a glaring deficiency in the NASA budget. Eroding infrastructure is creating long-term issues of reliability and supportability. There have been incidents where eroding infrastructure has created serious safety concerns and launch delays. Some of the infrastructure impacts and concerns include:

In the Launch Control Center (LCC), operators have had to change firing rooms for each of the last two launches because of computer interface failures.

Within the last six months, the Vehicle Assembly Building (VAB) had to shut down during stacking because of antiquated load breaker switches, which have a potential to explode and burn.

Although NASA has spent millions of dollars to crutch the crumbling 8-acre VAB roof and corroded exterior paneling on the facility, paneling designed to withstand winds in excess of 100 mph, is being blown off the facility at winds of half the design load.

The corrosive salt air environment of the Florida coast and launch plume impingement on the Shuttle launch pads result in a continuing battle against corrosion. Although the launch pads are periodically refurbished, the extensive amount of structure and operational activity restrictions has resulted in serious corrosion problems that need attention.

There are also corrosion and obsolescence issues with respect to the crawler/transporters and the mobile launch platforms that have been in service since Apollo.

Power, water, high-pressure gas, steam, and communications cabling distribution systems are suffering increasing failures due to age degradation and obsolescence. These basic utility distribution systems, at multiple operational locations, have outlived their design life.

One-of-a-kind test equipment used for flight hardware repairs and spare parts production have been in service since the early 1970's and are not expected to last through the now-extended Shuttle program life.

At JSC, outdated, unsupported computer systems operated by obsolete computer languages are performing critical flight software validation. In some cases, these systems are still loaded with punch cards.

The Electrical Power Systems Laboratory (EPSL), a one-of-a-kind replica of the Space Shuttle Electrical Power Distribution and Control System, is over 20 years old. Trends indicate major maintenance costs in the near term unless major updates in test equipment, facilities, and maintenance of this unique Shuttle asset are made.

At Stennis Space Center, propellant barges are in dire need of having their old mechanical and electrical systems replaced as well as having their hulls overhauled in dry dock. The barges operate in a harsh, corrosive atmosphere on a continuous basis. Barge overhaul has not occurred in over 15 years, yet, the Coast Guard recommends every 5 years. Additionally, recent operating experience and inspection of the barges indicate a loss or compaction of vessel insulation.

Large High Pressure Industrial Water (HPIW) Pumps that provide water for flame bucket cooling and deluge water to the Shuttle main engine test stands are in need of refurbishment. These pumps were installed at Stennis Space Center in

the mid-1960's. The rotating elements of the pumps and gearboxes need to be replaced to assure reliable service.

One half of annual maintenance budgets are spent band-aiding systems that are failing and then maintaining the band-aids, which becomes an additional maintenance burden. Expensive makeshift fabrications are a common occurrence as obsolescent spare parts and replacement units become harder and harder to acquire.

We believe infrastructure improvements can wait no longer. The Federal Government must begin to budget annual funds to address NASA's prioritized list of infrastructure projects.

Shuttle Operations

USA has become increasingly concerned that NASA will resort to reductions in the number of Shuttle flights as a stopgap method of accounting for anticipated shortfalls in its budget. Reduction of the number of Shuttle flights presents serious erosion in the capability of NASA to engage in human space flight activities. USA does not believe that a reduction in space flights is in the best interest of the nation. Moreover, such an approach fails to recognize the impact of flight rate on program costs.

The Shuttle program's extraordinary achievement in operational efficiencies was driven by NASA's desire to help sustain the Shuttle program, thus assuring that the workhorse of the nation's Human Space Flight programs would be available to meet the full demands of research and human development of space. Reducing the number of flights as a budgetary tool wipes out years of developing these operating efficiencies. At some point, reduced activity eliminates operating efficiencies and results in unjustifiable increased operating costs on a per mission basis. A flight schedule of at least six flights per year must be maintained to sustain the efficiency of the Shuttle Program. Flight reductions also threaten to seriously erode and irreparably harm the entire Human Space Flight program. Reducing the flight schedule below six flights per year will force a delay in the pace of the Space Station assembly thereby driving further ISS cost growth as the assembly process stretches in time. A decision to limit Shuttle flights would also severely limit opportunities for space based scientific research, which remains a top priority for the Congress.

Shuttle Workforce

The Shuttle workforce is at the lowest number of personnel it has ever been, and yet, through numerous efficiencies, it is achieving the aggressive goals of the Space Shuttle Program with the best record in its history of on-time launches (excluding weather, the last 6 missions launched without delays) and lowest number of in-flight anomalies (IFA) (averaged 20 IFAs in FY92 and steadily decreased to an average of 4 in FY00). The workforce total has stabilized over the past two years and morale is high. Even with the prospect of a lower flight rate, the demands on the workforce are increasing due to aging hardware, upgrades implementation, and normal lifecycle modifications. We need to be ever watchful that this very talented and dedicated workforce is protected and augmented when necessary. The experience of our management, engineering, and technician personnel will keep an aging Shuttle program at its highest level of efficiency. The dedication and skill of this workforce is the cornerstone of Shuttle safety.

Summary

Mr. Chairman and Members of the Subcommittee, USA is proud to operate this unique and indispensable national asset. The Space Shuttle is a critical part of the nation's space infrastructure and must continue to fly safely for at least another decade, possibly longer. To ensure continued safe and efficient operation of the nation's Shuttle fleet, NASA and USA must pursue vehicle hardware, processing and ground facility improvements. Safety, maintainability and obsolescence issues must not be allowed to cripple the progress of our nation's Human Space Flight program while next generation systems are being developed. Given the likely lead times associated with the definition, funding and development of a new human-rated space vehicle, the Space Shuttle should be acknowledged and supported as the primary method for humans to reach the ISS throughout the Station's life.

Over the past decade, the Space Shuttle program has done an outstanding job of continuing to fly the Shuttle safely and reliably while reducing costs. The Space Shuttle program is now under-funded. If we hope to continue our world leadership role in human space flight, it is imperative that adequate funding be provided to keep the Shuttle flying safely and reliably, including specific funding for Shuttle upgrades and infrastructure revitalization.

Thank you for this opportunity to testify before your Subcommittee. I will be happy to answer any questions you might have.

Senator WYDEN. Thank you very much for some very helpful testimony.

Mr. Blomberg, I think you heard me address one of the comments you had made earlier, because I was particularly struck with this assessment you made that it is hard to know when you are getting close to the line. I did not read into the record at that time that you stated, apparently somewhat thankfully, that fortunately you did not have to get into the budget issues in the past.

My guess is, that is going to have to change in the days ahead, because these calls are so difficult, so gut-wrenching, with respect to the choices we are making, but we are very pleased that there is an independent safety advisory group, and that you all are part of it, and why don't you go ahead.

STATEMENT OF RICHARD D. BLOMBERG, CHAIR, AEROSPACE SAFETY ADVISORY PANEL, AND PRESIDENT, DUNLOP & ASSOCIATES, INC.

Mr. BLOMBERG. Thank you, Mr. Chairman, and distinguished Members of the Subcommittee. I am pleased to be here today to summarize the Aerospace Safety Advisory Panel's current view of Space Shuttle safety. Both NASA and its contractors are handling near-term Space Shuttle safety admirably. Our primary concern, therefore, relates to the long-term picture, which has seemingly deteriorated since we highlighted it in our last annual report, which was last February.

The Space Shuttle cannot continue indefinitely at an acceptable level of risk unless appropriate steps are taken now. There are four areas that we on the panel believe are critical to long-term Space Shuttle safety, and many of them have been mentioned, but I think it is worth reiterating them. The first deals with flight system improvements to reduce the risks associated with the servicing and use of the flight hardware. Unfortunately, budgetary pressures have forced the Space Shuttle program to eliminate or defer many needed upgrades. The panel does not think this is prudent, because it means the system must continue to operate at a higher risk level than is necessary, resulting in a lost safety opportunity.

Under present guidelines, upgrades must be funded at the expense of activities needed to continue flying safely in the present. No program should be forced into a position in which tradeoffs between current and future safety are required. Safety should be foremost forever.

The panel cautions that now is not the time for significant cutbacks. At this stage in the life of a complex vehicle that will likely remain in service for several more decades, increased rather than diminished risk reduction efforts are necessary.

Our second focal area relates to the renewal of the ground infrastructure, and we include in that facilities, ground support equipment, and test and checkout gear, not just the buildings. These assets, like the vehicle itself, are aging. Much maintenance and improvement of this infrastructure has been deferred to conserve resources for operations. As a result, there is a large backlog of restoration and upgrade work. If needed efforts are delayed further, it may become impossible to catch up.

Aging infrastructure becomes unreliable. Safety can be compromised when systems fail at inopportune times or multiple simultaneous failures occur, and the risk of this goes up as infrastructure ages.

The third area requiring attention is logistics. An aging flight vehicle faces logistics challenges not only from wear and tear, but also from obsolescence. Some suppliers lose skills when they stop production. Others go out of business, or lose interest in maintaining capabilities when relegated to a minor support role.

Space Shuttle logistics are hampered by a lack of sufficient assets to support the program for its likely service life. Where total inventory is adequate, flight-ready spares are still often less than desirable, because of slow repair turn-around times. NASA must analyze its logistics needs for the entire projected life of the Space Shuttle, and adopt a realistic program for acquiring and supporting sufficient numbers of suitable components and maintaining a key supplier base. Acquisitions must be made soon because of the long lead times for some complex, safety-critical Space Shuttle components.

The final area I would like to highlight deals with work force. NASA and its contractors are inexorably losing experienced workers to retirement. Previous downsizing and hiring freezes that have already been mentioned have limited the available numbers of fully qualified successors. This projected loss of experience need not be detrimental to future safety if current planning is adequate to present the next generation of Space Shuttle managers with reasonable tasks. The knowledge and experience of current personnel must be captured and transferred to the future work force if safety and efficiency are to be maximized.

In summary, in order to fly safely until 2020 and beyond, and we firmly believe that this vehicle will be the human space flight vehicle for this nation during that period, the Space Shuttle will need improvements, additional care, infrastructure revitalization, better logistics, a skilled and experienced work force, and development of an operational posture consistent with the capabilities of that work force. The longer that these vital steps are postponed, the harder they will be to accomplish, the more they will cost, and the higher will be the safety risk.

The preferred alternative is to acknowledge now the role of the Space Shuttle as our human space flight vehicle for the foreseeable future, and to care for the total system appropriately in a timely manner.

As Senator Wyden quoted, the boundary between safe and unsafe operations can never be well-defined. As equipment and facilities age, and work force experience is lost, the likelihood that the line will be inadvertently crossed, even by well-meaning managers, increases. The best way to prevent problems is to be proactive and continuous with risk reduction efforts. The panel fears that the Space Shuttle program is not being allowed to do this, and in fact has been forced to forego appropriate long-term planning in order to maximize the safety of present operations. This is not a wise approach, and we hope it will not continue.

I thank you for this opportunity to present the thoughts of the Aerospace Safety Advisory Panel, and I stand ready to answer any questions you might have.

[The prepared statement of Mr. Blomberg follows:]

PREPARED STATEMENT OF RICHARD D. BLOMBERG, CHAIR, AEROSPACE SAFETY ADVISORY PANEL, AND PRESIDENT, DUNLOP & ASSOCIATES, INC.

Mr. Chairman and Distinguished Members of the Subcommittee:

I am pleased to appear before you today to summarize the Aerospace Safety Advisory Panel's current position on issues relevant to the safety of the Space Shuttle. The Subcommittee's focus on both the short-term and the post-2012 era is particularly germane. The Panel has focused much recent attention on the clear dichotomy between future Space Shuttle risk levels and the extent of current planning and investment directed at operating an aging space vehicle for the foreseeable future—to 2020 and beyond. Our most recent *Annual Report* delivered to the NASA Administrator last February highlighted the issues. We noted that efforts of NASA and its contractors were being primarily addressed to the immediate safety needs of the Space Shuttle. Little effort was being expended on the long-term safe use of the system. The overarching theme of our report, therefore, was the need for NASA, the Administration and the Congress to use a longer, more realistic planning horizon when making decisions with respect to the Space Shuttle.

In the months since last year's report was prepared, the long-term situation has deteriorated. Budget constraints imposed on NASA's human spaceflight programs have forced the Space Shuttle program to adopt an even shorter planning horizon in order to continue flying safely. As a result, more items that should be addressed now are being deferred. This adds to the backlog of restorations and upgrades required for safety and continued efficient operations and postpones many risk reduction benefits. The resulting situation is suboptimal at best and gives the Panel cause for significant long-term concern. NASA needs a reliable human rated space vehicle to reap the full benefits of the International Space Station (ISS), and the Panel believes that, with adequate planning and investment, that vehicle can be the Space Shuttle.

Before addressing our concerns, it is important to stress that the Panel does not believe that safety has been compromised at present. NASA and its contractors maintain an excellent level of safety consciousness, and this has contributed to significant flight achievements. The defined requirements for flying at an acceptable level of risk are always met. Increasingly, though, these requirements can only be achieved through the innovative and tireless efforts of an experienced workforce. As hardware wears out and veterans retire, the program will inevitably lose some of this compensatory ability. The options will then be to accept increased risk or to ground the fleet until time-consuming improvements and repairs can be accomplished. Neither of these is an acceptable option when there are clearly defined paths to reduce risk and increase operational reliability in the future.

The Panel believes that four areas are critical to the long-term safe operation of the Space Shuttle:

- Flight system improvements—Reducing the risks associated with the servicing and use of flight hardware and compensating for obsolescence and wear.
- Renewal of the ground infrastructure—Ensuring that the facilities, ground support equipment and test and checkout gear used with the Space Shuttle are fully capable and supportive of operations at the lowest possible risk.
- Logistics—Providing for the timely availability of properly functioning components throughout the projected life of the Space Shuttle.
- Workforce—Providing for the continuing availability of critical skills and the retention of experienced personnel.

Flight System Improvements

The Space Shuttle is not unique as an aging aerospace vehicle that still possesses substantial flight potential and has yet to be superseded by significant new technology. Any replacement for the Space Shuttle started now would likely take a decade or more to be designed, built and certified and likely would not be materially more capable than the current system with appropriate updates. Commercial airlines and the military have faced the same situation and have implemented timely

product improvement programs for older aircraft to provide many additional years of safe, capable and cost effective service.

The Space Shuttle program is not presently able to follow this proven approach. Responding to budgetary pressures has forced the program to eliminate or defer many already planned and engineered improvements. Some of these would directly reduce flight risk. Others would improve operability or the launch reliability of the system and are therefore potentially related to safety. In addition to the obvious safety concerns related to loss of vehicle and crew, we view anything that might ground the Space Shuttle while the ISS is inhabited as unnecessarily increasing risk. The Panel also does not think it is prudent to delay ready to install safety upgrades and to continue to operate at a higher risk level than is necessary.

An example of a potentially valuable improvement that has recently been dropped is the electric auxiliary power unit (EAPU). This upgrade can reduce risk both on the ground and in flight through the elimination of hydrazine and the high-speed turbo-machinery characteristic of the current auxiliary power unit (APU). It can also improve operability by doing away with the use of cumbersome Self Contained Atmospheric Protective Ensemble (SCAPE) suits and the need to clear the work area during many APU ground-processing steps. Development of an acceptable EAPU will require some battery technology advances and weight reduction efforts. If the Space Shuttle is to fly until 2020 and beyond, it would appear that an investment in this type of multi-pronged improvement would be well justified. Under present guidelines, however, the human spaceflight program would have to fund EAPU development and certification at the expense of activities needed to continue flying safely in the present. No program should be forced into a position in which tradeoffs between current and future safety are required. Total risk can only be minimized if managers are free to make decisions with full recognition of the entire expected life cycle of the system for which they are responsible.

Also, if the Space Shuttle does not introduce the EAPU or another replacement, it must rely on the present hydrazine-powered APU for the life of the program. This will require focusing additional current attention on ensuring the long-term availability of APU components and maintaining the ability of the supplier to provide support.

Other improvements to the orbiter and the other Space Shuttle elements are being delayed in order to accommodate current budget needs. This type of "stretch out" usually ends up costing a program significant additional funds in the long run. More importantly, when risk reduction efforts, such as the advanced health monitoring for the Space Shuttle Main Engines, Phase II of the Cockpit Avionics Upgrade, orbiter wire redundancy separation, the orbiter radiator isolation valve and the helium auxiliary power unit for the solid rocket boosters, are deferred, astronauts are needlessly exposed to current levels of flight risk for longer than necessary. This is a lost opportunity that is not offset by any real life cycle cost saving for the program.

The Panel cautions that now is not the time for significant cutbacks. At this stage in the life of a complex vehicle that will likely remain in service for several more decades, increased rather than diminished risk reduction efforts are essential. NASA must focus on applying the best available technologies to increasing the safety of the total system.

Ground Infrastructure

In order to fly safely, the Space Shuttle must be supported by a properly functioning ground infrastructure including facilities, ground support equipment and test and checkout gear. These assets, like the vehicle itself, are aging. Much maintenance and improvement of this infrastructure has already been deferred to conserve resources for operations. As a result, there is a large backlog of restoration and upgrade work. The sheer magnitude of this backlog means that it will take some time to bring the infrastructure back to an acceptable condition if the available numbers of trained and experienced managers and engineers are applied to the task and funding is available. Unfortunately, rather than improving, the situation becomes worse each year. If restoration continues to be delayed, it will reach a point at which it may be impossible to catch up.

Aging infrastructure becomes unreliable. At best, this will be a costly nuisance when failures delay launches. At worst, safety can be compromised when systems fail at inopportune times or multiple, simultaneous failures occur. As individual system reliability goes down, the likelihood of conjoint failures typically increases. Often, these multiple malfunctions have safety implications when the individual failures of which they are composed do not. The Panel is particularly concerned about the infrastructure at the Kennedy Space Center. The data cables leading to the launch pads and the deteriorating roof and siding panels on the Vehicle Assem-

bly Building are examples of weak spots that could blossom into full-fledged safety or operations issues.

Much of the Space Shuttle ground infrastructure dates to the Apollo era or earlier. It will be needed for at least another 20 years of Space Shuttle operations. In order to keep these critical parts of the system safe and fully supportive of the overall program, NASA needs to revitalize them as expeditiously as possible. If the infrastructure is updated and kept viable, it can also be a legacy to any vehicle that supersedes the Space Shuttle.

Logistics

A safe flight program needs a viable supply chain that ensures the availability of functionally appropriate and reliable spare parts. An aging flight vehicle faces logistics challenges not only from wear and tear but also from obsolescence. Suppliers often lose skills when they stop production. Some go out of business or lose interest in maintaining capabilities when relegated to a minor support role. Technological advances can also strain the logistics function when new, safer approaches to subsystems become available and must be phased in.

Space Shuttle logistics, although handled admirably by NASA and its contractors, is hampered by a lack of assets. Simply, the program has inadequate spare parts for many key subsystems. The Ku-band antenna is an example of a component for which the available stock is simply not sufficient. Where total inventory is adequate, flight-ready spares are still often less than desirable because of slow repair turnaround times. The logistics problem facing the Space Shuttle program is exacerbated by the long lead times for the manufacture of many critical components. The program is keeping up with logistics needs at present, but as the vehicle and its systems continue to age, problems can be expected. The response to these types of problems is often cannibalization of components from one vehicle to another. When cannibalization is used as a routine response to parts shortages, safety can be compromised.

Supportability is also a logistics concern. The nozzle for the Space Shuttle Main Engine (SSME) is one example. It retains its original design in which over 1,000 tubes for carrying coolant must be inserted by hand before they are brazed. This is a highly specialized task that is dependent on an eroding base of experienced contractor personnel. If the Space Shuttle is to fly safely for its entire anticipated life, attention must be focused now either on developing a new nozzle or on procuring a sufficient number of the existing nozzles to ensure the availability of safe components and the maintenance of the contractor's skill base.

Overall, NASA must analyze its logistics needs for the entire projected life of the Space Shuttle and adopt a realistic program for acquiring and supporting sufficient numbers of suitable components.

Workforce

Identifying and implementing essential vehicle, infrastructure and logistics improvements to the Space Shuttle system requires an appropriately trained, experienced and motivated workforce. Motivation does not seem to be an issue. When permitted, NASA and its contractors have been successful in recruiting some of the best and brightest engineers and technicians even at less than prevailing industry salaries. These individuals almost universally express a desire to work on the Space Shuttle and ISS because they represent inspiring and challenging opportunities. It is fair to say that when it comes to human spaceflight, the dream is still truly alive!

A complex endeavor such as the Space Shuttle, however, requires an experienced as well as a skilled and motivated workforce. Even with extensive training, inexperienced engineers and technicians are more prone to errors and less likely to detect problems than their experienced counterparts. NASA and its contractors are inexorably losing experienced workers to retirement. The hiatus in new hires during the 1990's has created a gap in the distribution of experience. As a result the successors to current managers will be operating without the same level of first-hand experience as their predecessors.

The projected loss of experience need not be detrimental to future safety if current planning is adequate to present the next generation of Space Shuttle managers with reasonable tasks. This can be accomplished by ensuring that they are given a vehicle that is upgraded to the maximum extent possible and fully ready to conduct its mission for a realistic service life. Allowing experienced personnel to plan and execute any needed upgrades before they retire will permit their successors to focus primarily on safe operations based on clearly defined requirements while they amass their own experience. It would also be advisable to capture as much of the knowledge of the existing workforce as possible so that it can be archived for use in the future.

Conclusion

The minimum risk approach is clear. In order to fly safely until 2020 and beyond, the Space Shuttle will need improvements, additional care, infrastructure revitalization, better logistics, a skilled and experienced workforce and development of an operational posture consistent with the capabilities of that workforce. The longer that these vital steps are postponed, the harder they will be to accomplish, the more they will cost and the higher will be the safety risk. The preferred alternative is to acknowledge now the role of the Space Shuttle as our human spaceflight vehicle for the foreseeable future and to care for the total system appropriately in a timely manner. This will give our astronauts a safer and more capable vehicle to operate and reduce life cycle cost.

Safety is an intangible whose true value is only appreciated in its absence. The boundary between safe and unsafe operations can never be well defined. As a result, even the most well meaning managers may not know when they cross it. Nobody would deliberately jeopardize Space Shuttle safety. But, as equipment and facilities age and workforce experience is lost, the likelihood that the line will be inadvertently breached increases. The best way to prevent problems is to be proactive and continuous with risk reduction efforts. The Aerospace Safety Advisory Panel fears that the Space Shuttle program is not being allowed to do this and, in fact, has been forced to forego appropriate long-term planning in order to maximize the safety of present operations. This is not a prudent approach to an ongoing program, and we hope it will not continue. Long-term safety is best achieved by giving capable managers a realistic budget and permitting them to exercise reasonable engineering discretion. By analogy, we would all willingly fly *today* on an airline whose aging aircraft were as well cared for as the Space Shuttle. If, however, that airline had neglected preparations for the future as the Space Shuttle program has been forced to do, we would certainly not invest in its stock.

Thank you for the opportunity to present the thoughts of the Aerospace Safety Advisory Panel on this important topic.

Senator WYDEN. Thank you, Mr. Blomberg. Mr. Li.

STATEMENT OF ALLEN LI, DIRECTOR, ACQUISITION & SOURCING MANAGEMENT TEAM, U.S. GOVERNMENT ACCOUNTING OFFICE

Mr. LI. Thank you, Mr. Chairman, and at the risk of Senator Nelson thinking I am a bean-counter, my background is aerospace engineering, so I am not a bean-counter, so I hope I am on your good side here.

Senator NELSON. But you are a good bean-counter.

[Laughter.]

Mr. LI. Mr. Chairman and Members of the Subcommittee, I am pleased to be here today to discuss work force and safety issues facing NASA's Space Shuttle program. As requested, I will highlight the key points in our prepared statement.

Two years ago, the Shuttle program was at a critical juncture. Its work force had declined significantly since 1995, its flight rate was about to double to support assembling a space station, and costly safety upgrades were planned to enhance the Shuttle's safe operation until at least 2012.

For the purposes of today's hearing, we updated our prior work to reflect where NASA is today. First, the work force issue. While NASA is making progress in rebuilding its Shuttle work force, many challenges still remain. NASA's current budget request projects an increase of more than 200 full-time equivalent staff through fiscal year 2002. During the past 1½ years, NASA has added 191 new hires and 33 transfers to the Shuttle program. Agency officials told us that the new staff are being assigned in areas critical to Shuttle safety.

NASA has also focused more attention on human capital management and its annual performance plan, by outlining an overall strategy to attract and retain a skilled work force. Even with these gains, however, challenges lie ahead. For example, because many of the additional staff are new hires, they will require extensive training, and they will need to be effectively integrated into the Shuttle program. Also, NASA still needs to fully staff areas critical to Shuttle safety, deal with critical losses to retirement in coming years, and most of all, sustain management attention to human capital reforms.

As Senator Allen stated earlier, NASA's work force problems are not unique. Many agencies have also been contending with serious human capital shortfalls. This is why GAO recently added strategic human capital management to its list of federal programs and operations identified as high risk.

Turning now to the issue of Shuttle upgrades, we see some progress. I believe that NASA's ability to implement safety upgrades in a timely manner is uncertain. On the positive side, NASA has started to define and develop some specific Shuttle upgrades. For example, requirements for the cockpit's avionics upgrade have been defined. Also, Phase I of the main engine advanced health monitoring system is in development.

NASA officials at Johnson told us that staffing for the upgrade program is now adequate. According to these officials, Johnson has added about 70 people to the upgrade program, while Marshall has added about 60 people. We did not assess the quality or sufficiency of the added staff, but according to officials from the development office, the work force skill level has improved to the point where the program has a good skill base.

On the down side, the agency is still assessing the full package of its plan improvements, and some projects have already encountered funding and scheduling problems. NASA has not yet fully defined plan upgrades. Studies on particular projects such as developing a crew escape system are not expected for sometime. Moreover, our previous concerns with the technical maturity and potential cost growth of particular projects have proven to be warranted.

For example, implementation of the electric APU has been delayed indefinitely because of technical uncertainties and cost growth. Also, the estimated cost of the Phase II of the main engine advanced health monitoring system has almost doubled, and NASA has canceled the proposed development of a Block III main engine improvement because of technological costs and schedule uncertainties.

Compounding these challenges is the uncertainty surrounding the long-term future of the Shuttle. NASA is attempting to develop alternatives to the Shuttle, but it is not yet clear what these alternatives will be, and when this will happen. I recently testified before the House Science Committee on NASA's Space Launch Initiative. This is a risk reduction effort enabling NASA and industry to make a decision in the 2006 timeframe on whether to proceed with the full-scale development of a reusable launch vehicle, also known as an RLV. A future RLV is envisioned to significantly reduce the cost of sending payloads to space, and would be an alternative to the Shuttle.

However, as illustrated by the difficulties NASA experienced with the X–33 RLV technology demonstrator, this is no easy task. Because an exact timeframe for the Shuttle's replacement cannot be determined at this time, Shuttle work force and upgrade issues will need to be considered without fully knowing how the program will evolve over the long run.

In conclusion, Mr. Chairman, NASA has made a start at addressing serious work force problems that could undermine Shuttle safety. It has also begun undertaking the important task of making needed safety and supportability upgrades. Nevertheless, the challenges ahead are significant. NASA is operating in an environment of uncertainty as to when the Shuttle will be replaced, and is still contending with the effects of its downsizing effort. As such, it will be exceedingly important that NASA sustain its attention and commitment to making Shuttle operation as safe as possible.

Mr. Chairman, this concludes my summary statement.

[The prepared statement of Mr. Li follows:]

PREPARED STATEMENT OF ALLEN LI, DIRECTOR, ACQUISITION & SOURCING MANAGEMENT TEAM, U.S. GOVERNMENT ACCOUNTING OFFICE

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss workforce and safety issues facing the National Aeronautics and Space Administration's (NASA) Space Shuttle program. As requested for this hearing, we have updated the information we provided to this Subcommittee in a March 2000 testimony and in an August 2000 report.[1] At the time, the Space Shuttle program was at a critical juncture: its workforce had declined significantly since 1995, its flight rate was to double over that of recent years to support the assembly of the International Space Station, and costly safety upgrades were planned to enhance the Space Shuttle's safe operation until at least 2012.

We reported that workforce reductions were jeopardizing NASA's ability to safely support the Shuttle's planned flight rate. For instance, many areas critical to safety were not sufficiently staffed by qualified workers. Recognizing the need to revitalize the Shuttle's workforce, NASA terminated its downsizing plans for the Shuttle program in December 1999 and initiated efforts to hire new staff. Furthermore, we also reported that NASA faced a number of programmatic and technical challenges in its efforts to develop and begin equipping the Shuttle fleet with a variety of safety and supportability upgrades over the next 5 years. These included a demanding schedule and undefined design and workforce requirements.

Today, I will discuss NASA's current progress in addressing these workforce and safety issues and the challenges still ahead. In brief, we found that NASA is making progress in revitalizing the Shuttle program's workforce. NASA's current budget request projects an increase of more than 200 full-time equivalent staff through fiscal year 2002. NASA has also focused more attention on human capital management in its annual performance plan by outlining an overall strategy to attract and retain a skilled workforce. Even with these gains, however, there are still considerable challenges ahead. For example, because many of the additional staff are new hires, they will require considerable training, and they will need to be effectively integrated into the Shuttle program. Also, NASA still needs to fully staff areas critical to Shuttle safety; deal with critical losses due to retirements in the coming years; and, most of all, sustain management attention to human capital reforms. NASA's workforce problems are not unique. Many agencies have also been contending with serious human capital shortfalls. We recently added strategic human capital management to our list of federal programs and operations identified as high risk. Moreover, while NASA is making strides in revitalizing its workforce, its ability to implement safety upgrades in a timely manner is uncertain. NASA is still assessing the full package of its planned improvements, and some projects have already encountered funding and scheduling problems. Overcoming challenges related to the up-

[1] See *Space Shuttle: Human Capital Challenges Require Management Attention* (GAO/T–NSIAD–00–133, Mar. 22, 2000) and *Space Shuttle: Human Capital and Safety Upgrade Challenges Require Continued Attention* (GAO/NSIAD/GGD–00–186, Aug. 15, 2000).

grades is critical since NASA will be relying on the Space Shuttle longer than originally anticipated.

Background

The Space Shuttle is the world's first reusable space transportation system. It consists of a reusable orbiter with three main engines, two partially reusable solid rocket boosters, and an expendable external fuel tank. Since it is the nation's only launch system capable of carrying people to and from space, the Shuttle's viability is important to NASA's other space programs, such as the International Space Station. NASA operates four orbiters in the Shuttle fleet.

Space systems are inherently risky because of the technology involved and the complexity of their activities. For example, thousands of people perform about 1.2 million separate procedures to prepare a Shuttle for flight. NASA has emphasized that the top priority for the Shuttle program is safety.

The Space Shuttle's workforce shrank from about 3,000 to about 1,800 full-time equivalent employees from fiscal year 1995 through fiscal year 1999. A major element of this workforce reduction was the transfer of Shuttle launch preparation and maintenance responsibilities from the government and multiple contractors to a single private contractor. NASA believed that consolidating Shuttle operations under a single contract would allow it to reduce the number of engineers, technicians, and inspectors directly involved in the day-to-day oversight of Shuttle processing. However, the agency later concluded that these reductions caused shortages of required personnel to perform in-house activities and maintain adequate oversight of the contractor.

Since the Shuttle's first flight in 1981, the Space Shuttle program has developed and incorporated many modifications to improve performance and safety. These include a super lightweight external tank, cockpit display enhancements, and main engine safety and reliability improvements. In 1994, NASA stopped approving additional upgrades, pending the potential replacement of the Shuttle with another reusable launch vehicle.

NASA now believes that it will have to maintain the current Shuttle fleet until at least 2012, and possibly through 2020. Accordingly, it has established a development office to identify and prioritize upgrades to maintain and improve Shuttle operational safety.

Progress and Challenges in Revitalizing the Shuttle Workforce

Last year, we reported that several internal studies showed that the Shuttle program's workforce had been negatively affected by downsizing.[2] These studies concluded that the existing workforce was stretched thin to the point where many areas critical to Shuttle safety—such as mechanical engineering, computer systems, and software assurance engineering—were not sufficiently staffed by qualified workers. (Appendix I identifies all of the key areas that were facing staff shortages). Moreover, the workforce was showing signs of overwork and fatigue. For example, indicators on forfeited leave, absences from training courses, and stress-related employee assistance visits were all on the rise. Lastly, the program's demographic shape had changed dramatically. Throughout the Office of Space Flight, which includes the Shuttle program, there were more than twice as many workers over 60 years old than under 30 years old. This condition clearly jeopardized the program's ability to hand off leadership roles to the next generation.

According to NASA's Associate Administrator for the Office of Space Flight, the agency faced significant safety and mission success risks because of workforce issues. This was reinforced by NASA's Aerospace Safety Advisory Panel, which concluded that workforce problems could potentially affect flight safety as the Shuttle launch rate increased.

NASA subsequently recognized the need to revitalize its workforce and began taking actions toward this end. In October 1999, NASA's Administrator directed the agency's highest-level managers to consider ways to reduce workplace stress. The Administrator later announced the creation of a new office to increase the agency's emphasis on health and safety and included improved health monitoring as an objective in its fiscal year 2001 performance plan.[3] Finally, in December 1999, NASA

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[2] Several workforce studies had been completed since 1996, including *Independent Assessment of the Shuttle Processing Directorate Engineering and Management Processes,* NASA Human Exploration and Development of Space Independent Assessment Office, (Nov. 4, 1999); *Annual Report for 1999,* Aerospace Safety Advisory Panel (Feb. 2000); and *Report to Associate Administrator, Office of Space Flight, Space Shuttle Independent Assessment Team* (Mar. 7, 2000).

[3] The Government Performance and Results Act of 1993 requires agencies to prepare annual performance plans. The purpose is to improve the efficiency of all federal agencies, under the goals of improving management, effectiveness, and public accountability; improving congres-

terminated its downsizing plans for the Shuttle program and initiated efforts to begin hiring new staff.

Following the termination of its downsizing plans, NASA and the Office of Management and Budget conducted an overall workforce review to examine personnel needs, barriers to achieving proper staffing levels and skill mixes, and potential reforms to help address the agency's long-term requirements. In performing this review, NASA used GAO's human capital self-assessment checklist.[4] The self-assessment framework provides a systematic approach for identifying and addressing human capital issues and allows agency managers to (1) quickly determine whether their approach to human capital supports their vision of who they are and what they want to accomplish and (2) identify those policies that are in particular need of attention. The checklist follows a five-part framework that includes strategic planning, organizational alignment, leadership, talent, and performance culture.

Recent Actions Taken by NASA

NASA has taken a number of actions this year to regenerate its Shuttle program workforce. Significantly, NASA's current budget request projects an increase of more than 200 full-time equivalent staff[5] for the Shuttle program through fiscal year 2002—both new hires and staff transfers. According to NASA, from the beginning of fiscal year 2000 through July 2001, the agency had actually added 191 new hires and 33 transfers to the Shuttle program. These new staff are being assigned to areas critical to Shuttle safety—such as project engineering, aerospace vehicle design, avionics, and software—according to NASA. As noted earlier, appendix I provides a list of critical skills where NASA is addressing personnel shortages.

NASA is also focusing more attention on human capital management in its annual performance plan. The Government Performance and Results Act requires a performance plan that describes how an agency's goals and objectives are to be achieved. These plans are to include a description of the (1) operational processes, skills, and technology and (2) human, capital and information resources required to meet those goals and objectives. On June 9, 2000, the President directed the heads of all federal executive branch agencies to fully integrate human resources management into agency planning, budget, and mission evaluation processes and to clearly state specific human resources management goals and objectives in their strategic and annual performance plans.

In its Fiscal Year 2002 Performance Plan, NASA describes plans to attract and retain a skilled workforce. The specifics include the following:

- Developing an initiative to enhance NASA's recruitment capabilities, focusing on college graduates.
- Cultivating a continued pipeline of talent to meet future science, math, and technology needs.
- Investing in technical training and career development.
- Supplementing the workforce with nonpermanent civil servants, where it makes sense.
- Funding more university-level courses and providing training in other core functional areas.
- Establishing a mentoring network for project managers.

We will provide a more detailed assessment of the agency's progress in achieving its human capital goals as part of our review of NASA's Fiscal Year 2002 Performance Plan requested by Senator Fred Thompson.

Alongside these initiatives, NASA is in the process of responding to a May 2001 directive from the Office of Management and Budget on workforce planning and restructuring.[6] The directive requires executive agencies to determine (1) what skills are vital to accomplishing their missions, (2) how changes expected in the agency's work will affect human resources, (3) how skill imbalances are being addressed, (4) what challenges impede the agency's ability to recruit and retain high-quality staff, and (5) what barriers there are to restructuring the workforce. NASA officials told

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sional decision-making on where to commit the nation's fiscal and human resources; and improving citizens' confidence in the government's performance.

[4] See *Human Capital: A Self-Assessment Checklist for Agency Leaders* (GAO/OCG–00–14G, Sept. 2000).

[5] Full-time equivalent is a measure of staff hours equal to those of an employee who works 40 hours per week in 1 year. Thus, a measure of 200 full-time equivalent staff does not necessarily represent the actual number of new hires.

[6] *Workforce Planning and Restructuring,* OMB Bulletin No. 01–07 (May 8, 2001).

us that they have already made these assessments. The next step is to develop plans specific to the space flight centers that focus on recruitment, retention, training, and succession and career development.

Remaining Workforce Challenges

If effectively implemented, the actions that NASA has been taking to strengthen the Shuttle workforce should enable the agency to carry out its mission more safely. But there are considerable challenges ahead. For example, as noted by the Aerospace Safety Advisory Panel in its most recent annual report, NASA now has the difficult task of training new employees and integrating them into organizations that are highly pressured by the Shuttle's expanded flight rates associated with the International Space Station.[7] As we stressed in our previous testimony, training alone may take as long as 2 years, while workload demands are higher than ever.

The panel also emphasized that (1) stress levels among some employees are still a matter of concern; (2) some critical areas, such as information technology and electrical/electronic engineering, are not yet fully staffed; and (3) NASA is still contending with the retirements of senior employees. Officials at Johnson Space Center also cited critical skill shortages as a continuing problem. Furthermore, NASA headquarters officials stated that the stress-related effects of the downsizing remain in the workforce. Addressing these particular challenges, according to the Aerospace Safety Advisory Panel, will require immediate actions, such as expanded training at the Centers, as well as a long-term workforce plan that will focus on retention, recruitment, training, and succession and career development needs.

Human Capital Shortfalls—A Governmentwide Problem

The workforce problems we identified during our review are not unique to NASA. As our January 2001 Performance and Accountability Series reports made clear, serious federal human capital shortfalls are now eroding the ability of many federal agencies—and threatening the ability of others—to economically, efficiently, and effectively perform their missions.[8] As the Comptroller General recently stated in testimony, the problem lies not with federal employees themselves, but with the lack of effective leadership and management, along with the lack of a strategic approach to marshaling, managing, and maintaining the human capital needed for government to discharge its responsibilities and deliver on its promises.[9] To highlight the urgency of this governmentwide challenge, in January 2001, we added strategic human capital management to our list of federal programs and operations identified as high risk.[10]

Our work has found human capital challenges across the federal government in several key areas.

- First, high-performing organizations establish a clear set of organizational intents—mission, vision, core values, goals and objectives, and strategies—and then integrate their human capital strategies to support these strategic and programmatic goals. However, under downsizing, budgetary, and other pressures, agencies have not consistently taken a strategic, results-oriented approach to human capital planning.
- Second, agencies do not have the sustained commitment from leaders and managers needed to implement reforms. Achieving this can be difficult to achieve in the face of cultural barriers to change and high levels of turnover among management ranks.
- Third, agencies have difficulties replacing the loss of skilled and experienced staff, and in some cases, filling certain mission-critical occupations because of increasing competition in the labor market.
- Fourth, agencies lack a crucial ingredient found in successful organizations: organizational cultures that promote high performance and accountability.

Progress and Challenges in Making Shuttle Safety Upgrades

At this time last year, NASA planned to develop and begin equipping the Shuttle fleet with a variety of safety and supportability upgrades, at an estimated cost of

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[7] See *Annual Report for 2000,* Aerospace Safety Advisory Panel.

[8] See *Performance and Accountability Series—Major Management Challenges and Program Risks: A Governmentwide Perspective* (GAO–01–241, Jan. 2001). In addition, see the accompanying 21 reports (numbered GAO–01–242 through GAO–01–262) on specific agencies.

[9] See *Human Capital: Taking Steps to Meet Current and Emerging Human Capital Challenges* (GAO–01–965T, July 17, 2001).

[10] See *High-Risk Series: An Update* (GAO–01–263, Jan. 2001). In addition, see *Human Capital: Meeting the Governmentwide High-Risk Challenge* (GAO–01–357T, Feb. 1, 2001).

$2.2 billion. These upgrades would affect every aspect of the Shuttle system, including the orbiter, external tank, main engine, and solid rocket booster.

Last year, we reported that NASA faced a number of programmatic and technical challenges in making these upgrades.

- First, several upgrade projects had not been fully approved, creating uncertainty within the program.
- Second, while NASA had begun to establish a dedicated Shuttle safety upgrade workforce, it had not fully determined its needs in this area.
- Third, the Shuttle program was subject to considerable scheduling pressure, which introduced the risk of unexpected cost increases, funding problems, and/or project delays. Specifically, the planned safety upgrade program could require developing and integrating at least nine major improvements in 5 years—possibly making it the most aggressive modification effort ever undertaken by the Shuttle program. At the same time, technical requirements for the program were not yet fully defined, and upgrades were planned to coincide with the peak assembly period of the International Space Station.

Since then, NASA has made some progress but has only partially addressed the challenges we identified last year. Specifically, NASA has started to define and develop some specific Shuttle upgrades. For example, requirements for the cockpit avionics upgrade have been defined. Also, Phase I of the main engine advanced health monitoring system is in development, and Friction Stir Welding on the external tank is being implemented.

In addition, according to Shuttle Development Office officials, staffing for the upgrade program is adequate. Since our last report, these officials told us that the Johnson Space Center has added about 70 people to the upgrade program, while the Marshall Space Flight Center has added another 50 to 60 people. We did not assess the quality or sufficiency of the added staff, but according to the development office officials, the workforce's skill level has improved to the point where the program has a "good" skill base.

Nevertheless, NASA has not yet fully defined its planned upgrades. The studies on particular projects, such as developing a crew escape system, are not expected to be done for some time. Moreover, our previous concerns with the technical maturity and potential cost growth of particular projects have proven to be warranted. For example, the implementation of the electric auxiliary power unit has been delayed indefinitely because of technical uncertainties and cost growth. Also, the estimated cost of Phase II of the main engine advanced health monitoring system has almost doubled, and NASA has canceled the proposed development of a Block III main engine improvement because of technological, cost, and schedule uncertainties.

Compounding the challenges that NASA is facing in making its upgrades is the uncertainty surrounding its Shuttle program. NASA is attempting to develop alternatives to the Space Shuttle, but it is not yet clear what these alternatives will be. We recently testified before the Subcommittee on Space and Aeronautics, House Committee on Science on the agency's Space Launch Initiative. This is a risk reduction effort aimed at enabling NASA and industry to make a decision in the 2006 time frame on whether the full-scale development of a reusable launch vehicle can be undertaken.[11] However, as illustrated by the difficulties NASA experienced with another reusable launch vehicle demonstrator—the Lockheed Martin X–33—an exact time frame for the Space Shuttle's replacement cannot be determined at this time. Consequently, Shuttle workforce and upgrade issues will need to be considered without fully knowing how the program will evolve over the long run.

In conclusion, NASA has made a start at addressing serious workforce problems that could undermine Space Shuttle safety. It has also begun undertaking the important task of making needed safety and supportability upgrades. Nevertheless, the challenges ahead are significant—particularly because NASA is operating in an environment of uncertainty and it is still contending with the effects of its downsizing effort. As such, it will be exceedingly important that NASA sustain its attention and commitment to making Space Shuttle operations as safe as possible.

Mr. Chairman, this concludes my statement. I would be happy to answer any questions that you or Members of the Subcommittee may have.

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[11] See *Space Transportation: Critical Areas NASA Needs to Address in Managing Its Reusable Launch Vehicle Program* (GAO–01–826T, June 20, 2001).

Contact and Acknowledgement

For further contact regarding this testimony, please contact Allen Li. Individuals making key contributions to this testimony included Jerry Herley, John Gilchrist, James Beard, Fred Felder, Vijay Barnabas, and Cristina Chaplain.

Appendix I: Space Shuttle Program Skill Shortfall Areas

In December 1999, the National Aeronautics and Space Administration (NASA) completed an internal workforce assessment focusing on the Office of Space Flight, which includes the Shuttle program. That assessment identified work areas in which NASA was experiencing skill shortfalls. At our request, NASA provided a listing of skill shortages in the Shuttle program. The areas the agency identified follow:

- Program/project management/project engineering
- Aerospace vehicle design and mission analysis
- Avionics
- Guidance, navigation, and control systems
- Materials analysis
- Mechanical engineering
- Thermal control
- Structural dynamics
- Vehicle dynamics
- Aircraft ground systems
- Human factors
- Environmental controls
- Robotic systems
- Computer systems
- Fluids (liquid propulsion systems)
- Information technology security
- Aerospace systems test engineering
- Software (applications and systems)
- Sensors and transducers
- Electrical engineering
- Software assurance engineering
- Flight assurance
- Quality engineering
- Reliability engineering
- Safety engineering
- Flight controls

Senator WYDEN. All right. Let us move now to Mr. O'Connor.

STATEMENT OF BRYAN D. O'CONNOR, DIRECTOR, ENGINEERING DIVISION, FUTRON CORPORATION

Mr. O'CONNOR. Mr. Chairman, Members of the Subcommittee, thank you very much for inviting me here to testify. My name is Bryan D. O'Connor, and I was the Chairman of the National Research Council's Committee on Space Shuttle Upgrades in 1998–1999.

Now, I know that goes back a little bit, but I think my purpose here today is to go back a little bit, about three years, and show you where we were with the upgrade situation back then, because that is what our committee was asked to do.

During fiscal year 1997, NASA lifted the design freeze that they had established the prior year, and they authorized the Space Shuttle program to dedicate about $100 million of its reserves each year to a new upgrade program. This program funded relatively minor modifications intended to improve safety, support missions, reduce obsolescence, and reduce costs. It also supported studies of potential major upgrades.

Implementation of any major upgrades, however, would necessarily be delayed until a high-level national decision scheduled

for the end of the decade was made on whether to phase out the Shuttle by the year 2012, or to continue operating it indefinitely.

At NASA's request, a committee of the National Research Council, the principal, operating arm of the National Academy, undertook an independent assessment of NASA's Space Shuttle upgrades program. Our committee looked at NASA's method for evaluating and selecting its upgrades. We also conducted a top-level technical assessment of several of the proposed Shuttle upgrades that had not yet been implemented.

The committee found that in spite of budget uncertainties at that time, and technical risks with the development of a Shuttle replacement, as well as existing national policy restrictions on the use of the Shuttle, NASA's approach appeared to be appropriate. The committee strongly supported their use of program goals, safety, schedule, supportability and cost to help prioritize these upgrades, and we suggested 25 specific improvements to the decision support process that they were using at that time.

Our committee believed that with a few improvements, a couple of the systems that they were using for decision support (one of which one of our panel members has mentioned here in terms of risk numbers, called the quantitative risk assessment system, and another one called decision support system) had the potential to be even more helpful aids and upgrade decisionmakers than they had been to that point.

Since the committee's report was published, events have dictated that NASA look at the Shuttle for longer term while difficult technology and market issues are worked out for its eventual replacement. At the same time, fiscal challenges with NASA's Human Space Flight programs require continued selectivity and prudence with Shuttle upgrade choices. The latest probablistic risk assessments for the Shuttle show that, although upgrades since the Challenger accident have improved the risk posture of the vehicle, it still falls well short of the kind of overall safety level NASA has required of future human-rated vehicles in its Space Launch Initiative (SLI), and even further below that required of military transports, as you have heard.

Considering the fundamental design and complexity of the Shuttle, it is my own personal opinion that no amount of money for upgrades will get it to those levels of reliability that we have as goals for that program. That does not mean we give up. While NASA works toward those worthy goals on SLI, they should continue looking with care at those affordable improvements to keep the Shuttle flying safely in an environment of component obsolescence. Moreover, it is equally important that they continue to pay very close attention to the people aspects of this complex system.

This unique, human-crewed space vehicle, with its high-risk propulsion and hydraulic control systems, and its extremely limited escape system, requires nothing short of full attention 100 percent of the time by the best 20,000-plus people that NASA and its contractors can field.

Thank you.

[The prepared statement of Mr. O'Connor follows:]

PREPARED STATEMENT OF BRYAN D. O'CONNOR, DIRECTOR, ENGINEERING DIVISION, FUTRON CORPORATION

Mr. Chairman and members of the Subcommittee, thank you for inviting me here to testify. My name is Bryan D. O'Connor. I was Chairman of the National Research Council's Committee on Space Shuttle Upgrades in 1998/99, and I hold a regular position as Director, Engineering Division at Futron Corporation in Washington, DC. As you know, the National Research Council (NRC) is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, chartered by Congress in 1863 to advise the government on matters of science and technology.

In May 1998, the National Aeronautics and Space Administration (NASA) asked the NRC to examine the agency's plan for further upgrades to the Space Shuttle system. The NRC was asked to assess NASA's method for evaluating and selecting upgrades and to conduct a top-level technical assessment of proposed upgrades. The committee finished its work in late 1998, and published its report in early 1999. NASA responded to the report in March 1999. The full report is available to the public through the National Academy Press. Attached to my written statement is the report's executive summary as well as NASA's written response.

At the time of the committee's assessment, NASA was looking ahead to a decision by the end of the decade to either begin a phase out of the Shuttle system, or to extend its operations beyond 2012. With this major decision still ahead of them it was difficult for NASA to plan with confidence on major upgrades, so their main efforts were being spent on those near term improvements that would make sense no matter what the decision might be. Flight safety was, as usual, the highest priority, and our committee looked at the upgrade selection process with that in mind. With only a few minor exceptions, we found their process and decision support tools consistent with safety and the other NASA priorities of launch schedule dependability, supportability of the system's aging components, and operations efficiency. Although we made no specific recommendations as to implementation of the various upgrade options, we did offer 25 recommendations for improvements in the upgrade selection process, most of which were agreed to and enacted by NASA.

Since the committee's report was published, events have dictated that NASA look at Shuttle for the long term while difficult technology and market issues are worked out for its eventual replacement. At the same time, fiscal challenges with NASA's human spaceflight programs require continued selectivity and prudence with Shuttle upgrade choices. The latest risk assessments for the Shuttle system show that changes since the Challenger accident have improved the risk posture of the vehicle by nearly an order of magnitude, but it still falls well short of the overall safety level NASA demands of future human rated vehicles. Considering the fundamental design and complexity of the Shuttle, it is my own personal opinion that no amount of money for upgrades will get it to the levels of reliability and operational cost that NASA has stated as its goals for the Space Launch Initiative (SLI). So, while the SLI works towards those worthy goals, NASA should continue looking with care at those affordable improvements that keep the Shuttle flying safely in an environment of component obsolescence. Moreover, it is equally important that they continue to pay close attention to the people aspects of such a complex system. This unique human-crewed space launch vehicle with its high risk propulsion and hydraulic control systems and extremely limited escape system will always need substantial hands on care and preparation between flights. It requires nothing short of full attention—100% of the time—by the best 20,000 people NASA and its contractors can field.

Attachments:

Executive Summary—Upgrading the Space Shuttle
NASA Response to the NRC Report on Space Shuttle Upgrades

EXECUTIVE SUMMARY—UPGRADING THE SPACE SHUTTLE

The Space Shuttle system has been modified many times since the first launch of Space Shuttle Columbia in 1981. During the 1980s, major upgrade programs were established to respond to problems and anomalies experienced during the initial flights and the Challenger accident. Additional upgrades were approved in the early 1990s to enable the Shuttle to visit the Mir space station and support the International Space Station. In 1996, however, the Shuttle program effectively ceased approving new changes to the Space Shuttle design to concentrate scarce resources on developing potential replacements for the Shuttle. The same year, the responsibility

for some operational elements of the Space Shuttle Program were transferred to the United Space Alliance (USA) corporation.

During fiscal year 1997, the National Aeronautics and Space Administration (NASA) lifted the "design freeze" and authorized the Space Shuttle Program to dedicate about $100 million of its reserves each year to a new upgrade program. This program funds relatively minor modifications intended to reduce obsolescence, support missions, improve safety, and reduce costs, as well as studies of potential major upgrades. Implementation of any major upgrades, however, will necessarily be held off until a high-level national decision scheduled for the end of the decade is made on whether to phase out the Shuttle by the year 2012 or to continue operating it indefinitely.

Information on potential upgrades to the Shuttle is collected, organized, and prioritized by the Space Shuttle Program Development Office, which reports to the manager of the Space Shuttle Program. Each candidate upgrade is designated as Phase I, Phase II, Phase III, or Phase IV, depending on when it was approved and its anticipated cost and effect on the Space Shuttle design (see Table ES–I).

Table ES–1 Upgrade Phases

Phase	Main Focus	Typical Cost	Status
I	Improving safety, supporting the International Space Station	>$100 million	Either completed or will be by 2000
II	Combating obsolescence	$10 to $50 million	Some underway; some in study phase
III	Enhancing Shuttle capability (does not change the fundamental Shuttle configuration)	$10s to $100s of millions	Studies only
IV	Enhancing Shuttle capability (changes the fundamental Shuttle configuration)	>$1 billion	Studies only

In addition to the phased upgrades, the USA corporation has limited incentives to initiate and implement cost-saving upgrades.

Choosing Upgrades

NASA uses its limited budget for Shuttle upgrades to fund minor upgrades with identifiable short-term benefits and to conduct preparatory studies for major upgrades that may be warranted if the Shuttle program is called upon to operate after 2012. In spite of budget uncertainties, technical risks with the development of a reusable launch vehicle (Shuttle replacement strategy), and existing national policy restrictions on Shuttle use, the committee believes that NASA's approach to upgrade planning is appropriate. Candidate upgrades are proposed to a central office, which prioritizes them with the assistance of tools that are under development. The committee commends NASA for its efforts to develop a formal process for evaluating and prioritizing upgrades.

Prioritizing and Selecting Upgrades

Decision makers in the Shuttle program are facing an uncertain future. They do not know how long the nation will want Shuttle flights to continue, the number of flights per year that will be required, or the missions (if any) beyond supporting the International Space Station (ISS) the Shuttle will be expected to perform. For these reasons, developing an appropriate process for selecting upgrades for implementation has been difficult. Other organizations, such as the U.S. Air Force, have faced similar situations, however, and NASA should evaluate their investment decision processes for upgrades and identify appropriate processes and investment strategies to emulate.

The committee strongly supports NASA's use of program goals to help prioritize upgrades. However, the Space Shuttle Program Development Office should restate the goals of the upgrade program to ensure that they reflect the upgrade program's actual priorities, are feasible, and are clearly understandable by everyone working in the program. NASA should also provide better incentives for the USA corporation (and any future prime contractors for Shuttle operations) to propose, fund, and implement upgrades to achieve the Shuttle program's goals. Whether or not a Shuttle

unique upgrade supports an increased flight rate should not be considered in the prioritization process unless NASA can prepare a viable business plan showing that (1) the Shuttle could attract enough additional business to justify the increased flight rate, (2) the Space Shuttle Program would not unfairly compete with commercial launch vehicles, and (3) the Shuttle, a national asset, would not be subjected to unnecessary risks.

NASA is taking steps to improve its process for selection of upgrade candidates for implementation. These steps are designed to provide a more visible quantitative comparison approach that should help balance some of the traditional internal and external political and other subjective pressures on the program.

One of the tools that NASA is using to help prioritize candidate upgrades is the quantitative risk assessment system (QRAS), a software tool being developed specifically for assessing risks to the Shuttle. The committee believes that this tool has the potential to be very helpful in assessing and comparing the impact of Shuttle upgrades on Shuttle safety. NASA should continue to increase the scope and capability of the QRAS system so that it provides better models of failures caused by human error, combinations of risks, abort modes, on-orbit hazards, reentry and landing hazards, and software problems. Until these improvements are made, the Space Shuttle Program Development Office should be very cautious in using QRAS to aid in prioritizing upgrades.

NASA is also funding development of the Decision Support System to assist in prioritizing upgrades. The committee believes that when this system is more mature, it will be a valuable tool. However, the current Decision Support System will require significant modifications before it can be a reliable input to the prioritization process. NASA should consider modifications that would place less emphasis on quantitative results and more on a clear, defensible decision process that takes into account all of the available evidence.

Upgrade cost estimates provided by NASA to the committee contained inconsistencies in their scope, assumptions, and basis. For these estimates to be helpful, the agency must ensure that they are as accurate as possible and are calculated consistently. All calculations, comparisons of costs and cost savings, and cost-benefit assessments should be based on fixed-year dollars and should include all of the costs associated with the upgrade, including hidden costs, such as integration costs and the cost of operating and maintaining the upgrade.

Improving Candidate Upgrades

To ensure that NASA can select the best upgrades for the Shuttle program, there must be a pool of high quality potential improvements. The Shuttle program can take steps to improve the pool of proposed upgrades such as external proposals, early compatibility studies, limits to software changes, and trade-off studies. The Space Shuttle Program Development Office should not consider proposed upgrades as stand-alone proposals, but where appropriate, should look for ways to combine upgrades (or features of upgrades) to efficiently meet future requirements.

Assessments of Proposed Upgrades

From the information presented to the committee, it is clear that a great deal of creative and useful work has been done to design and develop ongoing and proposed upgrades to the Space Shuttle system. The committee was able to assess the potential of some key upgrades to meet Space Shuttle Program goals, point out areas of technical or programmatic risk, and suggest alternatives. Figure ES–I shows the locations of selected representative upgrades in the Shuttle system.

Phase II Upgrades

Checkout Launch and Control System

The checkout launch and control system (CLCS) is an upgrade to the launch processing system used to check out, control, and process Shuttle flight systems, ground support equipment, and facilities at Kennedy Space Center. The current system is growing obsolete, and the CLCS upgrade will replace it with modern commercial hardware and software. Based on historical precedent, the committee believes that the large and complex CLCS upgrade is likely to experience schedule delays and budget overruns. NASA should audit the requirements, specifications, plans, schedules, development budgets, status, and life cycle costs of the CLCS project. The objective of this audit should not be to cancel the upgrade but to make more accurate estimates of the time and cost required to complete it and to identify potential problems early enough in the project to rectify them.

Protection from Micrometeoroids and Orbital Debris

As part of the Phase II upgrade program, the Shuttle orbiters will be modified during 1999 and 2000 to protect the radiators and the leading edge of the wings from meteoroids and orbital debris. Considering the predicted high level of risk from this hazard even after these modifications are made, the Space Shuttle upgrades program should solicit additional upgrade proposals for protecting the Shuttle from meteoroids and orbital debris.

Phase III Upgrades

Auxiliary Power Unit

Every Shuttle orbiter has three auxiliary power units (APUs) to pressurize the vehicle's hydraulic systems during ascent and reentry. NASA is studying a number of options for replacing the current APUs—which use toxic hydrazine propellant—with an electric system that would be safer and easier to maintain. NASA should continue studying potential modifications to the APUs to determine the costs, benefits, and appropriate scope of each upgrade. The development of electric power systems worldwide should be monitored for technologies and techniques that could improve an APU upgrade.

Avionics

The orbiter's current avionics system was conceived in the early 1970s but contains hardware that was added during the 1980s and 1990s. The objective of NASA's proposed avionics upgrade is to avoid the growing costs associated with obsolescent components by judiciously replacing hardware and, at the same time, positioning upgrades as components of a modern, functionally partitioned avionics architecture. NASA should continue this strategy and should develop and publish scaleable, long-term requirements and interface definitions for the future architecture.

Channel-Wall Nozzle

The channel-wall nozzle is a proposed replacement for the current Space Shuttle main engine nozzle. The channel-wall nozzle is a relatively simple design based on a manufacturing process developed in Russia. NASA plans to build the nozzle in Russia (through Rocketdyne's subcontractor Aerojet) to reduce development costs. If NASA decides to implement this upgrade, it should take steps to ensure that channel-wall nozzles are available in the United States, either by stockpiling additional nozzles or developing a channel-wall nozzle manufacturing capability in the United States.

Extended Nose Landing Gear

The proposed extended nose landing gear is a modification intended to reduce loads on the orbiter's landing gear. Based on work performed to date, the proposed upgrade appears to be a good design for reducing Shuttle landing loads. However, the existing nose landing gear meets current requirements, so NASA should pursue the upgrade only if future plans require that the Shuttle land with heavier payloads than are currently allowable.

Long-Life Fuel Cell

The orbiter's fuel cells provide electric power for the orbiter and water for the crew. Two distinct upgrades—longer-life alkaline fuel cells and proton exchange membrane (PEM) fuel cells—are being considered to replace the current cells. Modified alkaline cells would be similar to the current cells but would require less maintenance. The PEM cells would last longer, produce more power, and be less toxic than either the current or the improved alkaline cells. However, the PEM cell upgrade would involve an expensive and potentially open-ended technology research program. NASA should explore the costs and benefits of the PEM cell further before deciding on a new fuel cell. Planners of future space missions that could benefit from PEM fuel cells should be closely involved in these studies. These planners could help determine the value of PEM cells for future missions, influence the design of the Shuttle's PEM cells so that they will be applicable to future missions, and, perhaps, provide funding.

Nontoxic Orbital Maneuvering System/Reaction Control System

This upgrade would modify the Shuttle Orbiter's orbital maneuvering and reaction control systems to use nontoxic liquid oxygen and ethanol propellants and would connect both systems to common propellant tanks. NASA believes that the proposed upgrade would reduce hazards on the ground and in orbit, improve ground operations and turnaround times, save money, and increase Shuttle performance. Before making any decision on implementation, however, NASA should very care-

fully study all of the risks inherent in changing to a liquid oxygen/ethanol system and conduct trade-off studies to determine whether modifications to the existing system may be a more cost-effective means of meeting program goals. Commonality with the propulsion (and possibly the life-support) systems of the ISS and other future NASA programs should be considered in the final design.

Water Membrane Evaporator

The water membrane evaporator (WME) is being considered as a replacement for the orbiter's flash evaporator system (FES), which cools the orbiter during ascent and entry and provides supplemental cooling in orbit. The WME appears to be a simple passive device that can accomplish the FES's cooling function without the corrosion that creates a risk of freon leaks in the FES. However, other options to reduce freon leakage (such as using more corrosion-resistant materials in the FES) could potentially be lower cost and lower risk solutions to the problem. NASA should carefully weigh the costs and benefits of all options for dealing with the FES corrosion problem before choosing a solution.

Phase IV Upgrades

NASA is currently evaluating the merits of two new first stage booster concepts: the five-segment reusable solid rocket booster (RSRB), and the liquid fly-back booster (LFBB). To varying degrees, each concept promises improvements in safety, performance, and life cycle cost. Each concept also requires significant system integration, as well as a thorough ground and flight test program. Each will also require large initial investment.

An important consideration in NASA's ongoing space transportation studies is that the existing four-segment RSRB has demonstrated high reliability since its first flight in 1988. It also satisfies NASA's known performance requirements for the Space Station era. These facts, combined with the risks involved in changing to a relatively unproven booster on a manned vehicle with only minimal crew escape capability means that NASA is not likely to, and the committee agrees it should not, enter into any major new booster program without substantial national need for the performance enhancements and long-term safety and cost benefits.

Five-Segment Reusable Solid Rocket Booster

A recent proposal by Thiokol Propulsion, this upgrade would add a fifth segment to the Shuttle's RSRB, alter the grain of the solid fuel to provide a safer thrust profile, and modify the RSRB's nozzle and insulation. On its surface, the five-segment RSRB appears to be a relatively straightforward approach to improving the performance of the booster, but it will require substantial integration engineering and testing. Early estimates suggest at least $1 billion development cost. A thorough evaluation of the potential for separate implementation of subsets of the proposal should be included in NASA's ongoing assessment.

Liquid Fly-Back Booster

This NASA generated concept would replace the Shuttle's solid rocket boosters with liquid-fueled boosters designed to fly back automatically to the launch site after they have separated from the orbiter. NASA believes that the LFBB would cost $4 to $5 billion to develop but would improve safety, reduce long-term operational costs, enable a higher flight rate, and increase the Shuttle's payload capacity. Before proceeding with the LFBB, NASA should initiate a detailed independent assessment of configuration trade-offs, costs, and programmatic and technical risks to determine the best fundamental configurations for a new liquid shuttle booster. Should NASA proceed with this program, they should closely coordinate their efforts with other government and industry transportation initiatives.

NASA RESPONSE TO THE NRC REPORT ON SPACE SHUTTLE UPGRADES

NRC Report on Shuttle Upgrades

In May 1998, NASA requested the National Research Council (NRC) to examine the Agency's plans for further upgrades to the Space Shuttle system. The assessment was conducted with reference to the National Space Transportation Policy and NASA's 1998 Strategic Plan, which calls for the Shuttle upgrade program to improve the reliability, performance, and longevity of Space Shuttle operations to meet International Space Station (ISS) needs and human exploration goals beyond 2012.

NASA presented the set of proposed Shuttle upgrades, including approved upgrades and upgrades currently under study, and the rational and criteria used to select the upgrades. The NRC, and its committee, assessed NASA's method for eval-

uating and selecting upgrades and conducted a top-level technical assessment of proposed upgrades that have not yet been implemented.

The NRC formed a committee composed of experts from various fields. The committee members are the individuals responsible to perform the study. Committee members are:

Bryan O'Connor (chair), Aerospace Safety Consultant, Alexandria, Virginia
Stephen Book, The Aerospace Corporation, Los Angeles, California
Benjamin Cosgrove, The Boeing Company (retired), Seattle, Washington
Donald Emero, Boeing Reusable Space System (retired), Fountain Valley, California
B. John Garrick, PLG (retired), St. George, Utah
Richard Harper, IBM Research, Raleigh, North Carolina
Nancy Leveson, MIT, Cambridge, Massachusetts
Donald Maricle, Maricle Consulting, Glastonbury, Connecticut
Robert Sackheim, TRW, Redondo Beach, California
George Sutton, ANSER, Arlington, Virginia
Richard Weiss, Richard R. Weiss Consultant Services, Palmdale, California

The committee delivered a sixty-page report to NASA that includes various observations and recommendations. The observations and recommendations are both programmatic and technical.

As part of its observation, "the committee believes that NASA's approach to upgrade planning is appropriate" (page 2) and the "committee commends NASA for its efforts to develop a formal process for evaluating and prioritizing upgrades" (page 2). Also, the committee "strongly supports" (page 3) the use of the goals set by the program to prioritize upgrades.

The committee acknowledges that the Shuttle Program's uncertainty of not knowing how long to operate and the number of flights per year required has made the development of an appropriate process for selecting upgrades and implementing them difficult. The committee states that "the Shuttle program's limited budget for upgrades has constrained the program's responses to this environment, which has made it difficult for program managers to prepare adequately for the range of possible future scenarios" (page 24). Also, the committee agrees with NASA's approach to use the limited upgrade funds to combat obsolescence problems and to perform studies on major upgrades that may be needed if the Shuttle is required to operate after 2012. The committee correctly identifies that the implementation of the larger upgrades will require additional support from the Administration and Congress.

NASA would like to thank the National Research Council for their assessment of the Space Shuttle Upgrades program. The Space Shuttle will remain an integral part of America's space program for the next decade and possibly beyond. It is imperative that NASA takes an aggressive role in ensuring that the Shuttle fleet is capable of supporting the monumental task of assembling the International Space Station; to successfully accomplish this, current obsolescence issues, aging hardware problems, and budgetary concerns must be resolved. The NRC, in their diligent review of the Shuttle Upgrades Program, formulated a list of twenty-five recommendations for NASA. Of those twenty-five recommendations, two have been implemented, twenty-one are being worked, and two are under consideration. The following is NASA's response to the NRC's recommendations.

NASA's Response to NRC Recommendations

Recommendation 1. *NASA should benchmark other large organizations' investment processes for technological upgrades and attempt to identify and emulate appropriate processes and investment strategies.*

NASA agrees with the recommendation. To date, the Shuttle Program has benchmarked upgrade programs like Concorde, B–1, B–52, F/A–18, nuclear power plants, and others. NASA will continue to look at organizations that have performed similar projects. Specifically, the move towards quantitative methodology, i.e. developing Quantitative Risk Assessment Software and use of Decision Support Software, was derived from industry benchmarking.

Recommendation 2. *The ability of a shuttle-unique upgrade to support an increased flight rate should not be a factor in the prioritization process, unless NASA can show through a viable business plan that has been reviewed and approved by financial and technical experts inside and outside the agency, as well as national policy makers (1) that the Shuttle could attract enough business to justify the increased flight rate, and (2) that the Shuttle program would not unfairly compete with commercial launch vehicles or pose unnecessary risks to a national asset.*

Currently, the focus of the Shuttle Upgrade program is on the Phase II upgrades, which primarily address obsolescence issues. NASA has not approved any upgrades solely to support an increase in launch rate. Most upgrades that enhance meeting the manifest commitments, increase supportability and reduce cost also inherently enable an increased capacity or launch rate. Increasing fundamental flight rate does provide short-term surge capability and added flexibility for unexpected manifest changes and would also reduce operations costs. For these reasons, NASA considers it appropriate to consider flight rate capability improvements as a factor in prioritization of Shuttle upgrade candidates. Given that: 1) the United States currently only enjoys a 40% market share in space launch and 2) that following International Space Station 'assembly complete,' Shuttle will have excess capacity, and 3) that NASA's current direction includes privatization of Shuttle processing and operations with the downstream vision to become an 'anchor tenant' for commercialized Shuttle services, it seems only prudent to look beyond the current restrictive national policy directives regarding Shuttle use.

NASA agrees that a viable business plan must be developed prior to implementing the Phase III & IV upgrades that will enable an increase in flight rate. As the committee recommends, NASA will continue to perform preliminary studies for the Phase III & IV upgrades.

Recommendation 3. *The Space Shuttle Program should reassess the goals used to prioritize candidate upgrades to ensure that they reflect the upgrade program's priorities, are feasible, and are clearly understandable to everyone working in the program.*

NASA agrees with the recommendation. The Space Shuttle Upgrades goals have been explicitly the same as the Space Shuttle Program since the Space Shuttle Development Office was organized in 1997. They, in turn, map to the NASA and HEDS Strategic Plans. They were selected to be simple, direct and consistent within the Space Shuttle Program. Without question, they could be collapsed into more focused goals which still compliment the Space Shuttle Program's objectives. NASA will re-evaluate the Space Shuttle Upgrades goals to ensure that these goals are properly balanced within the Space Shuttle Program.

Recommendation 4. *The Human Exploration and Development of Space Enterprise should bring the cost goals for the Space Shuttle in its strategic plan into line with budget and policy realities.*

NASA agrees with the recommendation. NASA continues to stretch for the maximum safe vehicle performance at the minimum cost. Striving for those stretch goals rather than settling for less challenging objectives causes the Shuttle Program to reinvent rather than do business as usual. Business as usual will not achieve the magnitude of improvement the Agency must achieve to live within a flat budget that equates to a 20% funding reduction when compensating for inflation over the five-year budget horizon.

Recommendation 5. *NASA should continue to increase the scope and capabilities of the quantitative risk assessment system by improving its models of failures attributable to combinations of risks, human error, abort modes, on-orbit hazards, reentry and landing, and software. Until these improvements are made, the Space Shuttle Program Development Office should be very cautious in using the quantitative risk assessment system to aid in prioritizing upgrades.*

NASA agrees with the recommendation. NASA's Quantitative Risk Assessment Software (QRAS) has been acknowledged by the quantitative modeling community as a 'world class' tool to help assess risk drivers within complex, interdependent systems. QRAS has been developed in a phased fashion. The first phase fielded the software and modeled the systems to at least the same fidelity was previous done by SAIC's PRA. The second phase added additional modeling fidelity and subsystems. The next phase of the quantitative risk assessment (QRA) system is currently being developed and will address the committee's recommendations. NASA recognizes that there are some limitations to the current QRAS model and until the model is fully developed will use the data accordingly as one of many inputs to the Shuttle upgrade decision making process.

Recommendation 6. *NASA should take care that the Decision Support System's quantitative tools are used as a supplement to, not as a substitute for, formal qualitative evaluations. Expert Elicitation should be considered as an additional formal qualitative tool. Also, NASA should consider modifying the quantification algorithm that the Decision Support System employs for cost-benefit comparisons so that it uses full probability values rather than 20th percentile S-curve values.*

NASA agrees with the recommendation. As the committee states in its report, the Decision Support System is one of the many tools that NASA uses in making up-

grade decisions. NASA has also used a more widely accepted method called 'Analytical Hierarchy Process' to do upgrade weighting and ranking. Expert Elicitation is simply another method of obtaining knowledge and evaluating solutions. Unmentioned in the NRC report, the Shuttle Program has also initiated the Orbiter and GFE Trending Report which has done trending of critical subsystems to identify the subsystems and components most in need of upgrades from a reliability and supportability standpoint.

The use of the 20th percentile S-curve in the DSS represents one method of comparative assessment. Discussions with the NRC panel in September 1998 included a healthy discussion of statistical and probabilistic theories. From these discussions, NASA is examining the suggestions made by the NRC to use other statistical methods to compare and rank the collection of upgrades. This activity is part of the continuing development of the DSS.

Recommendation 7. *All calculations, comparisons of costs and cost savings, and cost-benefit assessments done by NASA, as well as its DSS independent contractor, should be performed using fixed-year dollars and should include all costs (including hidden costs) associated with the upgrade.*

NASA agrees with the recommendation and will continue to account for all costs as projects mature. The Space Shuttle Upgrades Program Requirements Control Board (SSU PRCB) membership includes all the Program elements, Program Integration, and the principle contractors. All upgrades and change requests are assessed by all parties prior to being presented to the board and dispositioned. Every attempt is made to establish integration costs and flush out hidden costs prior to approval of each upgrade.

Recommendation 8. *NASA should provide stronger incentives for the Shuttle prime contractor to propose, finance, and implement upgrades to meet the Shuttle program's goals.*

NASA agrees with the recommendation and has developed and implemented a plan. The challenge is to have the incumbent contractor invest in upgrades that do not show return on investment within the remaining life of the contract when the contractor is being simultaneously incentivized to reduce program cost for which he receives a 35% share of the savings. A modified 'Value Engineering Clause' has been implemented as a way of compensating the contractor for upgrades with a longer payback time should that contractor not be selected for the follow-on contract option(s). This method is currently being reviewed at NASA Headquarters and approval is anticipated in the near term.

Recommendation 9. *Upgrade project managers should involve industry more in the definition and early development of candidate upgrades.*

NASA agrees with the recommendation. NASA has involved industry, other NASA Centers and academia in the identification and selection of upgrades. All Centers and contractors are welcome to propose upgrades to the SSU PRCB under the sponsorship of NASA or USA. The NRC committee chairman agrees that the level of involvement of these contractors and industry is adequate.

The Integrated Product Teams (IPT) supporting the Shuttle upgrade projects have members representing a variety of government and industry organizations. IPT membership generally includes representatives from NASA Engineering, NASA Operations, NASA Project Management, United Space Alliance (USA) Engineering, USA Logistics, USA operations, and Boeing Engineering. In addition, IPT's, such as the Avionics IPT and the Cockpit IPT, have members from the Department of Defense and the Department of the Navy.

Since its inception, the Space Shuttle Upgrades Development Office has sponsored numerous symposia to bring the best from industry to focus on Shuttle Upgrades (SATWG at Boeing, Seattle; SATWG at JSC, Houston; ATWG at KSC, Florida; ATWG at Palmdale, CA; Nano-MEMS Technology Conference JSC; USA Industry Space Council, United Technologies, East Hartford, CT; USA Joint NASA-Industry Upgrades Conference TBD).

Recommendation 10. *The Space Shuttle Program should institute a process early in the development of a candidate upgrade to ensure that the upgrade is compatible with other Shuttle systems and relevant to meeting program goals.*

NASA agrees with the recommendation. As the committee stated in its report, the upgrade priorities are based on Shuttle Program goals. All proposed upgrades must compete within the SSU PRCB forum for scarce resources. The composition of the SSU PRCB makes compatibility and relevance explicit parts of the evaluation process. All upgrades are vetted by other Shuttle Program elements for impacts to hardware, training, cost and schedule.

Recommendation 11. *NASA should limit the software changes associated with new Shuttle upgrades. The agency should consider standardizing its guidelines for using commercial off-the-shelf software in Shuttle upgrades.*

NASA agrees with the recommendation. As part of the system engineering process, all software changes required for each candidate upgrade are evaluated. Commercial off-the-shelf (COTS) products are considered to reduce cost and schedule. The Shuttle Program's experience in using COTS products has occasionally uncovered deficiencies which may be costly in terms of schedule and program risk. NASA (JSC Engineering) has developed a set of COTS utilization guidelines that will be used for all Orbiter Government Furnished Equipment hardware. These guidelines will also be reviewed and considered for broader adoption by the Shuttle Program.

Where appropriate, for example, the Government Furnished Equipment projects, NASA is in the process of developing standards for off-the-shelf software and hardware.

Recommendation 12. *Before embarking on the larger, more costly upgrades, NASA should examine alternative solutions and conduct trade-off studies to determine if the proposed upgrade is the best way to achieve the desired result.*

NASA agrees with the recommendation. Trade-off studies will be performed prior to the implementation of any upgrade. Case in point, NASA conducted a trade study for the Phase III global Avionics Upgrade to the Orbiter. Studies are currently underway on Phase III Integrated Communications Upgrade and Liquid Flyback Booster versus Fifth Segment Solid Rocket Motor Phase IV upgrades.

Recommendation 13. *The Space Shuttle Program Development Office should not consider proposed upgrades as stand-alone modifications but should look for opportunities to combine upgrades (or features of upgrades) to efficiently meet future requirements.*

NASA agrees with the recommendation. NASA will continue to combine upgrades in the most efficient and practical manner while adhering to the Shuttle Upgrade goals and the Shuttle Program goals. NASA has challenged the Space Flight Operations Contract (SFOC) contractor, United Space Alliance, and the Orbiter contractor, Boeing North American, to strive for synergy within the upgrades proposed.

Recommendation 14. *NASA should conduct an audit of the requirements, specifications, plans, schedules, development budgets, status, and life cycle costs of the checkout launch and control system project. The objective of this audit should not be to cancel the upgrade but to estimate more accurately the time and cost required to complete it and to identify potential problems early enough to rectify them.*

NASA agrees with the recommendation. The Independent Assessment Review (IAR) team has completed a review of CLCS project and the Shuttle Program is formulating a response to the IAR. The review to date shows the base system on COTS platforms and application program interfaces are near completion, thereby traversing a period of unknown complexity. The end product functionality is better understood and defined. The remaining development is being addressed and replanned with particular attention on lessons learned metrics gathered to date. On the strength of new detailed basis of estimate, a schedule of the remaining tasks and an updated budget is being finalized for review by program management.

Recommendation 15. *The Space Shuttle Program Development Office should solicit additional proposals for upgrades to protect the Shuttle from meteoroids and orbital debris.*

Under evaluation. The Space Shuttle Program has used and continues to use control of the attitude timeline to minimize debris impact risks. In preparation for International Space Station assembly missions, where the attitude is constrained by assembly requirements, the Program conducted an extensive evaluation of the components with the highest contribution margin to debris risk. To minimize the risk of early termination of the mission, modifications are being made to the radiator systems. "Armor" is being applied over the coolant flow loops and isolation valves are being added, so that if a radiator is penetrated, it can be isolated so that the fluid is not lost from the water boiler portion of the heat rejection loop. To minimize the risk of significant critical damage during entry the thermal protection of the wing leading edge has been modified to contain the heating loads of plasma flow due to a penetration of the reusable carbon-carbon leading edge. Previously the design accommodated only the radiant heat loads from the RCC. While other potential changes have been identified they have not demonstrated significant impact on the overall meteoroid and debris risk.

Recommendation 16. *NASA should continue studying potential modifications to the APUs to better determine the costs, benefits, and appropriate scope of an upgrade.*

Developments in electric power systems worldwide should be monitored to identify technologies and techniques that could be useful for an APU upgrade.

NASA agrees with the recommendation. NASA continues to develop a proof of concept for an electric Auxiliary Power Unit to eliminate the toxic propellant, high temperature hazard in the aft fuselage, eliminate high speed rotating turbine wheels and reduce the continuing maintenance and reliability burdens.

Recommendation 17. *NASA should continue its strategy of judiciously replacing obsolete avionics components while developing a plan for a future improved architecture. Consistent with the year 2000 decision process, NASA should develop scaleable, long-term requirements and interface definitions for the future architecture.*

NASA agrees with the recommendation and will continue to develop an avionics upgrade plan. NASA has already solicited the major aerospace contractors' architectures and costs to address this issue. This is a phase III upgrade candidate.

Recommendation 18. *If NASA decides to implement this upgrade, it should take steps to ensure that channel-wall nozzles are available in the United States, either by stockpiling additional nozzles or developing a channel-wall nozzle manufacturing capability in the United States.*

NASA agrees with the recommendation. The decision has been made that if NASA decides to implement the channel wall nozzle, the nozzle will be manufactured in the United States.

Recommendation 19. *NASA should pursue the extended nose landing gear only if future plans require that the Shuttle land with heavier payloads than are currently allowable.*

Under evaluation. The Extended Nose Landing Gear modification is currently under review by the Space Shuttle Program. The Extended Nose Landing Gear project will be presented to the Space Shuttle Upgrades Program Requirements Control Board (SSU PRCB) in April 1999. The decision to proceed with this upgrade will be based on the amount of additional margin this upgrade provides versus the cost and complexity of the upgrade. If the cost (~$20 M) and complexity does not justify the gain in margin then this upgrade would be put on hold. If larger orbiter landing weights are required in the future and this change proves to be beneficial in providing additional downweight capability, along with significant structural modifications, then this upgrade may be reconsidered.

Recommendation 20. *NASA should continue to explore the costs and benefits of PEM cells before making a decision on a future Shuttle fuel cell. Planners of future space vehicles and/or missions that could benefit from PEM fuel cells should be closely involved in these studies.*

NASA agrees with the recommendation. NASA has decided to implement the long life alkaline Fuel Cell for the Shuttle Program to address reliability and maintainability issues for the next decade. At the present time, though, the technology is elusive for space applications with only modest progress having been made in terrestrial applications despite the investment of approximately $10B worldwide in the automotive industry. Shuttle integration and implementation are likely to be complex and expensive due to incompatibility with current plumbing. Without question, Proton Exchange Membrane (PEM) Fuel Cell technology has tremendous potential for future space systems.

Recommendation 21. *Before NASA makes any decision on implementation, it should very carefully study the risks inherent in changing to a nontoxic OMS/RCS system and conduct trade-off studies to determine whether modifications to the existing system may be a more cost-effective means of meeting program goals. Commonality with the propulsion (and potentially life-support) systems of the ISS and other future NASA programs should be considered in any final design.*

NASA agrees with the recommendation. NASA will consider all factors prior to implementing Non-toxic Orbital Maneuvering System/Reaction Control System. Currently the reliability driver is the RCS thrusters.

Recommendation 22. *NASA should reassess the costs (including those associated with surface tension issues and development testing) and benefits of all options for dealing with the corrosion problems in the flash evaporator system before choosing a solution.*

NASA agrees with the recommendation. NASA is evaluating various options. The Water Membrane Evaporator is, as yet, only a promising technology. In the interim, NASA continues to repair and fabricate the existing design.

Recommendation 23. *NASA should formally evaluate the merits of the five-segment reusable solid rocket booster as it prepares for the decision on the future of the*

Shuttle program. A thorough evaluation of the potential for the separate implementation of subsets of the proposal should be included in this assessment.

NASA agrees with the recommendation. NASA's Office of Independent Assessments is currently conducting a trade of Liquid Flyback Booster vs. 5th Segment SRB. NASA has approved funding for a fifth segment Solid Rocket Booster study that will aid in the evaluation of alternative booster options for the Space Shuttle Program. Refinements continue to the existing RSRM/SRBs to address remaining opportunities to reduce CILs and address environmental and material obsolescence issues.

Recommendation 24. *NASA should initiate a detailed independent assessment of configuration trade-offs, costs, and programmatic and technical risks for a new Shuttle booster.*

NASA agrees with the recommendation. An independent assessment of the booster options is being performed by the NASA Langley Research Center Independent Assessment Office.

Recommendation 25. *NASA should coordinate closely with other government and industry transportation initiatives in determining the need and, if appropriate the resources for any new Shuttle booster.*

NASA agrees with the recommendation. NASA is currently working with industry on the Space Transportation Architecture Study to develop an evolutionary path for reusable first stage technologies and possible evolution of a subscale demonstration vehicle.

Senator WYDEN. Thank you very much. Gentlemen, I have got to leave in a few minutes to deal with the problems faced by the Klamath County farmers in my home State that you may have heard about. Therefore, I am going to turn the hearing over to our colleague, Senator Nelson, but I did want to ask a couple of questions. One quick question for you, Mr. Li.

In the GAO report that has been recently released, at page 4 of the report, there appears to be what certainly strikes me as a very troubling finding by your agency, indicating that when it comes to the Space Station, NASA cannot really tell you what it is they have spent thus far. I want to know, if that is the case, if I am reading it correctly.

For obvious reasons, there are those of us who agree with Senator Nelson that we are going to have to spend money, as it relates to these safety upgrades. However, it is going to be pretty difficult to convince our colleagues that these expenditures ought to be made when those who are not so sympathetic come back and wave a GAO report in our face and say, well, page 4, it says it cannot tell you what they have already spent.

Are we reading that correctly, number one? And, if so, what are the implications? Just so the NASA people are at the ready here, I will be asking you to respond after Mr. Li has answered my question.

Mr. LI. Yes. This is a very complicated issue. What we were asked to do was the Congress asked us to make sure that there was no exceeding of the cap that was established. What we found was that at the subsystems level, at the system level, at the individual modules, they could not identify what was actually spent for that particular component.

NASA disagrees and feels that their accounting system, in terms of using simply the budget authority that is being provided to them, is sufficient. We were looking for actual expenses, and they do not track it in that manner.

Senator WYDEN. Does NASA want to respond to that?

Mr. READDY. Mr. Chairman, I am prepared to speak today on the Space Shuttle, and I can assure you that in the Space Shuttle arena, we are down to a tenth of a percent in terms of accounting for what we spend in our program.

Senator WYDEN. That is fair. Let us just say I would like a response to that in writing, though, with respect to the Space Station.

Mr. READDY. Yes, sir.

[The information referred to follows:]

NASA has complete and reliable data concerning the total cost of the International Space Station program. The disagreement between GAO and NASA centers on how NASA should track Space Station costs at a detailed level.

GAO believes that NASA should track the cost of individual Space Station subsystems or elements. NASA, however, believes that for project management purposes it is important to track costs by work breakdown structure. This approach facilitates NASA's and the contractor's understanding of costs incurred and future projected costs. Within these work breakdown structures are identified subsystems and hardware elements, among others. NASA requires the identification of all supporting costs, such as systems engineering and safety and mission assurance, but these costs remain separate and are not included in the costs of individual subsystems and hardware elements. This approach provides NASA with a valuable project management tool and assures that all Space Station costs are fully accounted for.

Senator WYDEN. Because it does go to the heart of this effort to properly fund safety. If we do not have answers to those questions and people wave GAO reports that make a finding like that, it will be difficult to get the funds that are needed for safety.

Let me ask one question for the entire panel, and I want to go right down the row. I think what we are going to see this issue come down to, given the budget situation, is looking at how to balance the safety gains, which are so important and which we have all made clear we are not going to compromise, against cost considerations and technical readiness. I would like to hear from each of you how you would go about trying to strike that balance because clearly, if you have unlimited funds, then there is no problem. You get everything under the sun with respect to safety and you hope some of it works, and if it does not, so be it. But we are going to have to figure out a way to balance these questions of necessary safety upgrades against cost and technical readiness.

If you would, pretend you have the election certificate and you are sitting up at this end of the dais and tell us how you would go about striking that balance. We will begin with NASA, and we will go right down the line. Then when I am done with that question, I am going to turn it over to our friend from Florida.

Mr. READDY. Mr. Chairman, I had prepared a very detailed answer for you, but it took 10 years and $40 billion to develop the Space Shuttle. It goes from a rocket ship for 8½ minutes to a space craft for 2 to 3 weeks to a hypersonic reentry vehicle for an hour, and the lowest L over D fighter type airplane you would ever land, fly by wire for about the last 5 minutes. It is complicated because it has to accomplish all those things in one vehicle. That investment is the foundation of human space flight for this nation, and the world counts on us to do that, to leverage the investment in the International Space Station.

We are on the threshold of being able to utilize that International Space Station, having just finished Phase II of the assem-

bly, using the Space Shuttle as the work horse and as the assembly platform and now to use it as the logistics platform and the utilization vehicle for that.

So, what hangs in the balance is not simply our previous investment, not only in Shuttle and Station, but the future harvest from the International Space Station from those other missions that are unique that the Space Shuttle can perform. So, I guess I would couch it in those terms.

Senator WYDEN. Mr. McCulley.

Mr. MCCULLEY. I will go back to part of my opening statement that said there is a fundamental question; that is, do you want human access to space in a safe and reliable vehicle? And a bit of a history lesson, which I might have already said, in the 1990–1991 timeframe the NASA Space Shuttle program manager, I think had about $5 billion for a budget, and today he has $3 billion for a budget. So, it is a 40 percent decrease in that 10-year period, yet we are still flying. We just finished a period where we flew at the same flight rate. So, we have given at the office, to put it in one form. And the life has changed because now we are looking at flying it for many more years, not just a few more years, and it requires investment.

I think it is probably more of a schedule issue and reliability issue in many cases than safety, because we have a very rigorous, some would say cumbersome, set of requirements that get you down to go fly at T–Zero, and we will continue to press to satisfy every single one of those thousands of requirements for each mission. But what we are going to find with infrastructure not being there and with the older systems on the Shuttle is that we will then end up with safety concerns.

If I were in your position, then I would answer that first question about whether we want that human access and then here is what it takes to get it. And, oh, by the way, these guys have done a pretty good job in the last 10 years bringing costs down, where many other agencies are having increasing budgets.

Senator WYDEN. Mr. Blomberg.

Mr. BLOMBERG. I certainly agree with what my two colleagues have said, but I would also like to point out that perhaps we have a semantic issue here when we use the phrase "upgrades." We think of that as an improvement, but we really have to look at upgrades first as holding our own. If we do not do something to this vehicle, the safety level will decline inevitably because of the aging nature of the vehicle and the infrastructure. So, I guess I would first focus on what will it take to just break even, and I think that is not trivial. As you mentioned, Senator, our panel does not look at budget, but I am afraid, from my own sense of things, that the budget is only barely adequate to break even, and maybe not even enough.

Then if you look at the opportunity for risk reduction that is out there, that is what can really be captured once you get to a stable position and say we can hold our current safety level. Now how can we improve it and what are the most cost effective ways to improve it? But we cannot lose sight of the fact that if we do not do something, this vehicle is going to get riskier and riskier to fly.

Senator WYDEN. Mr. Li?

Mr. LI. I guess I have, perhaps a slightly different perspective on this. I think it is a matter of setting priorities, and that sounds very trite. I think when you set priorities, you have to be able to establish what is the risk level of each one of these individual improvements you want to make.

I think one of the difficulties that NASA has is that there is a mixture of both safety and performance capabilities in a lot of these upgrades. Of course, sometimes you cannot really differentiate and say that if you are going to improve the performance, you would not be improving the safety also at the same time. I think that those are very difficult to differentiate.

The other thing that I would provide as a suggestion is that you need to take a look at how long is your exposure to risk. In my testimony, I mentioned the fact that if the replacement, which is possibly an RLV, how long is it going to take for that vehicle to come about. If that vehicle is going to be coming in 2012, I may make different decisions than if it is going to be in 2020. I have an 1986 Volvo. If I know I am going to keep it for another 5 years, I may get myself a new pump or something, a new water pump. But if I am going to get rid of it next week, I am certainly not going to do it.

Senator WYDEN. Good. Thank you.

Mr. O'Connor?

Mr. O'CONNOR. Mr. Chairman, I do not have much to add to what you have heard other than when we first came up with Space Shuttle, we saw it as an operational vehicle. It had a huge, high flight rate. It had all kinds of missions. It was flying commercial type activities very early. You remember that we declared the Space Shuttle "operational" after its fourth test flight.

Today it is not anywhere close to operational. If you look at the risk picture of this vehicle, from an operational viewpoint, they are so well below what would be considered an operational vehicle from a safety risk view, or of any kind of a DOD or commercial flying vehicle. The Space Shuttle is far from that. Further, it has no escape system to accommodate that high risk.

Therefore, I believe that we continue to fly operations with what I would consider to be a risk prototype, an R&D type vehicle. It is doing very well, but we cannot let it go backward. As Mr. Blomberg pointed out, you have to spend money to keep the risk level where it is today, and it must be replaced by something that started from the bottom up to be operational, and this time we need to do it right.

Mr. READDY. Mr. Chairman, if I could amplify Colonel O'Connor's statement there. Just for comparison, the F–22, which of course is undergoing flight test right now, has flown approximately 600 flight test missions. The Space Shuttle has flown a little over 100. We are going to field the F–22 in 2005 or thereabouts. It has had over 1,200 flying hours to date. The Space Shuttle in dynamic flight, 8½ minutes of ascent and roughly an hour on entry, has had about 120 hours of dynamic flight test. So, we are nowhere near the operational program that we would like to be at this particular point, and it is going to require continued R&D to maintain our Human Space Flight program.

Senator WYDEN. Gentlemen, I wish I could stay here longer, but in a sense, at least for me, this may be a good breaking point as well. I want to leave you, though, with one thought.

My thought is that as Chairman of this Subcommittee, I am very sympathetic to this issue of additional funds being needed with respect to safety. I can tell you, even apart from the fact that Bill Nelson has been a friend of mine for now 2 decades, for 20 years, I would still be willing to go to Barbara Mikulski and to those that are on this conference and to make the case for additional funding.

But I would urge you to do what Mr. Li just mentioned, and that is to set some priorities. That is absolutely critical at a time when this budget is strapped in a very dramatic fashion. Senator Nelson and I represent a lot of senior citizens. This morning we were told that the Administration recosted prescription drug benefits and one-third of the money disappeared. One-third of the money, in effect, just vanished. So, these budget choices are going to be very, very tough. I am prepared to go to Senator Mikulski and those on that Subcommittee with my colleagues to argue for additional funds, but I would urge you to take heed of what Mr. Li has said with respect to some priorities. They have got to be set.

In addition, if I might paraphrase what my mother always said. When we were talking about a budget, she would always say, son, sharpen your pencil because there are savings that can be found and economies that can be found in every single budget.

You have been an excellent panel. Senator Nelson has told me about how dedicated all of you are and that is very evident in your comments here today. I look forward as Chairman of the Subcommittee to working very closely with each of you. With that, I am going to turn it over to Senator Nelson.

Senator NELSON. Mr. Chairman, before you leave, let me just say that I think the quandary, the conundrum that we find ourselves in, the reason we are trying to have this hearing today, is the fact that NASA has mismanaged the Space Station, and as a result, you have had these huge cost overruns. But then when confronted with what we are going to do in the future, it appears that sources would want to punish NASA for NASA's misdeeds by cutting back on other parts of the program which I think the testimony here from all these people has dramatically demonstrated that we do so at the risk of life, indeed at the risk of the entire Human Space Flight program.

So, it kind of reminds me of my colloquy on the floor with Senator McCain. He was very rightly taking out after NASA's mismanagement and cost overruns on the Space Station. But we have got to get beyond that because we have got a lot at stake right here.

Senator WYDEN. Very good.

Why do we not recognize Senator Allen and Senator Nelson will chair.

Senator NELSON [presiding]. Thank you.

Senator ALLEN.

Senator ALLEN. Thank you, Mr. Chairman-designee.

We have about 5 minutes. There are so many questions listening to you all.

I want to say to Mr. Li that I loved the way you use an analogy, whether it is the Volvo or an automobile. Senator Wyden and I were saying about these add-ons or upgrades, it is like getting upgraded tires, although your tires on the Space Shuttle cost $9 million for the upgrades, which of course may seem very high. But regardless, I think to get public support and understanding for some of these things, I like to use analogies and try to just use some common sense ways of looking at things.

I will try to prioritize my questions to everyone here. First to Mr. McCulley, of this projected $218 million shortfall in fiscal year 2002, $54 million was due to contractor rate increases, according to NASA. This is the same sort of thing to some extent with fuel, for example, that anybody would understand, with the costs for natural gas, the spike we had with that earlier, as well as just regular old fuel that some of us would use in our Volvos or Dodges or Fords or whatever.

As a contractor or the operator of it, can you elaborate on what this $54 million increase in costs is?

Mr. MCCULLEY. The $218 million is program-wide, and United Space Alliance is approximately 50 percent of the program-wide budget. So, just on a straight scale, linear scale, we would represent maybe half of that $218 million. I do not know exactly how it is distributed.

But what we have done for the first 5 years of the space flight operations contract and what we have projected for the years in front of us has been basically 4 percent a year for each of those years. And we have performed very, very close to our projections. That 4 percent is our merit pool. It is our annual raise to account for inflation and to keep our engineers, technicians, and other employees lined up with the rest of the economy.

We are maybe $1.5 billion or so for the whole contract. I think between Florida and Texas, maybe two-thirds of that is in the salaries and medical and benefits range. So, if you take 4 percent of that, then that puts you in the $40 million or so there. The $54 million would probably apply to all the contractors, not just to us. So, that would represent I think around a 4 percent or so escalation, which is what most of us have been telling NASA all along. Both our historical track record and our projections have been at that 4 percent rate.

Senator ALLEN. I know I am green and new here, but should that not somehow be reflected in budget projections rather than saying it is a shortfall if everyone has known that the salary increases and so forth are going to be going up 4 percent?

Mr. MCCULLEY. Yes, sir. There is a difference between contract value which is back when we started the contract and we bid the proposal to NASA, we put those escalation rates into our pricing for our proposal. However, the budget is quite a bit different than the contract value, as it turns out, and the contract value has been higher every year than the budget. So, we had those escalation numbers in the proposal that was accepted when the contract was originally issued. The budget numbers are a different subject.

Senator ALLEN. It is just the way, I guess, things operate up here. It does not make a great deal of sense to me having come from the real world.

[Laughter.]

Senator ALLEN. Let me ask you this question because I think it matters a great deal. I am glad they will have some of those Space Shuttle objects flying around the Richmond International Raceway Saturday night—the Winston Cup Races. But other than for the Space Station assembly, what do you see as the prospects for the future use of the Shuttle, and are there any commercial interests in the Shuttle orbiters that you are aware of?

Mr. MCCULLEY. Let us see. Mr. Readdy may be better.

Senator ALLEN. Well, either one. I thought you would. Whoever feels most capable of answering.

Mr. MCCULLEY. Let me start. Then you can finish.

Next year we have a Hubble servicing mission, which will be the third or fourth trip back to Hubble Space Telescope. There is a science mission on the horizon that would utilize Columbia either late next year or early the next year. And let me go to Mr. Readdy with that.

Senator ALLEN. Hubble folks understand that. But, for example, whatever the last thing you said was. What did you say?

Mr. MCCULLEY. A science mission that would supplement Space Station, and I think it is presently on the manifest for early 2003.

Senator ALLEN. Yes, but what is the science that is being transacted?

Mr. READDY. Human biology and microgravity research. It maybe is not quite ready for International Space Station yet, so the Space Shuttle is being used as an augmentation to do near-term research.

Senator ALLEN. Are there any commercial interests involved in that?

Mr. READDY. There are commercial payloads that we fly. On typical missions we will fly commercial payloads, and we are making more of an initiative to seek out commercial payloads. We have SpaceHAB, which is one of our contractors, that has a set-aside for a percentage for commercial on each and every one of their lab module missions. So, we are doing that.

The other thing that we have is preliminary discussions for maybe a salvage mission in space for a commercial satellite.

We also have another interagency support mission that we have done. We did a Shuttle radar topography mission for the DOD. We have a rich history of having launched communication satellites before Challenger, and we have supported all manner of missions over the Shuttle's 106 flights.

Mr. MCCULLEY. And as a company we have worked, in the last couple of years, fairly actively with the Air Force and with other DOD interests to make sure they know that the capability is there, the heavy-lift capability in the Shuttle, for some of their payloads.

Senator ALLEN. Thank you.

Colonel O'Connor, this was generally what Senator Wyden was getting at and you brought it up in your testimony about finding a quantitative way. I was reading through these briefings of all the different improvements that were safety improvements, whether it is the Space Shuttle Main Engine Block III, or the Advanced Health Management System, or the Thrust Vector Controls, and so forth and so on. In each and every one of them that I went

through, there was an analysis. This might reduce it by 40 percent and so forth. Mr. Li naturally understood all those.

You mentioned as well having a quantitative approach or try to get some way of judging, if you cannot do everything, what will have the most bang for the buck, what is the most affordable.

Your 1999 NRC report recommended that NASA should modify its system for prioritizing upgrades. Now, has NASA changed its system in your view to adequately prioritize the implementation of new upgrades? And if not, would you suggest any improvements?

Mr. O'CONNOR. We made something like 25 recommendations. There was only one that they did not endorse and take action on, and they may have since then. That had to do with putting more effort on looking for ways to reduce orbital debris risk.

The reason we brought that up, though, was right on the mark you are making. We looked at how much money was spent to reduce the risk of the main engines, over $1 billion at that time on the turbo pump upgrades, and the reduction in risk that that represented was a certain value. Then we looked at how much money was spent to reduce almost that same amount of risk for the whole Shuttle on orbital debris upgrades where they had put some covers on the radiators that are exposed to orbital debris risk on orbit, and they had changed the thermal control system for the leading edge of the wings so that if they did take a hit, it would not destroy the vehicle on reentry. That was something like $60 million. So, you got almost the same reduction in risk for a tremendous difference in price.

My numbers may be a little off, but when we looked at that, we realized that you need to always look at that. You need to look at the bang for the buck that you get for these things when you are looking at safety.

Now, having said that, we also realize that you should never use just one of these tools to make your decisions. The committee was firm in saying they do not believe in making your decisions only on a quantitative bang for the buck study. You have to do the qualitative, the subjective, the engineering looks.

If you like analogies, the one I use is when I was a little kid growing up in southern California, my dad on some weekends would take us to Disneyland. At the time Disneyland was not built yet. They had a green fence around the whole place. Mr. Disney was a great guy. He put little holes in that fence at various heights so children of all sizes could look through and see what is going on at Disneyland. But the routine was that the parents would bring the children, they would look in the fence, they would drive around the block, they would look in that hole in the fence, they would drive around the block, they would look in that hole, and they would look through about four or five different holes to try to get some understanding of what was going on in Disneyland.

And that is what they have to do with these upgrades, to prioritize them, to see which ones are the best. It is not just a single bang for the buck peephole, but do the engineering and the qualitative and all these other things along with that. That was our recommendation.

Senator ALLEN. And do you feel that NASA has followed through on that recommendation?

Mr. O'CONNOR. Yes, sir. At that time, when we looked at it. Again I have not been looking at Space Shuttle myself since this committee, which is about 2 years ago now, to watch for the follow-ons. The committee was not asked to do that. But at that time, we thought they have an excellent system for prioritizing. They did not use just one system. They had independent look-sees to try to take care of the normal biases you get from center to center, from region to region, the advocates from different companies saying that mine is the best. They hired independent people to come and take a look and try to strip that away and get the best they could, and we thought they were doing the appropriate actions.

Senator ALLEN. Well, it seems like they did. Seeing how you are outside of it now, but obviously with a great deal of knowledge from the recent past, it seems to me that in a roundabout way on some of these that ended up on this—Electric Auxiliary Power Unit I believe it was. The cost just kept going up and up and up, and they finally said let us have some reality here. We are not sure about the quality of this, the engineering of it, and certainly the cost. It seems to me that almost got winnowed out by using that sort of an analysis. Would you agree, Mr. Readdy?

Mr. READDY. Yes, sir. Senator Allen, I would like to submit something for the record here that was omitted from your package.

First I would like to say that with respect to the NRC study, they had 25 recommendations. We implemented all 25. We have had 9 independent reviews from external groups to look over our shoulder on Space Shuttle upgrades. They have all found that we have a systematic approach to address the risk in the Space Shuttle program.

A picture is worth a thousand words. If I could share this with you. I am sorry I only have one copy, but I will bring it forward. Basically what it shows is all these little icons are elements of the different components of the Shuttle. Some are main engine. Some have to do with solid rocket boosters. Some have to do with the external tank. Some have to do with the orbiter itself. What we did was used a quantitative tool that Colonel O'Connor described, and we looked at each and every one of those elements. This box down here represents the highest risk. We methodically put in place an upgrade program to address each and every one of those.

For example, in the electric APU, that remains the highest risk item in the Space Shuttle orbiter. The unfortunate thing is the battery technology, the packaging density for those batteries does not exist today to be able to implement it. As a result, we thought we made a prudent decision to go ahead and stop that program, put some money into technology, and use that money for other purposes. But we have done the same thing with the other upgrades. So, we do have a very systematic approach to attack each and every one of these higher risk items.

Senator ALLEN. Thank you. Thank you very much. Mr. Chairman, I will yield to you. I know I went way over 5 minutes.

Senator NELSON. No, Senator Allen. I had them turn off the lights because we are going to be at this as long as we need to.

I wanted to follow up on an initial question of Senator Allen's. He was wondering about what does the Space Shuttle deliver for

us today, and it occurred to me, did we not launch the Chandra Observatory on the Space Shuttle?

Mr. READDY. Yes, sir, we did. STS–93 in July 1999.

Senator NELSON. Does it have a capability of being serviced by the Space Shuttle?

Mr. READDY. Chandra does not, but the Hubble Space Telescope does. And we are flying our fourth servicing mission. It is scheduled for this coming January.

Senator NELSON. The point that I want to make, Senator Allen, in response to your question, is just today—I know it is in *The Washington Post,* so it must be in most every other newspaper.

Senator ALLEN. You might want to get an independent verification. But go ahead.

[Laughter.]

Senator NELSON. What is the name of the Richmond newspaper?

Senator ALLEN. Richmond Times Dispatch.

Senator NELSON. It is probably in the *Richmond Times Dispatch* as well because it was a major story. The fact is that the Chandra observatory, which is one of the great observatories that the Space Shuttle has put up, like the Hubble Space Telescope, which is in the visual part of the electromagnetic spectrum—the Chandra is the in X-ray spectrum. Chandra has discovered a huge black hole that we have been looking for for years. And it is just another example that it is a routine article, nevertheless a very important news article, in this morning's newspapers about what is the viability and the importance to the country as we are explorers, as we are adventurers in trying to understand what is out there and where we came from and how it evolved and what still might be out there. So, I just mention that to you. It is a timely story.

Please feel free to——

Senator ALLEN. I have to go.

Senator NELSON. You are going to have to go. And we are going to have a vote momentarily, but even if I have to recess, we are going to keep going and get all the questions in.

Mr. Blomberg said that he thinks that the current budget may only be barely enough to break even, or words to the effect that you used. So, Mr. Readdy, I want to ask in your professional opinion, is the fiscal year 2002 budget, as proposed by NASA, enough to break even at a flight rate of six flights a year?

Mr. READDY. Sir, as I said in my statement, we are facing a shortfall right now in 2002 of $218 million. Inflation continues to erode our purchasing power and we are somewhere around 40 percent of what we were starting in 1990 at this point, and it will continue to erode at the rate of inflation. Maybe Mr. McCulley can speak to it, but I see it being increasingly hard to get more efficiencies out of the contract that we have with United Space Alliance, even if we go to further privatization.

Senator NELSON. Does anybody else want to comment on that?

Mr. MCCULLEY. Also, to put that $218 million in perspective, I think it is around maybe 7 or 8 percent of the total Shuttle program budget. So, it is a number that will work. If it is what we have to live with, then it is what we have to live with. As I said earlier, the process we go through to satisfy requirements to make us safe, Senator, we will go through that process. What will suffer

in the short term, in particular, is schedule. If you cannot get there, there is not enough money for overtime or you do not have enough people, you just do it at a slower rate, but you still do it in a safe manner. And safety always is number one.

So, from my point of view as the contractor with the people who do the hands-on work, if I am given some budget challenge that I did not expect, whether it is $20 million, $30 million, $40 million, or $50 million, then I will have to figure out what to do with that.

Now, as a service contractor, most of my budget is in people, and so I do not have very much flexibility to not buy parts and put them on the shelf or delay the development of something. Because the vast majority of my resources are spent on people doing things, as I mentioned earlier, over the years I have gotten to be an expert in how to do layoffs whether I wanted to or not. So, if we are told to eat some unanticipated amount of money, then we will just go deal with that, and it will impact the work force predominantly in Florida and Texas.

Senator NELSON. I want to show you a chart and I want to talk about it. You all are quite familiar with this chart. This is before Challenger when the risk was 1 in 25 because the 25th flight blew up. Post Challenger, with the upgrades that were made, the catastrophic risk on ascent is 1 in 78. You all upgraded that to 1 in 248. It has now been upgraded to where we are now to about 1 in 483. The idea was to double that to 1 in 1,000. Again to compare, Mr. Readdy, with what you said, a Boeing 777 is 1 in multiples of thousands. I think you said 20,000.

Mr. READDY. A combat aircraft, 20,000; and a commercial aircraft, 1 in a million.

Senator NELSON. One in a million; a combat aircraft, 1 in 20,000.

So, we are just trying to get the Space Shuttle on ascent to 1 in 1,000. But you have got to do these things. So, let us go through these, let us talk about them, and let us see if we can get some sense—and I invite all of you. I cannot thank you enough for all of your participation today because you bring your particular expertise to the table and it is very valuable. So, let us talk about it.

The orbiter avionics/cockpit safety upgrade. If you got into an emergency landing, return to the site of launch, RTLS, or a trans-Atlantic abort, for that commander and for that pilot, it would sure be nice to have that, would it not?

Mr. READDY. Yes, sir. And this is what we have today. We have got checklists on velcro that we put up in the window. You know these because you flew them, and they have not really changed much other than the procedural steps since STS–1. But that is what we have at our disposal to fly our Mach 25 rocket ship.

Senator NELSON. What are we talking about in cost for that and over what period? What are we looking at for the first cost?

Mr. READDY. Well, we will get you the precise numbers, Senator.

Senator NELSON. If I recall, it is about $380 million, and that is over some period of time. You would be talking about $60 million in 2002.

Mr. READDY. The rough order of magnitude that we submitted in November 2000 was between $400 million and $500 million to implement that upgrade, sir.

Senator NELSON. Do you want to assign a percentage to that of all these upgrades to double the safety or, to describe it another way, to half the risk? Do you want to assign a percentage to that of how important that is to us?

Mr. READDY. Well, in terms of operation of the Space Shuttle, when we do our quantitative risk assessment, we use the crew as a reliability of 1.0. The crew always makes perfect decisions. The ground always makes perfect decisions because we model only the hardware aspects of it. So, the cockpit is one upgrade that gives the ground control and the flight crew on board the decisionmaking aids to be able to crisply decide among what the different abort options are among the systems.

For example, on STS–93, the crew had a momentary indication on a caution and warning panel, but the crew did not really have any idea what sub-bus, what other systems were affected until the ground, with literally dozens of flight controllers, could assess the situation and send up not only what had failed but what the corrective action should be. The crew did not have the situational awareness to be able to deal with that on board. That is what we are trying to provide.

Mr. BLOMBERG. Senator, if I may.

Senator NELSON. Yes, please, Mr. Blomberg.

Mr. BLOMBERG. I do a lot of work in cockpit displays of various aircraft. The Space Shuttle is the fastest vehicle that humans fly. So, things happen most quickly. Decision making has to go on most quickly. And it has the lowest level of situational awareness of any vehicle I have ever seen. So, perhaps that will put it in context for you.

Senator NELSON. Yes. This is year 2001 and the Space Shuttle started to be developed in the year 1971. It is basically 30-year-old technology. And in order for it to fly for another 20 years, it is going to need to be upgraded.

Mr. BLOMBERG. And it is 30-year-old technology that was barely adequate for just under Mach 1, and we have a hypersonic vehicle.

Senator NELSON. All right. Let us talk about some more. The electric APU. Right now you have an APU that has all of these explosive materials. You call them hypergolics. That adds additional risk. What you would like to do is to make that APU electric and, therefore, take out that explosive risk. As you said, you are having difficulty developing the batteries and to get the batteries down into a sufficiently small size and small weight. What would you assign to that as a percentage of risk so that we can half the risk for the Space Shuttle?

Mr. READDY. As memory serves here, that was about 15 percent of the total Shuttle risk, and that winds up being the highest risk driver on the Space Shuttle orbiter vehicle.

Senator NELSON. 15 percent of the overall catastrophic failure risk, but in the orbiter risk, it brings the risk down from 30 percent to less than 5 percent. This is a costly item, is it not?

Mr. READDY. Yes, sir.

Senator NELSON. It started out at about $224 million, and now the costs keep escalating.

Mr. MCCULLEY. It is important to note on that particular upgrade, that that also has tremendous implications for the ground

processing team, in addition to just the flight, because dealing with the hydrazine fuels requires a self-contained breathing apparatus. It requires safety considerations that slow down the overall process. So, that upgrade, more than any of the others on there, definitely affects the ground systems as well as the flight systems.

Senator NELSON. Speaking of that, when I get back from voting, Mr. McCulley, I wish you would remind me. I want you to tell the story about what happened in the orbiter processing facility with regard to the hypergolics and how it could have blown up the whole Shuttle and the orbital processing facility, just another example.

In this particular case, if we are doing this, we are not just doing it for the Space Shuttle. We are doing it for the future manned space vehicle that ultimately in 20 years or so is going to take over the Space Shuttle. These are technologies that are going to be applied for the future. Is that correct?

Mr. READDY. Yes, sir. We should never commit to building another human space flight vehicle that we have to process that has hypergolic propellants.

Senator NELSON. Let us talk about the main engine.

Mr. BLOMBERG. Excuse me, Senator. Could I just also add?

Senator NELSON. Please, yes. All of you interrupt any time, please.

Mr. BLOMBERG. If we are going to fly the Space Shuttle to 2020 or beyond, as we believe it will be, the current APU's cannot support. They will wear out. There will have to be an investment in APU's one way or the other. So, the issue is—and I do not know the numbers—do you buy more of the current APU's from a vendor who may or may not still have the capability or do you upgrade? It is not purely an upgrade. There is an obsolescence issue and a wear and tear issue here also.

Senator NELSON. And you underscore the point, are we going to have human space flight or not? And if we are, as you point out, Mr. Blomberg, it is getting to be obsolescent, and for that reason alone, you are going to have to change.

All right. I am down to 2 minutes to vote. What I am going to do is recess the hearing. I am going to go over and vote and come right back. The next thing we are going to talk about is the main engine advanced health management.

[Recess.]

Senator NELSON. The Subcommittee will resume.

Let us resume discussing these upgrades. The main engine advanced health management. Mr. Readdy?

Mr. READDY. Yes, sir. Our quantitative risk assessment shows that that would be about a 19 percent decrease in ascent risk.

Senator NELSON. And how much of a cost is that? It looks like it is about $155 million?

Mr. READDY. Phase I of that is $27 million, and Phase II of it—excuse me. That is the remaining. Phase I is $55 million and Phase II is $100 million, sir.

Senator NELSON. And that upgrade is done over how long a period, just approximately?

Mr. READDY. About 5 years, sir.

Senator NELSON. Let us talk about the main engine Block III. That is under study. You told us a little bit about that. Tell us some more.

Mr. READDY. Yes, sir. Well, I think you have been provided the ascent risk breakdown with the icons associated with all the different elements. If you look at the one that says SSME, our current engine configuration shows the cluster of three main engines at 1 in 1,000.

Then as you march up and left on that chart, the next highest risk element is the high pressure fuel turbo pump, which we have just flown on STS–104 and are planning to fly again here on STS–108 at the end of November.

We have already implemented the next element, which is the high pressure oxidizer turbo pump, and if you continue up and left on that line, the large throat main combustion chamber we have implemented. The main injector we have implemented. The fuel preburner we have implemented.

And the next item up there, right about the middle of the chart, is the nozzle. That is really the core around which the Block III main engine would be built. That is the single element in the main engine that has not received any upgrade over the time since we have been flying STS–1. So, that would be what we would build the Block III main engine around.

Unfortunately, Colonel O'Connor talked about over $1 billion invested in bringing the Block II engine to fruition. We also think that a Block III main engine would probably also be on the order of over $1 billion to develop.

Mr. READDY. But there again, Senator, if I could point out that the propulsion specialist on our panel, who is the former head of the SSME program for NASA, has expressed great concern about the ability of the current nozzle to last throughout the entire program. So, there is an issue here again of either a need to acquire more nozzles and reinitiate the manufacturing capability or develop a new one. You are not going to get there with the current resources.

Senator NELSON. Well said.

Mr. Readdy, that is over what kind of period for Block III?

Mr. READDY. That would be least 5 years in development. The past track record on the pumps has been it could take as long as 10 years.

Senator NELSON. And that is roughly about a $400 million program up to $1 billion, did you say?

Mr. READDY. I think $1 billion would be a reasonable estimate based on what the pumps have cost, sir.

Senator NELSON. Are there any of these others that you want to comment on?

Mr. READDY. Well, once again, looking at our stack-up of risks, the other element that we did want to look at was the solid rocket booster thrust vector controller. Right now that is the one that is shown with the icon for the solid rocket booster that says HPU. That stands for hydraulic power unit. That is, in essence, an APU for the orbiter that has a lesser duty cycle, and there are two of them per solid rocket booster. They operate for about 2½ minutes and then, of course, they splash down in the Atlantic, get dragged

back to Florida, refurbished, and used again. But it has the same toxic, flammable propellant (hydrazine), the same high temperature environment, the same kind of rotating machinery that goes around at 80,000 rpm or more. So, we would hope to retire a similar amount of risk in that area.

Senator NELSON. And would that be replacing the hydrazine with electric?

Mr. READDY. In this particular case, because it has got a lesser duty cycle of only 2½ minutes, instead of 8½ minutes in ascent and an hour plus on entry, our proposal right now would be to use high pressure helium, which is an inert gas, as the motive agent instead of hydrazine. Helium, of course, is nontoxic, nonflammable.

Senator NELSON. This reduces the SRB failure by about 21 percent.

Mr. READDY. For the SRB, that may be correct. For overall ascent mission risk, it would be about a 9 percent contribution.

Senator NELSON. It is roughly a $200 million item?

Mr. READDY. Yes, sir.

Senator NELSON. Now, Mr. Readdy, did you have a chart that you wanted to show us on this same issue?

Mr. READDY. We affectionately call that particular chart the "Volkswagen" chart. You see kind of the streamlines as it goes up.

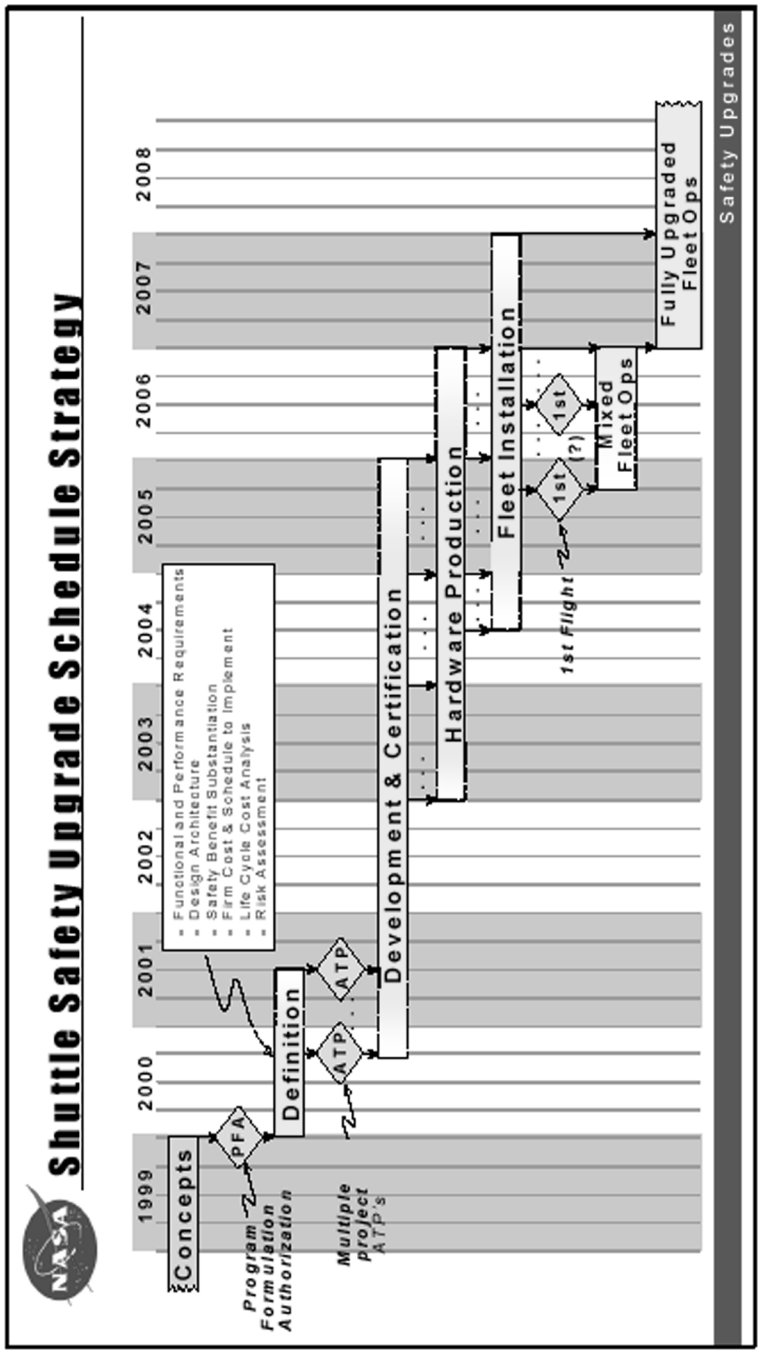
Really the attempt there was to illustrate where we are now and what the possibilities are. We do not have a precise number because these are all probabilities. We have got a range of numbers that go up vertically there.

Senator NELSON. You have a chart on the Space Shuttle program historical budget that you wanted to show us.

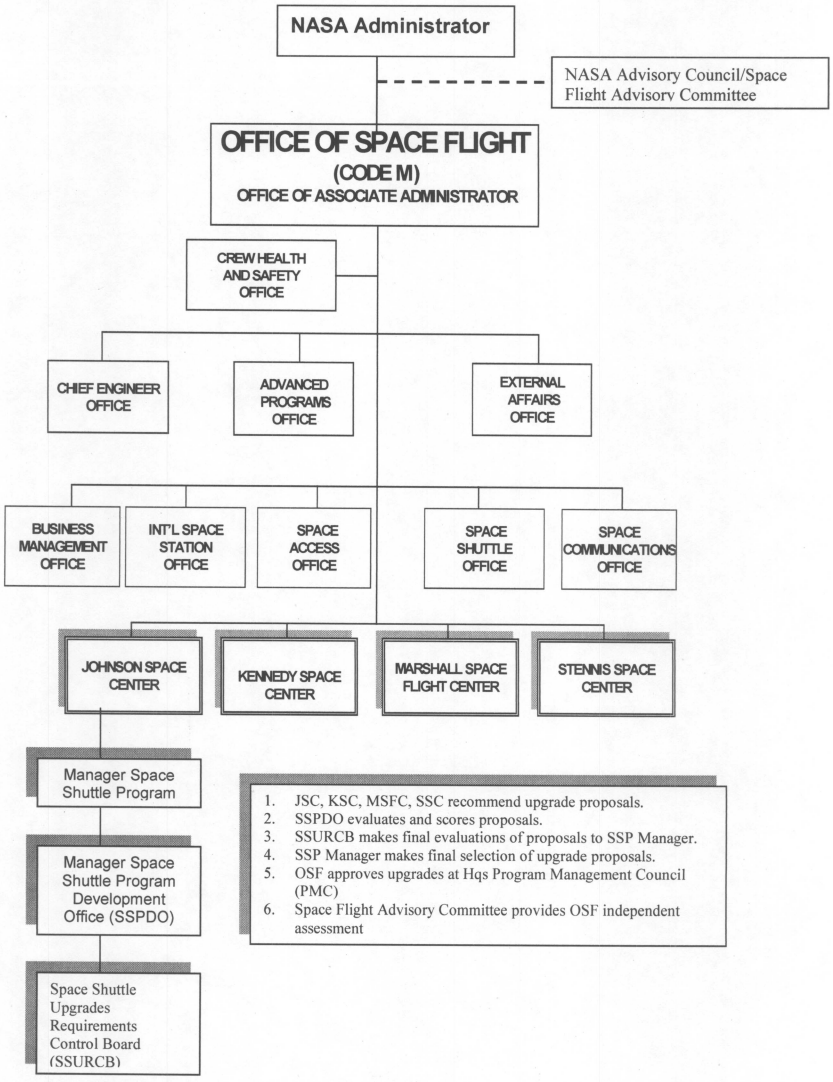
By the way, we will enter into the record the Block II configuration ascent that we have just gone over.

[The charts follow:]

Addendum 1


Shuttle Safety Upgrade Schedule Strategy
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Concepts
PFA
Program Formulation Authorization
Definition
- Functional and Performance Requirements
- Design Architecture
- Safety Benefit Substantiation
- Firm Cost & Schedule to Implement
- Life Cycle Cost Analysis
- Risk Assessment
ATP
ATP
Multiple project ATP's
Development & Certification
Hardware Production
Fleet Installation
1st Flight
1st
1st (?)
Mixed Fleet Ops
Fully Upgraded Fleet Ops
Safety Upgrades

Addendum 2

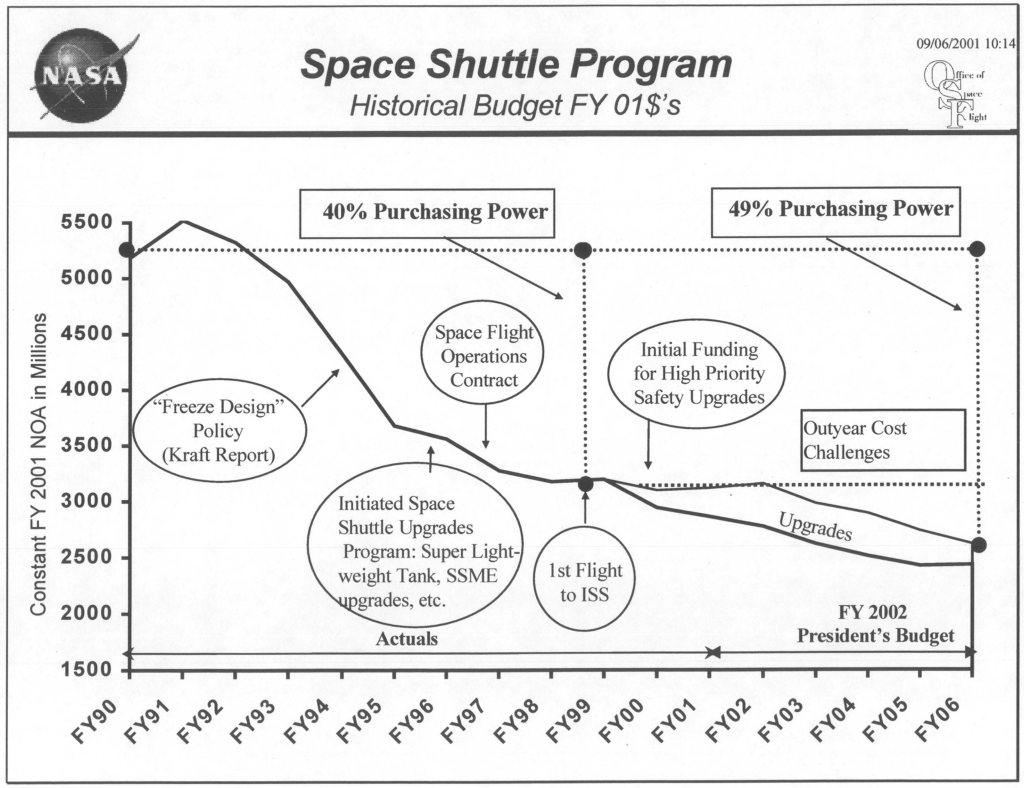

NASA Administrator
NASA Advisory Council/Space Flight Advisory Committee
OFFICE OF SPACE FLIGHT
(CODE M)
OFFICE OF ASSOCIATE ADMINISTRATOR
CREW HEALTH AND SAFETY OFFICE
CHIEF ENGINEER OFFICE
ADVANCED PROGRAMS OFFICE
EXTERNAL AFFAIRS OFFICE
BUSINESS MANAGEMENT OFFICE
INT'L SPACE STATION OFFICE
SPACE ACCESS OFFICE
SPACE SHUTTLE OFFICE
SPACE COMMUNICATIONS OFFICE
JOHNSON SPACE CENTER
KENNEDY SPACE CENTER
MARSHALL SPACE FLIGHT CENTER
STENNIS SPACE CENTER
Manager Space Shuttle Program
Manager Space Shuttle Program Development Office (SSPDO)
Space Shuttle Upgrades Requirements Control Board (SSURCB)
1. JSC, KSC, MSFC, SSC recommend upgrade proposals.
2. SSPDO evaluates and scores proposals.
3. SSURCB makes final evaluations of proposals to SSP Manager.
4. SSP Manager makes final selection of upgrade proposals.
5. OSF approves upgrades at Hqs Program Management Council (PMC)
6. Space Flight Advisory Committee provides OSF independent assessment

Addendum 3
Summary of the SSP Independent Assessments

No.	Organization	Report Date	Findings	Recommendations	NASA Response
1	NRC	1999	"Approach to upgrade planning is appropriate", formal selection process goal oriented for evaluation and prioritization of upgrades.	**25 recommendations** regarding invest strategies, quantitative and decision support systems usage, evaluation and prioritization criteria, specific upgrades to include, industry involvement, etc	All recommendations implemented
2	GAO	Aug-2000	"NASA's strategic human capital planning was inadequate"	**1 recommendation** for developing and implementing plans to have a proper worker skill mix and staffing levels to support SSP.	Staffing plans developed and implemented for FY 2000 & FY 2001 **(I)**
3	SFAC	Aug-2000	"A tremendous amount of outstanding work being done on Space Shuttle Upgrades." This was the first meeting of SFAC to evaluate SSP upgrades	**3 recommendations** regarding elaboration of selection criteria, realistic cost, schedule, budget information, and "human error" parameter inclusion for risk assessment.	Recommendations implemented.
4	SFAC	Nov-2000	Status review of Aug-2000 Report	Revised guidance on recommendations	NASA will continue to implement based on revised guidance
5	SIAT	Mar-2000	SIAT formed as a result of STS-93 ascent anomalies; (wiring problems) there were issues with SSP risk management, operations, etc. SIAT reviewed avionics, human factors, wiring, APUs, problem reporting, wiring safety & mission assurance.	**4 recommendations** required for implementation prior to return to flight; **37 recommendations** required prior to making 4 more flights; **30 recommendations** required prior to 1/1/01, and **10 recommendations** required by FY 2005.	Majority of recommendations implemented and the rest were to be implemented by FY 2005, but may be deferred.
6	ASAP	Feb-2001	Comments on shuttle planning horizon for upgrades; crew escape system study; hydraulic line maintenance; launch & landing paperwork and aging of ground support and checkout test facilities and equipment; and comments on CY1999 report recommendations (24) for implementation	**6 recommendations** regarding maintenance long-term planning, crew escape study, hydraulic line maintenance, paperwork closeout , updating engineering drawings, and budget plan to maintain KSC assets that support SSP	CY2000 recommendations are in work; 13 of the 24 CY1999 ASAP report recommendations have been closed, remainder are still in work.
7	SFAC	Mar-2001	$1.6 Billion budget for safety upgrades and 2005 implementation is unrealistic; Shuttle still operational a decade after 2012; more upgrades needed, especially in propulsion and crew escape.	**2 recommendations**, 1 on review of requirements for cockpit avionics, EAPU, shuttle engine Phase II, SRB TVC	Plans are in work for implementation
8	SFAC IPAO	Jun-2001 Jul-2001	Cockpit Avionics and EAPU upgrade evaluations	**8 CAU recommendations.** CAU is ready to proceed as an actual project. EAPU is not recommended as an upgrade; technology is still too much of a challenge.	CAU recommendations in work; EAPU will become a technology project. EAPU money not transferred to ISS.
9	ASAP	Aug-2001	**9 Findings** in assessing the overall SSP risk posture, due to FY 2002 cost challenges, in regards to delaying Orbiter Maintenance Modifications (OMMs) for Discovery and Endeavour until FY 2005/2006 respectively; and retaining Orbiter Structural Inspections (SIs) at KSC.	**5 recommendations** in regards to providing experienced/trained workforce, planning SI requirements, availability of KSC or Palmdale without interrupting the launch schedule and still fly safely; and long-term OMM/OMDP staffing plans for the foreseeable life of the Space Shuttle.	JSC SSP management evaluating options.

(I) Under review due to budget issues

Addendum 4
Part I



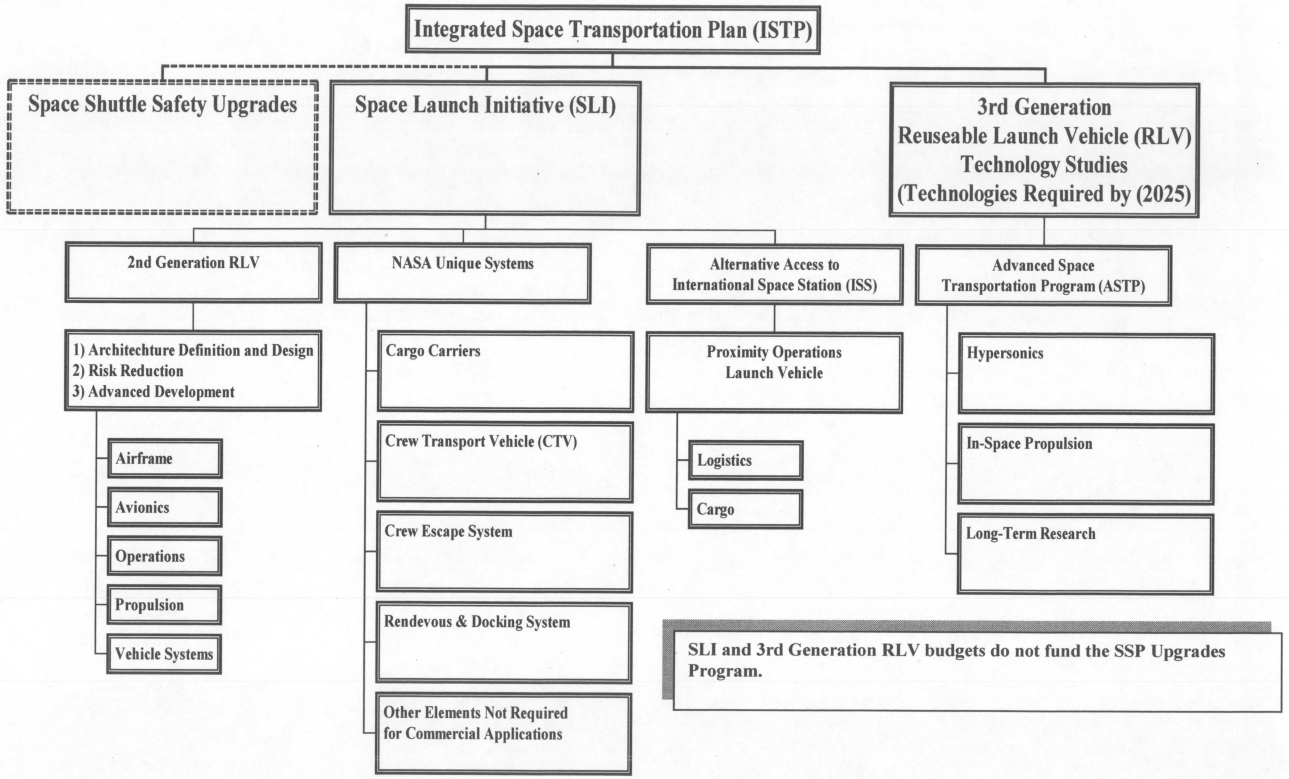
Space Shuttle Budget
OMB Guidance

President's FY'02 Budget Blueprint

- ***Space Shuttle:*** The budget provides for a sustained level of six Space Shuttle flights per year and continues funding for Space Shuttle safety improvements, within which NASA will establish safety investment priorities for Shuttle safety upgrades and critical facilities.

- ***Space Shuttle Privatization:*** NASA will aggressively pursue Space Shuttle privatization opportunities that improve the Shuttle's safety and operational efficiency. This reform will include continued implementation of planned and new privatization efforts through the Space Shuttle prime contract and further efforts to safely and effectively transfer civil service positions and responsibilities to the Space Shuttle contractor.

Addendum 5


Integrated Space Transportation Plan (ISTP)
Space Shuttle Safety Upgrades
Space Launch Initiative (SLI)
3rd Generation Reuseable Launch Vehicle (RLV) Technology Studies (Technologies Required by (2025)
2nd Generation RLV
NASA Unique Systems
Alternative Access to International Space Station (ISS)
Advanced Space Transportation Program (ASTP)
1) Architechture Definition and Design
2) Risk Reduction
3) Advanced Development
Airframe
Avionics
Operations
Propulsion
Vehicle Systems
Cargo Carriers
Crew Transport Vehicle (CTV)
Crew Escape System
Rendevous & Docking System
Other Elements Not Required for Commercial Applications
Proximity Operations Launch Vehicle
Logistics
Cargo
Hypersonics
In-Space Propulsion
Long-Term Research
SLI and 3rd Generation RLV budgets do not fund the SSP Upgrades Program.

Senator NELSON. Please.

Mr. READDY. Yes, sir. I think this really speaks to Senator Allen's original question, credibility in terms of cost estimation. I think even though we would not characterize our vehicle as operational in terms of the relative risk, we would certainly characterize the program as operational in that we know, to a pretty large degree, what it costs for the hardware and what it costs for the people to run the program.

What we have done here is we have put it in current year dollars and adjusted it backward for inflation and then forward we have discounted the dollars to show the effect of inflation on our budget. Our current budget in real year dollars is a constant $3.2 billion. This shows the upgrades wedge that you all initiated, and it also shows what is resourced for six flights per year in the current budget.

Senator NELSON. Does anybody else want to comment on the chart?

Mr. MCCULLEY. Well, Senator, I would repeat what I said earlier that it is that profile that has me greatly concerned because as an almost people-only contract, the only way to achieve those numbers is to reduce staff by significant numbers, which is not only painful but dangerous to the long-term health of the program.

Senator NELSON. Mr. Blomberg, you were shaking your head.

Mr. BLOMBERG. I was shaking my head, Senator, because just the thought of reducing any of the people right now would mean, almost with certainty, that certain critical skills would be eliminated from the program and risk would just go out of sight.

That curve is really almost the mirror image of what it should be for a vehicle of this age. At this point in time, there should be an increased investment in the vehicle to bring it back to the operating state that it had when it was new and to apply modern technology to reduce risk.

I think there are two stages, as I mentioned, that you have got to go through. One is let us make sure we are holding our own and we have a vehicle that is as capable as it was when it was new or, in this case, when it was redesigned after Challenger. And then let us see what makes sense to improve the reliability and improve the safety of the vehicle above that. You cannot do that with a funding profile like that. That is just the opposite.

Mr. MCCULLEY. Richard, I would only comment that "vehicle" is too narrow a term because you need to include the whole system.

Mr. BLOMBERG. I agree with you completely.

Senator NELSON. Right, which is an excellent reminder that you have got a force of people who are trained who are experienced, and if you do not have that and you have to lay off people, then it takes you a long time to accumulate that kind of experience as you would ramp up in the future.

Take this opportunity, Mr. McCulley, to tell them about what happened a few years ago and how the orbiter processing facility, along with the orbiter, could have gone sky high.

Mr. MCCULLEY. One of my reasons for being such a big fan of those two upgrades that dealt with the auxiliary power units—one of them would be replaced by helium; the other would be by electric—is that the very things that make those fuels work so well in

orbit also result—you really have a controlled fire going on in those in the back.

But in the ground processing system, you have valves that leak and heaters that fail and things of that nature. So, you routinely have to work on those orbital maneuvering system pods and in and around those hypergolic fuels and the hydrazine on the auxiliary power units.

But the incident to which you are referring was we were working on OMUS pod on Endeavor in OPF processing facility bay 1, 3, or 4 years ago, and the techs and inspectors, who were in the protective gear—and we had the bay cleared—opened the line up that they thought had been cleared of fluids but it was not. These things are self-igniting. So, second shift, everything is cleared out of the way. These three guys found themselves up inside a very confined space with an uncontrolled fire in their face.

They had a couple of options at that point. One was to run, and nobody would have faulted them for that because they were working with something that could have exploded catastrophically very quickly. It was all caught on tape because we have these video cameras that run as a safety and security issue. So, we were able to watch this thing take place the next day. It was absolutely incredible the way these three men responded to that fire.

They were wearing gloves. But one guy was beating the fire out with his hands, which were gloved. In the meantime, one of the other guys got the nearest water bucket that he could get, and the third guy got on the phone. They each did a part that was there. And the end result was they put the fire out in about 25 or 30 seconds, and the damage was minimal. Actually there was more water damage than there was heat damage, the way it turned out.

But it points out what you wanted to point out that there is not just flight hazards associated with these types of fuels, there are also ground hazards that we have to deal with. It puts our folks in a hazardous environment, and that by definition makes it a more expensive and less efficient environment. So, this particular set of upgrades not only would make life safer on the ground and in the air, but it would also greatly increase efficiency and your ability to manifest and schedule.

Senator NELSON. Let us talk about some of the upgrades for the infrastructure and why that is important. One of the obvious things, there was a hurricane that was headed straight for the Cape about 2 years ago, and thankfully it turned. Yet, some winds did hit the Cape and blew off some panels of the Vehicle Assembly Building or VAB. The continuing assault of corrosion, as well as, I understand, other things that have been there since the Apollo days that simply are going to have to be updated. Share with us what you know about all of that and how does that fit with the overall safety that we are looking at here and the efficiency.

Mr. MCCULLEY. First of all, from a Shuttle program point of view, it is far more than just a Kennedy problem. The Johnson Space Center has a huge number of facilities that are devoted to the Shuttle program, simulators, trainers, mock-ups, a number of things, that also require periodic upgrading or repair and maintenance. The Stennis Center in Mississippi has propellant barges that, like all ships, need refurbishment that has been put off. They

have water pumps that are out on the test stands that need work. The Marshall Space Flight Center has a number of areas that need work. Then, as you mentioned, the Kennedy Space Center, the most visible, of course, is the vehicle assembly building.

These are facilities that were built many years ago. We have done the required maintenance over the years, and that is evidenced by the fact, as I said earlier, we launched 8 times in the last 11 months and we had no failures of things like fuel pumps that pump the fuel into the vehicle, heaters, electrical switch boxes, RF transmitters, any of those things. So, the facility is working but it is working primarily because we are just doing what has to be done and we are not doing as much of what you would like to do so that it is still there 10 years from now to protect.

Some of it is things like 1970's technology-based, oil-based circuit breakers that can get hot and can explode, and the technology today would allow you to be much further along. Those sort of upgrades are not very glamorous, certainly nothing like putting a new main engine or some sort of fancy cockpit in, but they are just as important for the long haul.

Senator NELSON. Does everybody agree with that?

Mr. BLOMBERG. Definitely, and I would just add another example that happens to be at the Kennedy Space Center. But the data cables that run out to the launch pads are in just a horrid state of repair. They are being Band-Aided. They have been working fine. People are doing as much as can be done with them, but the bottom line is they need to be replaced. They could be replaced with fiber optics or modern technology and become much less of a worry. If they fail at the wrong time, a smart failure as we call it, it could be a very serious safety issue.

Senator NELSON. I would like to get your opinions on the record. Since we have concentrated on the Shuttle safety, now I would like you to put on the record your opinions with regard to the threat with the safety to the International Space Station. If the Shuttle is grounded, obviously we have got a problem except for the crew escape vehicle. But what are some of the other things that would imperil the Space Station vis-a-vis Shuttle safety and these upgrades?

Mr. READDY. I think our mission in the Space Shuttle program is to provide safe, reliable, sustainable, human-rated space transportation during the International Space Station era. Those things which allow us to do that, of course, are very important. We have got Captain Frank Culbertson and his crew orbiting right this minute on International Space Station. Pretty soon there will be a year of continuous crew on board International Space Station. We expect to do this for the next 15 years. Without the Space Shuttle to provide crew rotation, to provide logistics, to provide repairs and a platform to be able to do further assembly, it does put that investment in the International Space Station at risk and it causes further reliance on our Russian partners in terms of the Soyuz vehicles for crew up and down, for crew rescue and progress vehicles for crew resupply.

Senator NELSON. Any other comments? Mr. Li?

Mr. LI. Yes, sir. While the Shuttle is extremely important for servicing the Space Station, I think that the alternatives obviously

that are available to us—they might not be the ones that we would want to use—are indeed more reliance on the Russians and perhaps reliance on the Europeans. They are developing an ATV vehicle that will provide that sort of replenishment.

But I am reminded, when I think about what the Shuttle has done recently, that there have been situations where the Shuttle was extremely useful in helping out the Space Station, for example, when they had difficulty with the air conditioning and they were actually using the air and the oxygen from the Space Station. There was that incident where to boost it to a higher orbit, they used some of the propellant and used some of the power from the Shuttle.

So, I think there are those instances, but I think that we have to take a look at the Shuttle as not being the sole provider for being able to help the Space Station.

Mr. READDY. In terms of harvesting that investment that we have made in the International Space Station, the other thing that the Shuttle provides is the research up and the research down from the Space Station. That harvest occurs because the Space Shuttle is able to take up those racks that are full of experiments, those materials that are used in those experiments, and also has the capacity to bring them down to a soft landing.

Senator NELSON. In other words, to put this in investment terms, everything that we have got invested in the Space Station is going to be dependent upon a workable, safe, and reliable Space Shuttle to get to and from the Space Station.

Mr. READDY. Yes, sir.

Senator NELSON. I would like your opinions, so that we can get on the record and clarify in people's minds what was conceived to be the follow-on vehicle to the Space Shuttle—I think it is referred to as the Space Launch Initiative. I wish you would tell about how that all has been delayed and set aside and how that is not likely to come for some period of time, but that in upgrading the Space Shuttle, you are also starting to do your advance, your planning, your design that can be incorporated in the Space Launch Initiative so that ultimately we have the follow-on vehicle. Mr. Readdy, and I would like to go right down the panel.

Mr. READDY. Well, I think Allen Li has recently testified on SLI, but from the Space Shuttle standpoint, we really enthusiastically support the Space Launch Initiative and the goals to provide a next generation vehicle. The Space Shuttle's 20 years of service, though, should be the launching platform because we wind up being a pathfinder for very many of these technologies because we can provide the test bed that takes them to the relevant environment and back.

Also, the lessons that Mike McCulley was talking about in terms of the vehicle processing. We always look at T–O, which is lift-off, to wheel stop, landing. That is only 10 percent of what happens in a reusable spacecraft's life cycle. Ninety percent of that time right now is spent in vehicle processing for the next mission. That is one of the lessons that we need to learn. Part of that is driven by the fact that we have toxic propellants. Part of it is driven by the fact that it was such a cutting edge endeavor to do in the first place that we had to shoehorn things into a vehicle rather than a priority to make them maintainable. So, the maintainability, the reliability

aspects need to be engineered into the next generation vehicle. Those technologies need to be started right now.

The 777 enjoyed, from the tip of the nose to the tip of the tail, the benefit of research that was done 20 and 30 years earlier in digital fly by wire flight control, super critical wing, composite primary structure, glass cockpit, high bypass turbo fan engine technology, et cetera. What we need to do is have the analog to that that will allow us in the next decades to build the next generation of vehicles.

Senator NELSON. Mr. Li?

Mr. LI. Yes, sir. The Space Launch Initiative that you referred to was really the latest reincarnation of what they have been trying to do. But if I can turn you a few years back, there was a recognition of the fact that the Shuttle, even though it is the only game in town, is a very expensive game in town.

That said, there was a need to be able to reduce the cost of sending payload to space from the $10,000 a pound that we currently pay on the Shuttle to maybe $1,000 a pound. The thought is, once we can bring it down to that level, we are going to be able to expand economies of scale, people will be interested, and it will suddenly be economical to send things up in space, and it will generate all these good things.

That said, a few years ago, NASA decided to embark upon an experiment with industry in a cooperative agreement with Lockheed Martin, who won competitively. It was a situation, Senator, where NASA in essence said we are going to put $900 million on the table and you put about $200 million something. With that amount of money, you go out and build the X–33 demonstrator. Well, as you perhaps know, that experiment was not successful.

One of the foundations of them feeling and being optimistic that that would work was that they felt that industry was going to be able to reap some benefits from the development of an RLV. They thought that tons of satellites would be launched and that the commercial sector would be willing to take advantage of that. But as you know, with the demise of things like Iridium and Teledesic, that did not happen. As a result, industry was not willing to fork over the additional amounts of money that would be required for the X–33 to continue.

The SLI process that you were referring to is the current one that NASA has, and they have about $700 million of contracts. Those contracts will go about reducing risk. They are not developing a vehicle. They are just coming up and identifying individual technologies. And that is what they are doing right now. They are hoping that by the 2006 timeframe they can make a decision on whether or not to go forward. But as I said in my statement, Senator, I think that having that 2006 timeframe and not knowing how long you are going to have to keep the Shuttle operational is a real difficult task that people like Mr. Readdy have to deal with.

Senator NELSON. Just to underscore that, what you had said, Mr. Readdy, earlier it took 10 years and $40 billion to develop the Space Shuttle and you compared it with some other programs that were developed.

Mr. READDY. Yes, sir.

Senator NELSON. What were they?

Mr. READDY. Well, that would be one end of the curve which is the first generation reusable launch vehicle. The other end of the curve—and I shamelessly pirated this from Norm Augustine's book *Augustine's Laws*—would be the 777, which Boeing would admit to $12 billion of their money tied up for 6 years to develop.

So, somewhere on that continuum is what it takes to do aerospace hardware. I guess my first order cut on it is it is probably somewhere in the middle, maybe more toward the Mach 25 end of it rather than the .85 end of it, not the subsonic end, but the hypersonic end.

Also, just to amplify what Mr. Li said. We talk about cost per pound to orbit, but the unit cost is not cost per pound. The unit cost is cost per launch. In the Apollo era, those launches were about $10 billion to $11 billion per launch. If you just take the Shuttle budget and divide it by our flight rate, right now it is on the order of about a half a billion dollars per launch, which is expensive, but it is on the same order as the Titan IV launch vehicle and it has the reliability of about 1 in 20 for similar lift capability compared to our launch reliability.

Then the final thing is where we would like to get to in terms of human-rated space transportation is where Herb Kelleher is in Southwest Airlines, and he does not charge by the pound either.

Senator NELSON. Well said. And when you add in the factor of how many billions of dollars that we have spent on the International Space Station that we are now assembling and the ability to use that asset, recognizing that the follow-on launch vehicle is going to be some number of years down the road, then you have got to provide an access to space to the Space Station. And we best get about the process of making this one as safe as we can for the future.

Now, my hat is off to you, all of you, for what you have done in the reliability and the increased safety that you have given to this point. With what you have done over 10 years of a declining budget in real dollars—that is overall NASA, but what you have done in a Space Shuttle budget with 40 percent less money over that decade is nothing short of miraculous to have the kind of safety record that you have today. But that is not going to continue for the future, and that is the whole point of us getting together today.

I was able to see Senator Bond on the floor when I went to vote. I grabbed Senator McCain. Those were the two that I grabbed and gave them a little bit of a vignette of what we have been talking about today, and I will continue to do this as we get ready to make the appropriations decisions on down the line.

Does the staff have any more questions that you want asked? OK.

We are going to keep the hearing record open for two weeks for any additional comments. Do any of you all have any additional comments that you would like to make?

Mr. LI. I would like to say something about lessons learned, Senator. I do not think I will be here 30 years from now, but if I were 30 years from now sitting at this table, I would not want to be in a situation where there was an operational RLV and we had the similar types of problems where we had to do upgrades. I want to go back to perhaps why this is happening.

I believe that the Shuttle was developed not with supportability and maintainability in mind, and I think that is what we have to do. If we go to a future vehicle, let us start thinking about building something that we can maintain, something that we can use every day, something that we do not require an army to take care of. Let us not shortchange that part of the process.

Senator NELSON. Well said.

And on the same issue of lessons learned, I deem it a great privilege to have the opportunity to be here now representing the State of Florida, and there were some lessons that I learned. And it is absolutely obligatory on my part, now that I sit as a Member of this Committee, to try to pass on those lessons learned, for that was a very painful time in January 1986, only 10 days after our flight had returned to earth and which almost happened to us what happened 10 days later. So, I just deem it a great privilege to be here and to try to speak out.

Mr. McCulley?

Mr. MCCULLEY. I told you earlier off the record—and I would like to say it again now on the record, and that is to thank you for bringing your interest and your expertise and having us here today and giving us a forum to express our concerns and with some confidence now that you can go do battle perhaps armed a little better than you were before. So, thank you very much.

Senator NELSON. Indeed. You all have brought excellent testimony to the Senate today, and I thank you.

The meeting is adjourned.

[Whereupon, at 5:04 p.m., the Subcommittee was adjourned.]

APPENDIX

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. ERNEST F. HOLLINGS TO WILLIAM F. READDY

Budget

Question 1. NASA has stated that due to cost growth its FY 2002 Space Shuttle budget would have a shortfall of $218 million. In briefing the Committee, NASA has identified $185 million in cost savings but was unable to address the remaining $33 million because costs are still in flux. Does NASA have a better grasp of how much the FY 2002 budget shortfall will be? Has NASA identified cost savings, which offset the entire amount of the shortfall?

Answer. NASA identified the FY 2002 Space Shuttle budget shortfall to be approximately $218 million. Changes to the outyear flight manifest reductions to a flight rate of four Shuttle missions per year may yield some modest additional savings in FY 2002. Additional program content adjustments may also be necessary to offset the entire amount.

Question 2. NASA is funding Shuttle supportability upgrades at about $100 million annually. However, cost growth on the Checkout and Launch Control System at Kennedy Space Center has reached the point that it almost consumes the annual funding for all supportability upgrades. How does NASA plan to fund other needed supportability upgrades in the future?

Answer. Although the Checkout and Launch Control System (CLCS) has experienced cost growth, it does not consume the annual Supportability Upgrades funding in the FY 2002 President's Budget. CLCS represents less than half the Supportability Upgrades budget for FY 2002, with a steady decline to less than 10 percent of the budget by FY 2006.

Orbiter Major Modifications

Question 3. The orbiter Discovery (OV–103) was scheduled for an OMM later this year. But NASA has proposed that, due to severe budget limitations, the OMM scheduled for the orbiter Discovery had been deferred and a more cursory "structural inspection" would be performed at the Kennedy Space Center in Florida. What are the differences between these two types of inspection? Will the structural inspection allow for the same level of safety that the OMM would? Please explain.

Answer. During an Orbiter Major Modification (OMM), at a minimum, major safety upgrades and structural inspections are performed on the orbiters and would be performed on Discovery irrespective of the location of the modifications. At this time, NASA is still assessing the pros and cons of both sites. The Office of Space Flight expects to decide the content and location by the end of CY–2001.

Workforce Issues

Question 4. Last year, GAO noted that training of new hires was a challenge facing NASA. Given the extent, to which the agency has recently added new hires to the workforce, what specific plan has NASA adopted to ensure that these workers are properly trained?

Answer. As a result of beginning to hire new employees and fresh-outs, the NASA Centers have instituted, or have begun to revitalize, various orientation and other training programs designed to assimilate new employees into the workforce and provide mentoring and career development guidance. Many programs also include the requirement for specific types of training (e.g., technical or administrative), and include both on-the-job and developmental experiences over a period of time. Components in many Centers' training programs also provide for guidance to supervisors in designing a training plan or individual development plan, providing mentoring and coaching, and evaluating work products and progress. The goals of these programs are to aid in the smooth and effective integration of new employees into the Center and Agency workforce. This will be accomplished by: providing a continuing and accelerated learning process; providing employees a way of identifying with the Center by understanding its mission and values; providing interaction with more

senior staff and leaders; and, providing opportunities to develop relationships with peers. At the Agency level, efforts are being initiated to establish a network of experienced practitioners who can provide mentoring and access to expertise in project management.

At the Agency level, resources have been requested to enable NASA to expand the delivery methods being utilized to develop the workforce. Specific emphasis is being placed on the development of e-learning alternatives that can be accessed at all locations and levels, and increasing the ability to expand participation levels across the Agency. In addition, new capabilities are being developed to facilitate learning within intact teams, delivering tailored content directly to a project team at the point in time specific training is needed. In addition, some Centers have also increased their resources available for training, and are instituting Center specific initiatives based upon Center needs. In addition, learning organization tools and methods being introduced in pilot projects within NASA are increasing organizational understanding, motivation, buy-in, and results. Examples of new initiatives include web-based course delivery and partnerships with universities for academic training.

Infrastructure

Question 5. In testimony before the Committee, Mr. Mike McCulley from United Space Alliance stated that we can no longer wait to begin infrastructure improvements. Why has NASA not included these projects in its annual budget request? Will the FY 2003 budget request begin to address this issue?

Answer. The President's FY 2002 budget request for NASA's Space Shuttle Program (SSP) assumed a flat budget, across the entire budget horizon, with assumed productivity offsets for inflation and other increased requirements. Over the past several years, the SSP has aggressively pursued, realized and exhausted operational and productivity efficiencies. To operate with a flat budget profile the Program must continually find productivity offsets for inflation and other increased requirements. As a result of operating in this environment, the Program has only been able to sustain a minimal maintenance schedule. The Shuttle program has determined infrastructure requirements necessary to support the Shuttle Program until 2012 and plans to address these requirements in future budget requests.

Because of a desire to limit growth of the Space Shuttle budget, the program has included a minimal maintenance schedule. The Shuttle program has determined infrastructure requirements necessary to support the Shuttle Program until 2012 and these requirements are being considered in preparation of the FY 2003 budget request.

Long-term Vision for Human Space Flight

Question 6. What is the long-term vision for human space flight now that the X–33 has been canceled? and cost overruns of the International Space Station are putting tremendous pressure on the budget? When the Shuttle is retired, what will the next generation space vehicle look like and be capable of? What is NASA doing to build that vehicle?

Answer. X–33 was an unmanned, suborbital technology demonstration project aimed at paving the way for an unpiloted, commercially-developed Lockheed-Martin Venture Star reusable launch vehicle. NASA's role in the follow-on Venture Star vehicle would have been to provide requirements and funding for 'human-rating' of the vehicle.

NASA is dedicated to assuring the nation continues to play a leadership role in human space flight. Despite International Space Station fiscal challenges, NASA remains committed to NASA's Space Launch Initiative (SLI) program. SLI is targeted at investing in the technology that offers the greatest potential to reduce the technical and business risk associated with the design, construction, and operation of the next generation reusable launch vehicle architecture to support human space flight and other NASA missions. The makeup of that architecture is being defined through a competition among industry's best ideas.

SLI investments are expected to lead to commercially developed and operated Earth-to-orbit vehicles/systems, combined with unique government assets that can meet NASA's human and robotic needs as well as commercial and military space access requirements. Recent SLI contract awards have committed approximately $750 million in funding as an investment in technology development and demonstrations for various critical technology drivers. Additional awards are expected next year. The Program will mature these technologies over the next several years to allow selection of at least two competing vehicle architectures by mid-decade with an initial operating capability early in the next decade.

Question 7. What will NASA's Human Space Flight enterprise be doing in ten years? In twenty years? In fifty years?

Answer. As described in NASA's current strategic plans for the future Human Exploration and Development of Space (HEDS), the coming decades will enable the U.S. and our international partners to achieve truly profound advances in scientific knowledge, in economic opportunity, and in building a better future for humanity.

In the coming decade, the Space Shuttle will continue to be operated safely and it will be also further privatized. The International Space Station (ISS) will be completed and groundbreaking scientific and applied research will create the foundation of knowledge needed to enable long-duration human space flight beyond low Earth orbit. Particular progress will be made in our knowledge of effects of long-term space flight on humans as well as needed countermeasures. At the same time, major new technologies will be validated in space and on ISS, setting the stage for a new generation of space systems and infrastructures opening up the Earth's neighborhood the area of space containing low and high Earth orbits, the moon and the Sun Earth and Earth-Moon Libration points) for space science, exploration and space development. NASA's Human Space Flight enterprise will partner with the science enterprises to understand and plan for the most effective science-driven human missions.

In the next twenty years, the International Space Station will transition to largely commercial operations that will include providing laboratory services to the science community while major new infrastructures are deployed for government and commercial applications—opening the way for revolutionary new space missions. Opportunities may include the deployment of a small, human-tended outpost near the Moon. From such an outpost, large new telescopes might be built and deployed and the global exploration of the Moon by robots and humans might be undertaken. At the same time, transformational new technologies and systems (including new Earth-to-orbit transportation) could be developed and demonstrated—setting the stage for human missions to Mars and the asteroids. On these foundations, new commercial opportunities can emerge, including new generations of communications satellites, commercial power utilities in space and public space travel.

Within the next fifty years, which is the same distance in time from the present as the present is from the earliest days of the space age; pursuing the current HEDS strategic plan will enable the U.S. economy to expand significantly into space. This will include new industries in low Earth orbit (e.g. space business parks and in-space manufacturing) and across the Earth's neighborhood (e.g. space solar power stations and the development of Solar System resources on the Moon and elsewhere). Also, new generations of lower-cost reusable space launch systems will be developed and deployed. The global exploration of the Moon and Mars by robot and human teams could have been accomplished—and permanent outposts on both worlds could have been established. The extraordinary space observatories made possible by our new capabilities in space will have made ground-breaking discoveries such as the imaging of the first Earth-like planets beyond our Solar System.

Furthermore, the development of the needed technologies and capabilities for these goals will also have made possible the transformation of our goals and accomplishments in the exploration of the Solar System beyond. This will include sample returns from the outer planets, probes beneath the icy crust of their moons, and perhaps the first probes beyond our Solar System.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO WILLIAM F. READDY

Question 1a. In correspondence to the Committee, NASA indicated that the cost of the Electric Auxiliary Power Unit (EAPU) has grown from an initial estimate of $224 million to as much as $600 million since its inception in 1999.

Can you explain this three-fold increase in such a relative short period of time?

Answer. The Space Shuttle Program (SSP) encountered significant technical challenges with the EAPU project as the technical formulation phase progressed. Assumptions made for the initial estimate about the maturity of necessary technology, primarily the power cells, turned out to be incorrect, and there was significantly more technology development that needed to be performed. The estimate of cost to project completion increased due to the inability to mature the technology resulting in significant weight, mass, and cost growth. As a result, the most recent proposal was close to $500–600 million, between two to three times the original cost estimates.

Question 1b. Is there a generic problem with cost estimating at NASA, given the type of estimate increases we have seen on other programs?

Answer. According to the recent International Space Station Management and Cost Evaluation (IMCE) Task Force report, continued escalation of cost estimates

are an indication of inadequate cost estimating methodology, tools and controls. Although a multitude of cost estimating techniques are used by NASA and its contractors, program control techniques have suffered from insufficient early warning analysis due to lack of experienced program control personnel, modern management information tools, reduced emphasis on control and reporting techniques, and diverse accounting systems.

NASA is responding to this concern by taking actions to improve cost management and cost estimating, including shifting of NASA personnel to enhance its program evaluation capability. The recent award of the Independent Program Assessment Contract to Booz-Allen-Hamilton/Raytheon is a step towards improving the Agency's independent assessment capability. The contractor will support the Johnson Space Center Systems Management Office in providing full programmatic and institutional assessment capability.

The increases in cost estimates on Electric APU were an indication of a generic problem with the ability of NASA's Human Space Flight programs to develop cost estimates. The causes in this case were primarily underestimating the technological risk remaining for developing the unique batteries required for EAPU as well as growth in requirements early in the formulation phase of the project or task.

Question 2a. You stated that NASA has a milestone for a Shuttle replacement to achieve "Initial Operating Capability" at the start of fiscal year 2012. This seems to be a very aggressive schedule given that it is only ten years away.

What firm plans does NASA have for this milestone other than the Space Launch Initiative, which does not guarantee an operational vehicle at the end of its efforts?

Answer. "Initial Operating Capability" is a Space Launch Initiative (SLI) milestone and, as explained below, is the point at which the Space Shuttle operations can begin to phase down as new systems begin operations. The Space Shuttle upgrades will improve the safety of the Space Shuttle fleet until the next generation system is operational. NASA will assess the progress of SLI in the middle of this decade, and may re-evaluate Space Shuttle upgrade needs for longer-term requirements if it appears that 2nd Generation RLV systems will not reach operational capability by 2012.

Question 2b. What is meant by "Initial Operating Capability?"

Answer. Certification of 2nd Generation RLV systems begins in the 2008 to 2009 timeframe with the first full-scale launch. The specifics of the certification process and the number of launches to certify the vehicle have not been defined; the vehicle type and the technologies used will influence the certification process. At the completion of the certification process, anticipated to be in 2012, the RLV system will be operational, reaching its "initial operating capability" milestone. At the time, Space Shuttle operations can begin to phase down as new systems begin operations.

Question 3. Can you explain why the NASA annual budget requests have not included funding for Shuttle infrastructure projects?

Answer. The President's FY 2002 budget request for NASA's Space Shuttle Program (SSP) assumed a flat budget, across the entire budget horizon, with assumed productivity offsets for inflation and other increased requirements. Over the past several years, the SSP has aggressively pursued, realized and exhausted operational and productivity efficiencies. To operate with a flat budget profile the Program must continually find productivity offsets for inflation and other increased requirements. As a result of operating in this environment, the Program has only been able to sustain a minimal maintenance schedule. The Shuttle program has determined infrastructure requirements necessary to support the Shuttle Program until 2012 and these requirements are being considered in preparation of the FY 2003 budget request.

Question 4. Of the projected $218 million shortfall in fiscal year 2002, $35 million is from core skills and business base erosion. Can you elaborate on what is included in this category?

Answer. Increases in core skills and business base erosion are a direct result of Rocketdyne business base declines in the production of major engine components. In last year's budget estimate, NASA assumed reductions in Rocketdyne funding consistent with production demands. In addition to the Space Shuttle Main Engine (SSME), other Rocketdyne business areas are below last year projections. Contributing factors are reduced demands for Delta launches, and cancellation of the X–33 causing the resultant drop to the RS–2200 Aerospike engine effort. Many of the personnel supporting the SSME project did so on a part-time basis, while working other projects as well. Because of the drop in other projects, the SSME project must pay for more than the time it needs from key Rocketdyne staff, in order to preserve the key skill base. The $35 million shortfall represents a preliminary estimate of

the cost to maintain core skills within Rocketdyne that NASA needs in support of the SSME project.

NASA is pursuing alternative approaches to preserving the necessary skill mix at Rocketdyne. Maximum use of Rocketdyne critical skills and capabilities on Space Shuttle upgrade activities is being fully explored, particularly for Space Shuttle Main Engine health monitoring. The potential impact of SLI-funded propulsion activities is also being fully incorporated into skill mix assessments. Finally, NASA is working with Rocketdyne to assess how information technology could be used to capture critical knowledge and skills from the Rocketdyne workforce, to assist in training and expand the flexibility of the workforce to reduce the need for supporting some skill areas. NASA believes that the critical skills can be preserved at lower cost than the initial estimate if the above actions are aggressively pursued.

Question 5. How many more years is NASA planning to operate the Shuttle orbiters?

Answer. NASA's current plans are to safely operate the Space Shuttle through at least 2012, to support the ISS for assembly and logistics missions, undertake non-ISS missions that require unique Space Shuttle capabilities, and to meet other national reusable launch vehicle (RLV) goals. The transition plan to a 2nd Generation RLV must ensure that the new system is operated effectively and efficiently before final retirement plans for the SSP are implemented. It is important to note that there is sufficient airframe margin remaining (70–75 missions) in the certified life of each Shuttle orbiter to operate the fleet beyond 2012 if necessary.

Question 6. GAO has stated in its written testimony for today that several upgrade projects for the Shuttle had not been fully approved which created uncertainty within the program, and while NASA had begun to establish a dedicated Shuttle safety upgrade workforce, it had not fully determined its needs in this area. Can you comment on these findings?

Answer. The FY 2002 Space Shuttle Upgrade program budget requirements are currently under review by Agency management, and this review has been complicated by the increased budget pressures and cost increases to Space Shuttle operations in FY 2002. These decisions will undoubtedly revise plans for the current upgrades portfolio. The SSP's goal is to resolve these competing priorities and cost challenges as expeditiously as possible, thus identifying the resultant impacts to the upgrades planning and the upgrades workforce.

Question 7. You have spoken about NASA's use of advisory panels and the role they play in your management. How do you distinguish between your responsibilities for planning, leading, organizing, and controlling projects and that of advisory panels?

Answer. NASA's responsibilities for providing direct management over its programs and projects are described in NASA Policy documentation. NASA Headquarters and Lead Center organizations (engineering, safety, reliability, quality assurance, etc.) generate specific policy and guidelines for carrying out their day-to-day duties as it pertains to the type of program/project being developed.

The present NASA advisory structure consists of two top-level committees that report to the NASA Administrator, the Aerospace Safety Advisory Panel (ASAP), established by Congress to examine safety issues, and the NASA Advisory Council (NAC). There are eight standing committees that report to the NAC. One of these subcommittees is the Space Flight Advisory Committee (SFAC). The Council and its committees review the agency's policies, programs, and strategies and consider the degree to which they achieve their objectives. The NAC also serves as an additional source of reflection and consultation for the NASA Administrator on broad-reaching issues. From time to time, study groups or task forces may be asked to examine particular issues of special concern.

The ASAP and the NAC and its subgroups are agency advisory committees and provide advice and counsel to the NASA Administrator. NASA also receives valuable advice from independent groups such as the Space Studies Board and the Aeronautics and Space Engineering Board, administered by the National Research Council for the National Academies of Sciences and Engineering. These two boards, however, are advisory to many elements of the Federal government and are primarily responsible to their parent academies. Thus, they provide their counsel from a different perspective than that of NASA's own advisory groups.

Question 8. You have testified that NASA has to balance funding priorities concerning crew safety, Space Shuttle operational requirements, high priority safety upgrades, and infrastructure projects. In this balance, infrastructure improvements are delayed creating a backlog. What can Congress do to help NASA more aggressively repair infrastructure problems and reduce the growing backlog?

Answer. The President's FY 2002 budget request for NASA's Space Shuttle Program (SSP) assumed a flat budget, across the entire budget horizon, with assumed productivity offsets for inflation and other increased requirements. Over the past several years, the SSP has aggressively pursued, realized and exhausted operational and productivity efficiencies. With the continued flat-lined Space Shuttle budget across the entire budget horizon, it has become more and more difficult to manage the program within these funding constraints. The program has had to continue to make some difficult decisions in order to address requirements to maintain its primary goal to fly safely. The majority of the real property the Shuttle program uses is currently more than 34 years old. The Agency will continue to use the Space Shuttle as the primary human rated space access vehicle through at least 2012. The Shuttle program has determined infrastructure requirements necessary to support the Shuttle Program until 2012 and these requirements are being considered in preparation of the FY 2003 budget request. It would be beneficial for the Congress to provide necessary budget flexibility within the Space Shuttle Program rather than mandating specific infrastructure projects.

Question 9. In 1999, the National Research Council (NRC) criticized your Decision Support System for prioritizing upgrades. What steps has NASA taken to create a "clear, defensible decision process that takes into account all of the available evidence?"

Answer. A separate Development Office was formed within the Space Shuttle Program Office at NASA's Johnson Space Center (JSC) to prioritize, select and fund upgrades. The role of this office is to select upgrades that are technologically ready for implementation. This Space Shuttle Program Development Office (SSPDO) manages the upgrades program content, and final approval of upgrades requires the approval of the Space Shuttle Program Manager.

In addition, the Space Shuttle program has benefitted from the advice of the Space Flight Advisory Committee (SFAC), an element of the NASA Advisory Committee (NAC). The SFAC reviews the prioritization process for upgrades and makes findings and recommendations based on their reviews. The review and validation of the upgrades decisions by this advisory group adds to a clear, defensible decision process.

The selection process for establishing the Space Shuttle Upgrades program content is based on prioritization of candidate upgrades based on rigorous systems analyses. The goal of this process is to develop and maintain an integrated suite of baselined upgrade projects that have been selected for optimal compliance with the Space Shuttle Upgrades program objectives. The portfolio therefore consists of candidate proposals undergoing initial definition and feasibility assessments, proposed upgrade projects, which have received formal approval for further definition and implementation planning, and those projects which have been approved for implementation and thus form the baselined Space Shuttle safety upgrades program content commitment.

The following general set of criteria and considerations are used by the SSPDO in developing a program content recommendation to the Space Shuttle Program Manager and higher level approving officials:

a) Significant improvement to flight safety is the highest priority of the Space Shuttle Upgrades program.

b) Significant Space Shuttle flight system supportability threats must be mitigated to have a viable and reliable SSP through at least 2012.

c) Iterative systems analysis and trade studies are used to search for a set of optimal affordable combinations of safety and supportability upgrades; i.e., focus is placed on substantiating safety risk and supportability threats through quantitative analysis, and alternate solutions are actively researched.

d) The SSPDO strategy in case of resource conflict among high priority safety improvement opportunities and supportability needs is to direct in-depth trade studies on options to solve the supportability threats adequately at lower cost than initially proposed. For example, trades may consider adequate but less comprehensive supportability upgrades, or analysis may show that temporary low cost solutions may allow deferral of longer term more expensive supportability solutions. In any case, every significant supportability threat shall be adequately addressed in the Space Shuttle Upgrades Program implementation planning.

Question 10. Both the NRC in 1999 and GAO recently have questioned the accuracy of NASA's cost estimates, and whether they accurately reflect the actual costs that

are incurred by programs. For example, there have been allegations that part of the $218 million shortfall is due to a deliberate NASA underestimate of contractor rate increases. How does NASA intend to improve its cost estimating system?

Answer. The Space Shuttle Program's budget has been on a steady decline over the past several years. The President's FY 2002 budget request for NASA's Space Shuttle Program (SSP) assumed a flat budget, across the entire budget horizon, which assumed productivity offsets for inflation and other increased requirements that have not been realized due to cost increases. Since that time, NASA identified additional increases for the SSP totaling $218 million in FY 2002, such as escalation of contractor rates and health benefit increases, utilities increases, core skills and business base erosion, and increasing orbiter maintenance modification estimates. These increases further exacerbated pressure on the already lean Shuttle budget.

NASA is responding to this concern by taking actions to improve cost management and cost estimating, including shifting of NASA personnel to enhance its program evaluation capability. The recent award of the Independent Program Assessment Contract to Booz-Allen-Hamilton/Raytheon is a step to improving the Agency's independent assessment capability. The contractor will support the Johnson Space Center Systems Management Office in providing full programmatic and institutional assessment capability.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO RICHARD D. BLOMBERG

Question 1. What type of investments in the Space Shuttle do you believe will be needed to allow NASA to reap the full benefits of the Space Station?

Answer. The Space Shuttle is the major resupply and crew transfer vehicle for the International Space Station (ISS). Its capabilities with respect to crew and payload size are unmatched by any other human-rated space vehicle. The Space Shuttle is the only vehicle servicing the ISS that is capable of returning payloads and science results from orbit. It has also been providing significant reboost for the ISS thereby reducing reliance on Russian Progress vehicles. It is essential to keep the Space Shuttle as reliable and safe as possible since it is the key element in the ISS logistics chain. The Aerospace Safety Advisory Panel is concerned that both the safety and reliability of the Space Shuttle are being compromised in the long term because of lack of investment in four areas:

- Flight systems—Many of the subsystems of the Space Shuttle are aging and likely cannot support flight at current risk levels for the entire expected service life of the total system. For many others, advancing technology has provided ways to reduce risk significantly if improved components are designed, developed, tested and certified. The Panel believes that, at a minimum, significant investment above and beyond current budget levels are required just to retain present safety margins over the next 20 or more years. Additional expenditures are warranted in areas for which risk can be meaningfully reduced from those produced by the original design. In both cases, it is important to recognize that the long lead times involved in manufacturing current components or designing and qualifying improved replacements dictate the need to make investments now so that the Space Shuttle is fully capable of safely meeting the flight needs for ISS support.
- Renewal of the ground infrastructure—Investment is critically needed to revitalize the launch facilities, ground support equipment, laboratories and test and checkout gear needed to support safe Space Shuttle flights. A significant portion of this infrastructure is over 30 years old, and continual budgetary pressures have forced the deferral of much needed maintenance and replacement. The ISS cannot be supported adequately if these ground assets force a reduced flight rate or a temporary grounding of the Space Shuttle. Safety of the Space Shuttle can be compromised by unreliable ground infrastructure. Interruptions of Space Shuttle flights would also markedly impact the chance of ISS mission success. The Panel believes that NASA must be able to make proactive investments in ground infrastructure to prevent failures and assure the availability of flight support for the ISS.
- Logistics—Providing for the timely availability of properly functioning components throughout the projected life of the Space Shuttle is essential to its ability to support the ISS. Many items for the flight vehicle and ground support equipment are not in sufficient supply to carry the program until a viable replacement vehicle is qualified. Therefore, in addition to making sure that flight systems and ground infrastructure are as capable as possible, NASA must invest

to ensure that there are sufficient assets readily available to support safe and effective operations for the lifetime of the Space Shuttle. The Panel believes that investment both for parts and in refurbishment capability is warranted.

- Workforce—The Space Shuttle is a complex system that will always depend on the ability and insight of a trained and experienced workforce for safe operation. Over the years, there has been a "natural" succession of Space Shuttle leaders. Experienced managers mentored younger members of the workforce and prepared them to assume leadership roles. Recent staff cutbacks and hiring freezes have created a gap in the ranks. Future budget limitations suggest that replenishing the "understudies" will be difficult. The Panel believes that NASA should be in a position to invest in the hiring and nurturing of future Space Shuttle managers. Such an investment would also create a cadre from which the leaders of future human spaceflight programs could be drawn just as many Space Shuttle veterans received their initial experience on the Apollo Program.

Question 2. You have mentioned four areas of which the ASAP considers critical to the long-term operation of the Shuttle: flight system improvements, renewal of ground infrastructure, logistics and workforce.

Did the Panel place these in any order of priority for NASA?

Answer. All four of these areas are critical over the expected service life of the Space Shuttle. The most immediate priority area, however, is likely maintaining and augmenting the workforce. This will provide the leadership necessary to direct the actions in the other three areas. Flight system improvements and infrastructure revitalization must also be given an immediate priority because of the relatively long lead times involved in their implementation. Some logistics actions can await decisions between the simple replacement of aging components and the development of improved substitutes.

Question 3. You have mentioned that any replacement for the Shuttle likely would not be more capable than the current system with appropriate upgrades. Can you elaborate on this conclusion?

Answer. One or more major technological advances will be needed in order to advance the state-of-the-art of human-rated spaceflight vehicles beyond the level of the Space Shuttle. For example, more efficient propulsion systems operating at lower stress levels could profoundly alter both the safety and cost of placing humans into earth orbit.

At present, there are no major technological breakthroughs available upon which a new, safer and more capable Space Shuttle replacement could be based. Upgrades have been identified, such as the electric auxiliary power unit and advanced health monitoring of the Space Shuttle main engines, which could improve the safety and reliability current vehicle. These same features would likely be standard equipment in any new vehicle designed today. Although they represent significant improvements, they are not the basis for a radical, new system design.

Question 4. You have mentioned the impact of budgetary constraints on the program. For the Advisory Panel's review of the program, did you find that management of existing funds was sufficient?

Answer. The Aerospace Safety Advisory Panel is chartered to examine the safety of NASA's operations. When appropriate, we will highlight budget shortfalls that we believe have the potential to be detrimental to safety. We do not trace the management of existing funds to determine if it is sufficient. Over the likely service life of the Space Shuttle, however, the magnitude of the present projected budget shortfall appears to be beyond the ability of any management to correct while still flying safely and meeting program objectives.

Question 5. You have mentioned that the Panel is particularly concerned about infrastructure at KSC. How do the infrastructure problems at KSC compare to the needs at other NASA centers?

Answer. All of the human spaceflight centers are facing similar infrastructure problems because the maintenance and restoration of key facilities has been continually deferred. The situation at KSC is of particular concern to the Aerospace Safety Advisory Panel because it has the most direct potential impact on Space Shuttle safety. Other centers evidence similar examples of obsolete and worn infrastructure, but the preponderance of infrastructure related to the preparation and launch of the Space Shuttle is at KSC. Many of the KSC facilities are legacies from the Apollo Program. Assets such as the data cables to the launch pads are old and deteriorated and are only being kept operational through the ingenuity of the workforce. This cannot continue indefinitely.

Question 6. How would you recommend capturing the knowledge of the current workforce for future use?

Answer. There are numerous emerging techniques for "mining" experience that have been developed as part of knowledge engineering efforts. Basically, however, two fundamental conditions must be satisfied before any sophisticated efforts can be effective. First, there must be an adequate supply of suitable replacement candidates within the operations of NASA and its contractors. If these individuals overlap the tenure of the current workforce, those with the best experience and knowledge can mentor them. This is an ideal way to perpetuate quality.

Second, once there is an adequate pipeline of prospective replacements, each entity within NASA must have a long range training and relief plan. Such a plan identifies each person who has a planned termination (retirement, resignation or transfer) as soon as it is known and designates a trainee, new hire or promotion candidate whose task it will be to capture the knowledge of the departing person. Since every worker is included, each can see his or her "career path" and identify the knowledge domain that will eventually be their responsibility.

Question 7. Your testimony states that the requirements for flying the Space Shuttle at an acceptable level of risk is achieved only through the innovation and tireless efforts of an experienced workforce. NASA Administrator Goldin has testified that a large portion of NASA's workforce is aging and about to retire. What effects will large-scale retirements of experienced NASA and contractor personnel have on Shuttle safety?

Answer. This question touches at the crux of the concerns of the Aerospace Safety Advisory Panel. As the Space Shuttle ages, it will require innovative technical and management initiatives to continue flying safely. Large-scale retirements of experienced NASA and contractor personnel will deprive the Program of the highly experienced people needed to formulate and execute these initiatives. It will therefore become increasingly difficult to know when the illusive line between safe and unsafe operations is being approached, and safety risk will almost assuredly increase.

The Panel believes that two major actions are needed now to compensate for the likely departure of much of the government and contractor talent responsible for safe Space Shuttle operations. First, as discussed above, both NASA and its contractors should begin a vigorous hiring program as soon as possible so people will be available to work at the sides of the prospective retirees before they leave. Second, the experienced workforce should be given the means to execute a meaningful life extension program for the Space Shuttle. If modeled after successful commercial and military aircraft life extension programs, this effort will reduce safety risk and simplify the tasks facing future generations of Space Shuttle managers. This will reduce rather than increase the reliance of the Space Shuttle on workforce experience to maintain safety.

Question 8. You also said that NASA must fund EAPU and other upgrade development and certification "at the expense of activities needed to continue flying safely at present." What creates this tradeoff? Should NASA's Human Space Flight account be restructured to prevent tradeoffs like these in the future?

Answer. Insufficient funding to meet present flight objectives and make appropriate investments for the future creates the referenced tradeoffs. When managers are faced with this dilemma, they have only two viable choices—defer upgrades and expenditures for the future or reduce current operations. The Space Shuttle program cannot reasonably reduce the present flight rate and still adequately support the construction and utilization of the ISS. Therefore, planning horizons have been severely limited to provide for current needs. Although this maintains current Space Shuttle safety, it has created serious concerns on the part of the Panel about the ability of the Program to maintain or improve risk levels in the future.

Question 9. Your testimony also highlights that the infrastructure situation becomes worse each year due to a growing backlog. What can NASA and Congress do to reverse the trend in this problem and ensure greater emphasis on the infrastructure maintenance?

Answer. This is purely a budget issue. Present funding is insufficient to support current operations, flight system improvements and infrastructure backlog reduction. NASA and contractor managers are well aware of the infrastructure weak spots. With adequate resources and a reasonable degree of flexibility, they can reverse the trend and begin improving the situation rather than letting it deteriorate further. Giving management prerogative to NASA and its contractors is essential because the relative priority of various infrastructure revitalization efforts can shift over time due to circumstances beyond the control of the Program.

Question 10. You have also stated today that logistics is a serious problem that is affecting the Space Shuttle Program. For example, the long lead times for the manufacture of critical components creates logistical problems and cannibalization. Can NASA use other contracting and purchase strategies, such as are used by commercial companies, to reduce these logistical bottlenecks?

Answer. In general, the long lead times NASA faces are due to the unique nature of the components in question. They are a technical rather than a management issue. Some critical components take a year or more to manufacture. Given the small production runs involved, it is likely not cost effective to invest significant sums to develop and qualify new, more rapid manufacturing techniques. NASA and its contractors must therefore accept the lengthy production schedules and plan sufficiently far in advance to ensure an adequate supply of components.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. JOHN MCCAIN TO BRYAN D. O'CONNOR

Question 1. You have mentioned that the Shuttle will always need substantial hands-on-care and preparations between flights. If the Space Launch Initiative (SLI) produces a new vehicle, do you feel that the same level of "hands-on-care" will be needed?

Answer. In my opinion. SLI will not get anywhere near production if its early development work suggests even half the hands-on of the Shuttle. Those hands are what make up the high cost of Shuttle operations, and SLI has as a goal an order of magnitude decrease in operational cost. Roughly, there can only be one RLV worker for every ten Shuttle workers (for a given mass of cargo to orbit) to meet that goal.

Question 2. You have stated that although the Shuttle has made significant safety improvements since the Challenger accident, it falls short of the overall safety levels NASA demands of future human space flight. Can you elaborate why you feel that no amount of upgrades to the Shuttle will get to the levels of reliability and operational costs envisioned for the SLI?

Answer. Since the Challenger accident, incremental improvements to Shuttle safety have come at great cost, largely due to the complexity and inflexibility of the basic design. It might be instructive to ask NASA for a summary account of cost of risk reduction over the past 15 years. It takes a lot of money to significantly reduce risk for this vehicle. I think you will also find that most of the easy changes have been made, and that any further marginal risk improvements will be difficult to accomplish and expensive. The money required to further reduce the crew safety number for Shuttle to the 1/10,000 mission goal that the SLI team is working is probably not reasonable. One of the biggest problems here is the difficulty in retrofitting a viable crew escape system into the Shuttle. That means that to meet the crew safety goal, the Shuttle system itself must meet the goal. The SLI program is starting from scratch, so, in principal, they have the flexibility to design a vehicle with less than 1/10,000 loss rate and an escape system that makes up the difference. For example, the Russian Buran was designed with an expected failure rate of 1/50. The design included a world class crew escape system with an expected success rate of 75% (throughout the high-risk portions of launch and entry). That combination gave them a crew loss prediction of 1/200 for the first manned flight, which was never flown due to cancellation of the program after one unmanned test flight. What that says is that an escape system with even marginal capability will substantially improve the crew safety story for a high-risk flight vehicle. If the same thinking were applied to Shuttle, it's current expected failure rate of ~1/500 would jump to 1/2000 with a similar escape capability. On the other hand, today's Shuttle would require an impossibly good escape system with a success rate of 95% to meet the expressed SLI goal. Unfortunately, several studies have shown that even a modest escape system for Shuttle is not feasible unless the agency is willing to pay several billions, give up performance and potentially crew size, and take several years down time to do the upgrade to each flight vehicle.

Question 3. In its 1999 report, the NRC recommended that NASA should "provide better incentives for the USA Corporation . . . to propose, fund, and implement upgrades to achieve the Shuttle program's goals." As you consider the recent cost shortfalls in the Shuttle program and delays in implementing Shuttle upgrades, do you believe that NASA is fully meeting this recommendation?

Answer. NASA's response to the NRC report was that they were in the process of changing the contract with USA to include a value engineering clause that would provide the needed incentive. My understanding is that this clause has since been

formalized, but I have no direct knowledge of how effective this incentive has been in encouraging USA to come forward with upgrade ideas or financial support for upgrades.

Question 4. The 1999 NRC report also recommended that NASA use more accurate cost estimates that include all costs associated with the upgrade, including hidden costs. In your opinion, has NASA followed this recommendation in evaluating Shuttle upgrade options?

Answer. NASA's response to the NRC report said that they were implementing the recommendation. Neither the NRC nor I have independently confirmed either the implementation or its effects.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. BILL NELSON TO MICHAEL JAMES MCCULLEY

Question 1. You have stated in your written statement that the Electric Auxiliary Power Unit (EAPU) project had completed the requirements definitions, resolved many technical issues, and was ready to produce detailed and cost-efficient designs. However, NASA's Space Flight Advisory Committee stated in a letter report, ". . . this upgrade appears to be much more challenging than originally anticipated. There are major weight, cost and technical issues. The Committee suggests that this project be removed as an active Shuttle upgrade project and that it become a technology project." NASA has terminated plans for full development of the EAPU until the technology is more mature.

Can you explain the apparent difference in opinions on this project?

Answer. While USA agrees with the statement that "this upgrade appears to be much more challenging than originally anticipated," it strongly disagrees with the characterization that there are cost issues, technical issues and that the project should not proceed toward full implementation.

This fundamental difference in opinion stems from the immaturity of the data that the NASA Space Flight Advisory Council (SFAC) reviewed and the inappropriate baseline that was used for comparison. Since the SFAC's review, progress has only confirmed our previously held position that the EAPU project has no technology issues and can be ready for implementation in FY03 if appropriate funding is made available in FY02.

NASA's Space Flight Advisory Council met May 1–2, 2001. At that time, the EAPU project was in the process of developing cost proposals, placing prototype units on test stands and validating designs and requirements as additional data became available. The review of the project was premature at that time since the project did not come forward for an Authorization to Proceed decision until October 2001. Key items not available for the SFAC's review include:

- Prototype testing results: The EAPU project was just starting its end-to-end testing of its high-fidelity prototype systems. This end-to-end system testing evaluated both hydraulic power performance and battery performance.
- Battery cell testing and design data: The battery cell Preliminary Design Review was held later in the month of May. That review contained key information about cell life, capacity, safety and the development process needed to produce a flight-qualified cell. The cell safety and performance testing (on over 100 cells) was on going at that time, and data was not available for the SFAC's review.
- Cost data: None of the cost proposals had been negotiated, nor had fact-finding been complete prior to the SFAC's review. Furthermore, the cost information that was reviewed contained almost $250M in Rough-Order-of-Magnitude cost data. The project office was in the process of issuing a Request for Proposal for the battery system and reviewing the content assumptions of the proposals when the project office was told that it would not be implemented in the near future.

As mentioned earlier, the EAPU project was in the formulation phase, not the implementation phase, when the SFAC reviewed its progress. During this phase, as specified in NASA plans, the project should be establishing requirements and programmatic cost and schedule baselines. Also, data and requirements from early studies should be updated to reflect any new design data that is available. The EAPU project followed this process. The original cost data that was developed for the project ($220M) was an early, low fidelity figure based on very conceptual design data, immature requirements and did not include large cost elements such as the required single-string EAPU flight demonstration (the so-called "1-of-3 flight" re-

quirement). Any comparison between this cost estimate and the rough proposal data is strictly an apples-to-oranges comparison. Likewise, the weight estimate was based on a different design, was not based any detailed estimates, and, did not have standard growth margins. This initial weight estimate helped establish the early EAPU requirement of 2000 pounds greater than the current APU system. This weight target is not a hard Shuttle requirement. It was not derived from capabilities or mission needs, but rather reflects a desire not to change a Space Station Interface Control Document. While the EAPU project cannot currently meet this requirement, its current weight estimate is within actual Shuttle capabilities based on mission requirements. Finally, it should be mentioned that the project's technical progress, as referenced above, was compared to systems that are in the implementation phase, not ones that were in the process of demonstrating technical feasibility and design approaches.

Excellent progress has been made since May 2001. During this time, the EAPU project completed its prototype testing, performed a cost reduction analysis, conducted five design reviews and revisited and validated its top-level requirements.

The prototype testing and design reviews demonstrated a number of very important system capabilities:

- The motor/pump system provides sufficient hydraulic power and power quality under standard Shuttle mission profiles and more stressing evaluation profiles. Comparisons with the current APU system show that the EAPU meets or exceeds its performance in transient response and hydraulic power quality.
- The battery meets performance characteristics of 50 mission cycles and overall mission energy.
- The battery cell test data indicates that the Lithium-ion cells are very durable, produce higher energy densities than their rated values and can be produced under standards that are acceptable for the Shuttle program.
- The safety and reliability benefits of the EAPU project have been established by extensive study and detailed probabilistic risk assessments. (The EAPU is ten times safer than the existing APU and eliminates the largest risk to Orbiter safety).

With hydraulic transparency to the existing hydrazine APU demonstrated and battery performance characteristics clearly met through test, USA does not see any technology-related issues with the development of the EAPU system.

The continuing cost reduction analysis, which focuses on finding alternatives to key cost drivers, has been exceptionally successful in reducing both cost and weight. By validating key requirements, the project found conservatism in many of them. Energy requirements were too high, ground operations constraints were too stringent and battery lifetimes did not reflect the new operational aspects of the design. These requirement reductions had a large effect on the overall design. The cell size was reduced. Likewise, consolidating functions reduced parts counts. The battery location and packaging was changed. Finally, the number of facility and test site modifications was also minimized. The result to date is an EAPU project that has a weight estimate of less than 6000 pounds (1000 pounds less than when SFAC reviewed the project) and a cost that is competitive with industry averages for the development of systems of this size and complexity.

The EAPU represents increased safety for our astronauts and for the Shuttle Team that gets them into space. No other safety upgrade improves the safety of the Shuttle as much as the Electric APU. The project has demonstrated its technology through test. It has validated its requirements and reduced its overall weight estimate. Furthermore, the EAPU project team performed all of these efforts within its authorized funding limits and within its schedule constraints.

The EAPU project has matured beyond technology development and should be funded to a level needed to support an implementation decision in FY03.

Question 2. What have been the changes to Shuttle operations since the termination of the X–33 program and the reality that the Shuttle is NASA's only option going forward for human space flight?

Answer. In terms of current, day-to-day operations of the Shuttle Program, there were no impacts or changes to the operations part of what we do. The strong safety focus with which we approach all our work and processes is the same, and we use the same Certification of Flight Readiness process to ensure that every element that supports a typical Shuttle mission is ready to proceed with every phase of flight (hardware, software, and people are ready). Of course, events like the termination of X–33, X–34, or other development/technology programs remind one that it becomes even more important to include a robust Shuttle Upgrades program as part

of the overall plan for future operations. If we need to operate the Shuttle longer, then we also need to be alert for more cases of obsolescence, increased wear and tear on the hardware, and we need to continue to look for improvements in safety and supportability.

Question 3. You have mentioned that if technological challenges on one upgrade program make it impossible to move aggressively forward on one project, NASA should revise its timetable for implementation or redirect to the next project, rather than reprogramming the funds for other purposes.

As the operator of the Shuttle program, have you had funds that have been taken from your contract and place in other areas of NASA?

Answer. Funds will be taken from the USA contract if the NASA proposed plan is implemented.

Question 4. You have talked about the flight schedule for the Shuttle program. The annual budget includes some fixed and variable costs, with those variable costs dependent upon the number of Shuttle flights. Can you comment on the marginal cost of a Shuttle launch?

Answer. There are two different concepts that are evaluated periodically relative to cost impacts for changes in the Space Shuttle flight rate. The first is the marginal cost associated with adding or deleting one flight, in one year only, from a current baseline (with adequate lead time notice) and then resuming the baseline flight rate. The second is changing the baseline flight rate to a sustained level at some specified rate.

Current ROM estimates for SFOC impacts for each of these cases are as follows:

1. Add one flight in one year only from a baseline of 6 flights per year—~$23M in FY03 dollars; $23M impact may not all occur in the same year as the year the flight is added. Impacts include significant overtime, expendable hardware, repairs, consumables and travel as added incremental cost.

2. Delete one flight in one year only from a baseline of 6 flights per year—~$10M in FY03 dollars; $10M impact may not all occur in the same year as the year the flight is deleted. Impacts include limited overtime, expendable hardware, repairs, consumables and travel as reduced incremental cost. The principal difference to the cost of adding one flight is overtime.

3. Initial studies on a sustained flight rate of 5 per year versus 6 per year indicate an average annual reduction in cost of ~$17M in FY03 dollars; the $17M impact may not all occur in the same year as the year the flight rate is changed from 6 to 5. Impacts include overtime, expendable hardware repairs, consumables and travel as reduced annual cost. These impacts are in the process of being revalidated.

4. An impact assessment of a sustained flight rate of 4 per year versus 6 per year is in process and will soon be provided to NASA.

Question 5. Based upon your experience as the operator of the Shuttle Program, what level of funding would we need to get the program at the level it should be? Also, what areas would you recommend for these changes?

Answer. Earlier this year, USA participated in the FY01 Program Operating Plan (POP) cycle, during which all elements partnered with their NASA counterparts a budget level that they thought was appropriate for continuing the program in a healthy, safe manner. That POP was first developed for a flight rate of seven missions per year and then adjusted for a flight rate of six missions per year. The recommended level from that effort represents the appropriate level of funding (developed by NASA and Contractor partnering) for operations for the Shuttle Program. Also, the recommended budget level for Shuttle Upgrades should be available with plus-ups for infrastructure supportability and Orbiter Maintenance and Modification (OMM) in addition to the operations budget.

Question 6. NASA is reported to be considering delaying Orbiter Major Modifications and delaying and canceling upgrades to the Space Shuttle. What affect will these delays have on the long-term use of the Space Shuttle?

The deferral of the efforts performed during the Orbiter Major Modifications (OMM) creates four main issues for the long-term use of the Space Shuttle System.

Answer. The first issue encountered by these deferrals is the potential Orbiter safety and hardware issues that would go undetected without the OMM. It must first be understood that the internal Orbiter access that is provided to the Shuttle team during the performance of major modifications provides the team with a unique insight into the vehicle's integrity that cannot be obtained during the regular

operational servicing of the vehicle. Simply put, many problems discovered during the OMM would not be discovered during routine maintenance or Orbiter Structural inspection. This is clearly illustrated by the wire inspections that were performed during the OV–102 (Columbia) OMM that yielded significantly more discrepancies than similar inspections in Orbiter processing flows. In addition, the presence of corrosion under the Orbiter 582 bulkhead and in the aft avionics bays was not discovered until the OV–102 OMM.

The second issue with OMM deferrals is the risk to the program schedule that is created by extended Orbiter down time due to hardware issues that are detected late in the processing flow or could be avoided by upgrading the component/system during the OMM. The major modifications to upgrade Orbiter system components cannot be incorporated into the normal processing flow of the Orbiter or even into a mini-modification period. These major modifications are more complex than the replacement of an existing component and are also extremely intrusive to the Orbiter's systems and subsystems. These major modifications require extensive end-to-end integrity checks to insure safe operation of the Orbiter when it is returned to the Space Shuttle fleet. In addition, major system/subsystem issues that are discovered during the OMM do not impact flight-processing activities for other vehicles and can be fixed while the system is disassembled.

A third issue that would be encountered by OMM deferrals is the additional cost and schedule growth that will be encountered when the OMM is performed downstream. As OMMs are deferred, the systems and subsystems that are currently part of the Orbiter obsolescence cause the Space Shuttle program to operate on a more costly "fix as you fly" basis as compared to upgrading the items. In addition, the continued use of the currently installed systems/subsystems will lead to increasing the likelihood of late mission scrubs on the pad and/or early mission terminations due to on-orbit failures. Also, deferral of the OMM delays or eliminates potential safety improvements that can be made with technological advances. Stretching out existing upgrades programs will lead to increased overall costs, as more is spent on studying how to fix on-going problems as compared to implementing solutions.

Finally, an OMM deferral will cause the loss of key personnel with critical Shuttle Orbiter knowledge. This loss of experienced personnel due to re-assignment, transfer, etc. will eventually drive up the total costs of implementing the needed Orbiter upgrades. The Space Shuttle program needs to ensure that the elimination/deferral of the OMM in the near term to meet today's funding issue doesn't create an untenable downstream cost, schedule and risk threat to the program due to the loss of the critical Orbiter vehicle knowledge and experience.

Question 7. Are there any upgrades that you believe must be implemented in order to ensure the safe operation of the Space Shuttle and that NASA has indicated an intention to cancel?

Answer. The Shuttle continues to operate safely within its current risk of loss parameters. We believe that delay of the safety upgrades will unnecessarily delay improving safety to levels that can be achieved with today's technology. USA recommends that any move to delay the implementation of Multifunction Electronic Display Subsystem (MEDS), to cancel the Advanced Health Monitoring System (AHMS Phase 2), the Solid Rocket Booster Thrust Vector Control (TVC), and Electric Auxiliary Power Unit (EAPU) projects and extend the schedule of the Cockpit Avionics Upgrade should not be approved.

Question 8. Your testimony also covers important NASA infrastructure problems and their effects on the Shuttle Program. In your opinion, is NASA putting the right amount of emphasis on infrastructure maintenance, such as repair of the Vehicle Assembly Building in Florida?

Answer. The short answer is that NASA has not been putting enough resources into maintaining infrastructure as evidenced by the size of the backlogged maintenance and repair of facilities.

NASA infrastructure maintenance occurs on two primary paths. First is day-to-day asset maintenance and repair. This type of maintenance is comprised of preventive maintenance procedures, which keep a reliable asset in proper operating condition, and corrective maintenance actions to repair unexpected system failures. Secondly is larger capital projects to replace systems, which have become unreliable or obsolete due to age degradation and/or lack of available vendors to provide for continued system use. Day-to-day maintenance is funded through the normal program-operating budget. Capital projects are funded primarily through the Construction of Facilities (CoF) cycle using either program or institutional fund sources.

Within NASA the recognized standard for necessary annual investment in infrastructure maintenance and repair is 2–4% of the current replacement value of all assets in operation. This standard was recommended in the American Public Works

Association Special Report #60 "Committing to the Cost of Ownership, Maintenance and Repair of Public Buildings," first published in 1990. Data gathered by NASA since 1996 shows that the agency has consistently invested below 2% of the current replacement value. Likewise, the Space Flight Centers at which the Shuttle Program operates have spent below 2% of the current replacement value.

The trend in CoF funding has also seen a sharp decline from annual investments of around $500M in the early 1990s to a low of less than $140M in 1998. NASA has begun to increase the investment level, but it is still just over one half of the earlier required investment. This funding supports NASA's new construction as well as projects of a "maintenance" nature.

With these investment strategies the Backlog of Maintenance and Repair in the agency has grown to near $900M (~$550M in Code M) and without a substantial investment to buy down this backlog a vicious cycle will worsen. This cycle is one in which more of the day-to-day maintenance and repair funding is expended performing band-aid type corrective maintenance on old, unreliable systems which are backlogged for permanent solutions due to lack of CoF level funding. As more day-to-day maintenance funding is expended on corrective maintenance, less can be used for preventive maintenance that results in accelerated degradation of operable systems.

SHUTTLE OFFICIALS PREPARE FOR IMPENDING BUDGET SHORTFALL

Space News, August 13, 2001

By Brian Berger, Staff Writer

WASHINGTON—When NASA's Space Shuttle Discovery returns later in August from its planned 11-day mission to deliver a fresh three-person crew to the international space station, the 18-year-old orbiter will not be sent out to the California desert for a new cockpit as previously planned.

That is because Discovery's year-long stay in Palmdale, Calif., for upgrades and thorough maintenance could be delayed until 2005 as part of a slew of cost-cutting measures NASA Space Shuttle officials are contemplating in light of a looming budget shortfall.

Higher than expected labor costs, rising energy bills and other expenses are expected to put a pinch on NASA's anticipated $3.2 billion-a-year Space Shuttle budget starting in 2002, forcing Shuttle officials to come up with hundreds of millions of dollars in savings in the coming years.

Facing a $218 million shortfall in 2002 alone, NASA Space Shuttle officials are preparing to scrap or scale-back a half-dozen safety upgrades and postpone sending Discovery and sister ship Endeavour to Palmdale for the installation of modern cockpit displays and other improvements.

Space Shuttles Atlantis and Columbia already have been to Palmdale to have their old-fashioned flight gauges and analog dials replaced with modern flat-panel displays designed to ease pilot workload. Until recently, NASA's plans called for modernizing all four Shuttles' cockpits by the end of 2002, but now it appears that date could slip to 2006 as Shuttle officials scramble to come up with near-term savings.

Also on the chopping block are several Shuttle upgrades NASA officials identified as recently as last year as high priorities with the potential to cut in half the odds of losing a Shuttle during launch.

NASA canceled one of those planned upgrades, an Electric Auxiliary Power Unit, in June, citing concerns that the battery-powered system would not be ready on time and within budget. Shuttle officials now are pondering canceling or scaling back two other high-priority upgrades, an advanced health monitoring system for the Shuttle's main engines and miscellaneous avionics and cockpit upgrades.

Other upgrade efforts that could be affected by NASA's budget woes include a thrust vector control system for the Shuttle's solid-rocket boosters, designing a stronger tire for the Shuttle's main landing gear, modifying the geometry of Shuttle solid-rocket propellant for a more uniform burn, and a study of further improvements for the craft's main engines.

NASA spokeswoman Kirsten Larson said such steps are being considered as the agency attempts to reconcile an essentially flat Shuttle budget with inflation and rising operations costs. Larson said NASA also is considering mothballing Columbia, the oldest and heaviest of the agency's four orbiters, in 2003 or 2004.

Larson said no final decisions have been made on any of the proposed cuts. Any decisions, she said, will depend on how the Shuttle program fares in NASA's 2003

budget, currently being developed in cooperation with the White House Office of Management and Budget and due to be released early next year.

NASA does not plan to abandon Shuttle upgrades altogether, according to Shuttle program officials. For example, the agency's 2002 budget includes funding for an initial phase of cockpit and main-engine health monitoring system upgrades, program officials said. NASA also intends to fund an effort to strengthen the Shuttle's external fuel tanks with a different welding technique.

Shuttle program officials said canceling or scaling back a half-dozen upgrades and postponing sending Discovery and Endeavour to Palmdale would enable the program to live within its proposed $3.2 billion budget for 2002, but would not fully eliminate funding shortfalls in subsequent years.

William Readdy, NASA's deputy associate administrator for human space flight, was unavailable to comment by press time due to his engagement in Discovery's launch preparations, Larson said.

Readdy assumed responsibility for the Shuttle program in an acting capacity Aug. 10 upon the retirement of Norman Starkey, the agency's deputy associate administrator for the Space Shuttle.

James Eyman, vice president and general manager for Space Shuttle upgrades at United Space Alliance, the Houston-based company that operates the Shuttle fleet under contract to NASA, said his company is prepared to continue operating the Shuttle at current risk rates if NASA scales back some of the planned upgrades. However, he said he remains hopeful that NASA will find a way to proceed with the upgrade strategy approved in 1999, two years after the agency lifted a three-year design freeze on Shuttle improvements.

"We are watching the political process just as others surely are," Eyman said. "We're hopeful NASA will get fully funded and will be able to continue most if not all of these upgrades."

Congress already has signaled a willingness to help NASA cover at least part of its $218 million shortfall in 2002.

The NASA budget bill approved by the U.S. House of Representatives in early August added $35 million to the Space Shuttle program's 2002 budget to pay for refurbishment of the Vehicle Assembly Building at NASA's Kennedy Space Center, Fla. Meanwhile, a companion bill in the Senate includes an extra $50 million for Shuttle safety upgrades.

But it remains unclear just how sympathetic lawmakers and other government officials will be to NASA's human space flight budget woes.

"Code M's problems are of their own making," one U.S. government official said, referring to the NASA division responsible for human space flight activities. Code M also is wrestling with a projected $4.8 billion cost overrun on the international space station.

A Washington space policy analyst said rising costs are putting a squeeze on NASA's Shuttle budget at a time when there is no place to look for savings other than the upgrades program. With the international space station's projected overrun putting intense pressure on NASA's human space flight budgets, the Shuttle program is "between the proverbial rock and a hard place," the analyst said.

Additionally, the analyst said, some Shuttle upgrades are turning out to be more expensive than NASA and its contractors had estimated. "This just raised further questions about the reliability of NASA's cost estimating procedures," the analyst said.

THE PLANETARY SOCIETY,
Pasadena, CA, May 15, 2001.

Hon. JOHN MCCAIN,
Washington, DC

Hon. ERNEST F. HOLLINGS,
Washington, DC

Dear Senator:

We know that Congress believes that it is important to hear from representatives of the public concerning matters of public interest. In that spirit we present this letter to you, and ask that it be included at the next opportunity with testimony before your Committee, in keeping with our efforts to provide information to Congress about public support for space exploration.

It has been six years since The Planetary Society testified before this Committee. During those years, the Society's membership included more than 250,000 people

who are interested in, and inspired by, the exploration of other worlds and the search for life elsewhere. We are, by far, the largest organized constituency in the space community.

The principle message of our constituency is that space exploration is popular—and your support for NASA programs should build on that popularity and public interest. There are four specific issues that we ask you to address in this year's budget deliberations.

First, we urge the restoration of program elements in NASA's human spaceflight enterprise to study concepts for future flight beyond low Earth orbit and to begin addressing the required technologies. The Space Station should not be the next step to nowhere as it is now. The purpose of the Space Station is to prepare humans for destinations beyond earth orbit.

Second, human spaceflight should lead eventually to Mars. We do not advocate a start now on any such human mission, but we urge you to insure that the robotic planetary program is designed to lead to that end. The Planetary Society believes this requires the establishment of robotic outposts on Mars that will support science goals in early phases and human habitation later when it is feasible.

We ask you to restore and support the *Pluto-Kuiper Express* mission that was removed from the Space Science budget. Otherwise, this nation will miss a unique opportunity to visit the last unexplored planet that will not reoccur for some time to come.

Fourth, we believe in the importance of international cooperation, public support, and interest in the space program and ask that you support international cooperation in the NASA program. Space exploration has become an inherently international enterprise, and this type of cooperation is key to carrying out complex exploratory and scientific programs in space.

Public Interest

In many conversations we have had with legislators and decision-makers over the years, almost all of them are positive about the value and popularity of space exploration. It may generate less public expression than bread-and-butter, financial, and quality of life issues, but as has been wisely said, "man does not live by bread alone." The public understands this. The support is proven by the way the public follows NASA missions that venture to other worlds; by the large numbers of visitors at the National Air and Space Museum, Kennedy and Johnson Space Centers; by the spectacular attention paid to scientific discoveries by Hubble, Mars Global Surveyor, the Near Earth Asteroid Rendezvous mission; and by the adventures of both humans, like John Glenn, and robots, like Mars Pathfinder.

Human Spaceflight

The basis of the popularity of space is exploration. It is the *raison d'etre* for NASA. We are concerned that exploration is threatened in the current NASA budget and cite the following examples of this in both the human and robotic program.

The space station is running into cost overruns and NASA has no resiliency to deal effectively with the problem without severely cutting the program. This lack of budget resiliency is a result of the large loss of purchasing power exceeding 30% in the last eight fiscal years—a budget reduction uniquely large compared to the rest of the Federal Government. So the crew on the space station will be limited, the duration of stay will be limited, the TransHab is cancelled, and no preparation or study of human space flight out of Earth orbit will be undertaken. In short, we have a human spaceflight program leading to nowhere. If the space station leads nowhere with astronauts neither conducting nor preparing for exploration, then it will turn off the public as happened a decade ago when we had a Shuttle program that also was leading nowhere.

The Planetary Society has consistently supported a space station worth the cost—we hope Congress and the Administration will provide adequate support to NASA so that the International Space Station remains so.

Robotic Spaceflight—Mars Outposts

Robotic scientific exploration of space has proven its value. Congress, the Clinton Administration, and now the Bush Administration have played a constructive role in providing increasing support for Mars exploration. It is no wonder—Mars is the only extraterrestrial world we know that holds clues to past life and the promise of future habitation. The public is enthralled with the search for extraterrestrial life and the attempts to understand humankind's place in the cosmos. Much of this endeavor centers on Mars. We ask you to support the increase in funding for Mars in the FY2002 budget request.

As good as the Mars program is, there is something lacking. It is not funding. As with the space station, it is direction. It is a subject about which we can only

whisper; it is too dangerous to say out loud in Washington. It is called humans. The irony is clear to us, but seems to escape many policy makers. While Mars has received increased funds and commitment for robotic missions, based on its link to possible microbial life and the sense of Mars as an ultimate human destination, the link to human exploration is not permitted. The public makes this link and most assume we are on our way there. But NASA is forced to cut even small study programs about the future of human exploration. We do not call for a premature and ill-founded political initiative for a human Mars mission. But there is no reason not to acknowledge this as a goal of the robotic program and begin to develop robotic Mars outposts that can one day serve as the infrastructure for human exploration when the time is right. Our position on Mars Outposts is submitted as an appendix to this letter.

Pluto

Mars is not the only planet in the Solar System, nor the only place for humankind to gain an understanding of our place in the cosmos. This country has explored the solar system from Mercury to Neptune, and has visited scores of solar system moons, asteroids and comets. But not Pluto. Pluto is the only unvisited planet in the solar system and also the most conspicuous member of a new class of objects about which we are just learning—the Kuiper Belt objects beyond the orbit of Neptune. The opportunity for our generation to complete the reconnaissance of the solar system and reach Pluto is fleeting. NASA has a plan to reach Pluto with a 2004 launch, the last chance for centuries to reach the planet with its atmosphere intact and with favorable lighting conditions. But for a lack of about 0.5% in the NASA budget, those plans are proposed for cancellation. Because this issue has received such great public attention, we specifically ask that Congress review the proposed cancellation in an open hearing. We will be pleased to testify about the important scientific reasons to explore the planet and the consequences if we fail to take advantage of the narrow window to launch a mission.

International Cooperation

There are many other issues that could be mentioned concerning the space program—too many for this letter. But we must cite one that deeply concerns us: losses to the U.S. space program resulting from inhibitions to international cooperation. The inability of the United States to develop low cost launchers coupled with a policy prohibiting Americans to take advantage of the world's oversupply of rockets and launch sites, is holding back the country's access to space. Additionally, technology and communication policies slow down scientific and technical accomplishment in the space program, or make it much more expensive. Congress has added restrictive language supposedly protecting American space launch industry that has actually restricted access to space and inhibiting American space exploration and development. Regulations imposed by the Congress are keeping American ideas earthbound instead of in space.

Public support for international cooperation is strongly evidenced by the space station—a program which gained little support as a nationalistic endeavor when first proposed, and which has enjoyed widespread support when converted to an international program. This is an important consideration in planning the future of the space exploration.

Conclusions

We ask that the Committee:

1. Add funds to Space Science specifically to accomplish a Pluto mission.
2. Initiate funding for programs to study the future of human space flight beyond low Earth orbit, including the development of Mars Outposts in the Space Science program.
3. Easing of regulations restricting international cooperation.

The Planetary Society presents our position in terms of public interest and popularity of space exploration. The Society is the largest space interest group on Earth. We ask for your consideration of the great interest in space exploration, and thank you for your attention.

Sincerely,

Bruce Murray	Wesley T. Huntress, Jr.	Louis Friedman
President	*Vice President*	*Executive Director*

NEXT OUTPOSTS IN SPACE

Recommendations For Mars Exploration

Bruce Murray, Wesley T. Huntress Jr., Louis Friedman, Risto Pellinen

The Planetary Society

A key issue now facing all spacefaring nations is the alignment of the International Space Station (ISS) and future goals in space. The main scientific rationale for investing billions of dollars in the ISS is to learn how to keep humans healthy in space over long durations. Scientists will conduct research onboard the orbiting laboratory to understand the debilitating effects of weightlessness and develop countermeasures. With this knowledge, humans will be able to venture beyond the Moon to Mars and other distant bodies. Thus, the station is an essential stepping stone for human exploration of our solar system.

But will humans venture beyond the Moon? When? Under current policy, this decision is deferred until after the ISS is assembled in 2005. To wait four years to plan our next steps in space is both unnecessary and unadvisable. Delaying the decision potentially threatens the ISS if something should go wrong during assembly—a likely possibility. If the station is perceived to be without purpose, difficulties experienced during assembly may imperil the program and thus our nation's human exploration goals.

To prevent such misfortune—and to demonstrate bold vision—The Planetary Society urges a new cornerstone of space policy be laid: a pathway—not yet an approved project—that leads to human exploration of space beyond Earth orbit, and eventually to the surface of Mars.

Currently, there is no planned transition from robotic missions (which are currently exploring the red planet) to future human expeditions. The Planetary Society proposes to form a bridge between these programs and make possible the incremental, affordable, and inevitable human exploration of Mars. Announcing such a policy would generate tremendous excitement, yet necessarily leaves open details such as cost, commitment, and the date for an eventual human mission to Mars.

To provide the draw towards the ultimate destination for humans in the 2lst Century, The Planetary Society proposes a program called Mars Outposts. It involves the selection of candidate outposts on Mars—high-intensity research sites—that in the future would serve as potential landing areas for human expeditions. At these sites, continuous communications and navigational systems would be established to support robotic missions, such as advanced rovers to search for evidence of life and return samples to Earth for study. In the years ahead, the same equipment would be used to facilitate in-situ production and storage of propellant and breathable oxygen and other key technologies for human missions.

The Mars Outposts program would create the necessary, and needed, transition from robotic exploration to human exploration. Importantly, it connects through policy and programs, the International Space Station, robotic missions to Mars, and the eventual launch of human expeditions.

The outposts can be viewed as "robotic Antarcticas" on Mars, areas of intensive scientific study of Mars from Earth. At these sites, robotic probes would comprehensively explore the surrounding terrain. Using virtual reality, humans worldwide would be able to participate in the exploration of our sister planet. Imagine looking through the "eyes" of a robotic probe as it first ventures through a canyon or over the lip of a hill, or digging below the surface and discovering evidence of water and possible life.

Just like the scientific station in Antarctica and the ISS the Mars Outposts would be built through international cooperation. In actuality, the outposts would be an extension of the ISS. And importantly, financial resources would be shared and allocated incrementally.

The Planetary Society urges the adoption of an international Mars Outposts program. Over the next four years, plans would be crafted and preliminary candidate sites selected. Space planetary programs would begin to be integrated with Human Space Flight programs to cross-fertilize engineering and operations. Mars Outposts that would eventually make possible human expeditions.

Exploration is the *raison d'etre* of a government space program. Public interest and support is repeatedly demonstrated by the new ventures to Mars, by the search for extraterrestrial life, understanding our origins and the sensing of the cosmos.

We are blessed to live at a time when we are able to not only dream about distant worlds, but to actually explore them. Mars is special—the only place so far discovered with hints of extraterrestrial life, the only world we can imagine humans settling on in the foreseeable future.

Mars Outposts will be the bridge to that possible future—a bridge affordable in today's space program but carrying us in tomorrow's. We look to the new Administration for leadership, on that bridge to the future and invite you to join us in "inspiring the people of Earth to explore other worlds and seek other life through research, education, and public participation." [1]

In addition to addressing the shortfall in resources for space science, a primary concern for the next administration will be the International Space Station. Its assembly is scheduled for completion in 2005. Dozens of flights must be precisely executed to complete the mission. Inevitably there will be problems, some potentially severe. It is critical for the new administration to guide the project to its completion, making sure that its main goal—learning how to keep humans healthy in space for long durations to enable human expeditions beyond the Moon—remains tied to the future goals of our nation's space program.

The ISS program will become increasing complex as components are added to the station's structure, and a full-time crew begins to pursue "scientific, exploration, engineering and commercial activities." Sixteen countries are involved in the construction of the orbiting laboratory—the largest, international effort ever undertaken.

Only by conducting research in space can scientists fully understand how space affects human health and how to develop and validate countermeasures. As explained in the 1990 *Augustine Report,* "A space station is needed specifically to establish effective strategies to prevent or mitigate the debilitating deconditioning effects on humans of long stays in low gravity fields, and to establish absolutely reliable and efficient life support systems for extended human stays in unforgiving, hostile environment."

With the knowledge gained from research aboard the ISS, humans will be able to venture beyond the Moon to Mars and other distant bodies. Thus, the station is a stepping stone to the exploration of our solar system by human expeditions.

But when will human missions begin? The main purpose of the ISS—exploration—has not be sufficiently integrated into potential human missions. To date, NASA has focused attention on building the space station and wants to delay determining the next step in our nation's space program until 2005, when the ISS is completed. Waiting four years wastes valuable time. It is unnecessary and inadvisable to delay until after the station is assembled to announce the next important goal in human exploration.

Mars Outposts

Robotic probes and human exploration tend to be viewed as separate goals. Conventional wisdom assumes robotic missions will be conducted for a period of time, then human expeditions will somehow take over. This view is flawed. Robotic probes and other robotic technologies are but tools and their contribution will not suddenly stop when humans plant a footstep on the surface of Mars.

At issue is understanding the tasks that can best be accomplished by robotic technologies and those tasks best performed by humans. There are a myriad of questions to be answered as we explore Mars with an eye toward human missions in the future. What operations on Mars can be handled autonomously? What tasks are best accomplished by humans using robotic tools?

The better we can understand the opportunities and limitations of robotic technologies, the better we will be able to mount a successful human expedition to Mars. To prepare for the future, the process of connecting robotic and human exploration of Mars can and should begin today.

The Planetary Society urges the new administration, as a cornerstone of its space policy, to announce a program, called Mars Outposts, to establish research sites on Mars. In the near term, the outposts would focus and enhance robotic exploration. Eventually, they would serve as potential landing areas for human expeditions. (This proposal assumes it is premature to commit to a date, cost, or other program specifics for a human Mars mission.)

At the Mars Outposts, continuous communications and navigational systems would be established to support robotic missions, such as rovers, balloons, and sample returns. Scientific instruments positioned at the sites would monitor radiation, dust and winds, creating an historical record so scientists can predict local weather patterns. In the years ahead, the robotic systems would be used to facilitate the in-situ production and storage of propellent and breathable oxygen, paving the way for human missions. We would have a comprehensive understanding of the surrounding terrain and know what specific scientific tasks should be undertaken by a human expedition.

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[1] The Planetary Society's mission statement.

Establishing the Mars Outposts creates a bridge between robotic and human exploration. Importantly, it connects through policy and programs, the International Space Station, the robotic exploration Mars, and eventual human expeditions.

The outposts would allow scientists and engineers to develop the "complex human/machine symbiosis of the future." Using virtual reality, the public would be able to directly experience the thrill of exploring a new world. Imagine looking through the "eyes" of a robotic probe as it ventures for the first time through a canyon or over the lip of a hill, or digging below the surface and discovering evidence of water and possible life.

Developing the robotic tools to explore Mars will stretch our imaginations and lead advanced technologies to assist the private sector.

Just as the space station is an international endeavor, so too will be the human exploration of Mars. The robotic outposts create the pathway. They provide the structure for the shared, robotic exploration of Mars, leading to human presence. Just as the nations of the world collaborate in scientific research on Antarctica, so would we join together to build the Mars Outposts.

To mount a human mission to Mars at this time is a very expensive proposition. Creating the Mars Outposts can be accomplished incrementally, with limited resources. The initial step would involve an announcement of the Mars Outposts program and inviting the participation of our international partners. Over the next four to eight years, we would select the potential landing sites and determine how they can best facilitate scientific exploration. Missions would be undertaken to place large, robust rovers and landers at the sites and establish continuous communications.

Over time, the sites would become familiar places, inspiring the world and a generation of students, as well as focus research for scientists. The next four year should not be wasted thinking about our future; we should be making our future. We cannot afford to delay until after the ISS is completed to plot our next step in space.

With the Mars Outposts program, the new administration can demonstrate its vision and make history by setting the path that will enhance science and lead to the eventual exploration of Mars.

APPENDIX

The Planetary Society

The Planetary Society has spearheaded numerous innovative opportunities for the general public to participate in the exploration of the solar system and the search for extraterrestrial life.

Conducting such exploration has traditionally been the province of scientists and engineers. Yet the rationale for spending public resources for exploration involves a greater societal interest that does not rest solely on science.

Among the more notable opportunities for the public's participation in our nation's space program are:

- The Mars Microphone—The first privately funded instrument to be sent to another world (was onboard the Mars Polar Lander);
- Red Rover Goes to Mars—The first commercial/education partnership on a planetary mission;
- Visions of Mars—A CD containing works of science fiction about Mars, designed to be placed on the Red Planet as the first library to serve future human explorers;
- MAPEX—A Microelectronics And Photonics Experiment to measure the level of radiation on Mars in preparation for human explorers, and contains an electron-beam lithograph of the names of all members of The Planetary Society;
- Participated in the naming of the spacecraft Magellan and Sojourner;
- Student-designed nanoexperiments to fly on a Mars lander;
- SETI@home—A software tool that allows millions of people to contribute to research and data processing in the search for extraterrestrial intelligence.

Such projects/events as above presage the day when planetary exploration will be truly a global, mass public enterprise, with people in their homes and schools in direct communication—and even control—of robotic devices on other worlds.

Mars Exploration

The Planetary Society advocates the exploration of Mars, with robotic missions leading to eventual human exploration. The Society has sponsored numerous projects connected with Mars exploration, including field tests of a Russian built rover, designing the guiderope system for a Mars Balloon, and the development of the Mars Microphone, which was an instrument on the Mars Polar Lander.

The Society has also sponsored the Mars Declaration calling for an international space goal of human Mars exploration.

Search For Extraterrestrial Intelligence (SETI)

The Planetary Society is the sponsor of one of the most innovative SETI projects on earth, *SETI@home* which utilizes the combined computing power of over 2 million personal computers to sift through data gathered in a radiotelescope SETI search. The Society has sponsored numerous SETI programs for nearly two decades, including radiotelescope searches Project BETA in Massachusetts and META in Argentina; and optical SETI searches in both Massachusetts and northern California.

The Planetary Society

Carl Sagan, Bruce Murray, and Louis Friedman founded the Society in 1980 to advance the exploration of the solar system and to continue the search for extraterrestrial life. With 100,000 members in more than 140 countries, the Society is the largest and most influential space interest group in the world.

The Society supports research and test programs, student projects, hands-on involvement for the public in space exploration, and special events.