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AUDIT REPORT

SPACE SHUTTLE SAFETY UPGRADES

July 01, 2002

National Aeronautics and
Space Administration

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Acronyms

AHMS	Advanced Health Management System
APU	Auxiliary Power Unit
CAU	Cockpit Avionics Upgrade
FY	Fiscal Year
GAO	General Accounting Office
NSTS	National Space Transportation System
OIG	Office of Inspector General
OMB	Office of Management and Budget
SSME	Space Shuttle Main Engine
SSP	Space Shuttle Program

W

TO: HQ/M/Associate Administrator for Space Flight
HQ/M/Deputy Associate Administrator for International Space Station and Space Shuttle
JSC/AA/Director, Lyndon B. Johnson Space Center

FROM: HQ/W/Assistant Inspector General for Audits

SUBJECT: Final Report on Space Shuttle Safety Upgrades
Assignment Number A-01-041-00
Report Number IG-02-020

The subject final report is provided for your use. Please refer to the Results in Brief for the overall audit results. We have included your comments in their entirety in Appendix E.

We appreciate the courtesies extended to the audit staff. If you have questions concerning the report, please contact Dennis E. Coldren, Program Director, Space Flight Audits, at (281) 483-4773, or Esther A. Judd, Program Manager, at (301) 286-3359. The final report distribution is in Appendix F.

[Original Signed By]

Alan J. Lamoreaux

Enclosure

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NASA Office of Inspector General

IG-02-020 **July 01, 2002**
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Audit of Space Shuttle Safety Upgrades

Introduction

The Space Shuttle is the only U.S. vehicle that can launch humans and payloads into space and safely return them from an Earth orbit. Since the Space Shuttle Challenger mishap,[1] NASA has improved the safety of the Space Shuttle; the estimated risk of catastrophic failure during launch decreased from 1 in 78 missions in 1986 to 1 in 556 missions today. The continued safe operation of the Space Shuttle is a top priority and is essential in NASA's ability to support the assembly and operations of the International Space Station.

NASA has made investments in Space Shuttle safety improvements over the last several years while, at the same time, NASA has reduced the Space Shuttle budget by about a third through efficiencies and contract consolidation. Having achieved these budget reductions, continued improvements in Space Shuttle safety will require additional investments.

The NASA Office of Inspector General (OIG) performed an audit of Space Shuttle safety upgrades. The overall objective was to evaluate NASA's management of Space Shuttle safety upgrades. Specifically, we determined whether NASA ensured that the approved safety upgrades[2] met established safety objectives, were selected based on a quantitative analysis or other measurable methodology, were adequately funded to ensure completion of the modifications when needed, and minimized adverse effects on the Space Shuttle flight schedule. Appendix A contains further details of our objectives, scope, and methodology.

During the audit, the Office of Management and Budget (OMB) issued "Fiscal Year 2003 Budget of the U.S. Government," which assessed the Space Shuttle Safety Upgrades Program as ineffective. The basis of OMB's assessment was NASA's large cost overruns[3] and schedule delays in improving the safety of Space Shuttle. Appendix B contains further details on OMB's conclusions.

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[1]The Space Shuttle Challenger 51-L was the 25th mission in NASA's Space Transportation System program. The January 28, 1986, Challenger explosion shortly after liftoff resulted in the destruction of the vehicle and death of its seven crew members.
[2]Approved upgrades are those safety upgrade projects that NASA has approved to proceed from formulation to implementation.
[3]OMB considered the cost increase from NASA's estimates provided early in project formulation as the cost overruns.

Results in Brief

NASA appropriately managed safety upgrades approved for implementation to ensure they met established safety objectives, were selected using quantitative and qualitative factors, and were adequately funded for fiscal year (FY) 2002. In addition, we found that NASA ensured that the integration of the safety upgrades did not adversely affect the Space Shuttle flight schedule. Although the safety upgrades approved for implementation were adequately funded for FY 2002, the Congress and Aerospace Safety Advisory Panel (the Panel)[4] expressed concerns about the adequacy of future funding (see report section entitled, Other Matters of Interest).

Background

The Space Shuttle Program (SSP) is an essential element of NASA's integrated space transportation strategy for the first decade of this century. That strategy includes continued utilization of the Space Shuttle as the nation's primary launch vehicle for human access to space well into the second decade of this century and possibly beyond. NASA's current plans are to safely operate the Space Shuttle through at least 2012,[5] to support the International Space Station for assembly and logistics missions, to undertake non-International Space Station missions that require unique Space Shuttle capabilities, and to meet other national goals for reusable launch vehicles.

In NASA's FY 2001 budget, the Congress appropriated $256 million to initiate the High-Priority Safety Upgrades Program. Congress directed the SSP to plan for and make prudent investments in system safety upgrades to reduce operational risk and to provide a more reliable capability to support NASA's human space mission objectives. Accordingly, the SSP established its Development Office to proactively provide a safer and more efficient Space Shuttle system that will continue to support the Agency's commitments and goals for human access to space. The FY 2002 budget for the SSP Development Office safety upgrades is $207 million.

[4]The Aerospace Safety Advisory Panel is a senior advisory committee that reports to NASA and the Congress. The Panel reviews safety studies and operations plans that are referred to it and reports to the NASA Administrator with respect to the hazards of proposed operations and to the adequacy of proposed or existing safety standards.
[5]NASA based the current Space Shuttle upgrade strategy on the premise of ensuring the Space Shuttle can fly safely until 2012. However, on March 25, 2002, the NASA Associate Administrator for Space Flight requested that the Director, Lyndon B. Johnson Space Center, develop a strategy to identify upgrades and supportability investments needed to maintain the Space Shuttle fleet capability to fly safely through 2020.

Space Shuttle Safety Upgrade Selection

The safety upgrade candidates[6] met at least one of the three safety objectives identified in National Space Transportation System (NSTS) 37400, "Space Shuttle Program Upgrades Management Plan," July 21, 2000. In addition, the suite of proposed safety upgrades[7] collectively met the targets established for each safety objective; however, two of the low-cost safety upgrades could not meet the established targets on an individual basis.

Space Shuttle Program Development Strategy

NASA intends that Space Shuttle upgrades further the primary goals of the SSP. The SSP goals are to fly safely, meet the Shuttle manifest, improve supportability, and improve the Space Transportation System to meet the Agency's commitments and strategies for human operation in space.

NASA's upgrade investment strategy considers two types of upgrades: high-priority safety upgrades (to improve system safety) and supportability upgrades (to mitigate obsolescence issues). Safety upgrades are those upgrades that minimize ascent, descent, and critical operations risks. The principal factors used to determine high-priority safety upgrades are the degree of safety improvement and how quickly the associated benefits can be realized. Supportability upgrades are primarily those system upgrades required to ensure that reliable Space Shuttle system hardware is available to the SSP to support the expected Space Shuttle mission manifest through at least 2012. The schedule for implementing obsolescence-driven supportability upgrades depends on when they are needed to mitigate a supportability threat.

Space Shuttle Safety Upgrade Objectives

NSTS 37400, "Space Shuttle Program Upgrades Management Plan," July 21, 2000,[8] describes NASA's safety upgrade objectives as follows:

- major reduction in ascent catastrophic risk (targeting up to a 50-percent risk reduction);
- significant reductions in orbital and entry/landing catastrophic risk (targeting up to a 30-percent risk reduction); and

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[6]The safety upgrade candidates that we reviewed included both approved and deferred upgrades: Cockpit Avionics Upgrade, Electric Auxiliary Power Unit, Space Shuttle Main Engine Advanced Health Management System Phase I, External Tank Friction Stir Weld, and Main Landing Gear Tire/Wheel. The Electric Auxiliary Power Unit was deferred in June 2001 because of a lack of technology development. The Space Shuttle Main Engine Advanced Health Management System Phase II was deferred in September 2001 because of limited funding. Appendix D contains additional details on these safety upgrades.
[7]The suite of safety upgrades includes upgrades that collectively would reduce Shuttle ascent risk by as much as 50 percent and reduce orbital and entry/landing risk by as much as 30 percent. Because of budget constraints and technical limitations, NASA deferred some of these upgrades (see Appendix D).
[8]We found that NSTS 37400 reflected upgrades that were no longer being considered due to budget constraints. Management stated that a draft of the revised management plan was in the review process.

- major improvement in flight crew situational awareness for managing critical flight operational situations through cockpit modernization.

The SSP Development Office established risk reduction target percentages for each stated safety upgrade objective. However, the selection of a specific upgrade did not depend solely on meeting one of the targeted percentages.

We reviewed the safety upgrade objectives and targets and found that NASA appropriately used the safety objectives to prioritize safety upgrades before considering affordability, technology readiness, and early implementation potential. Although we also found that two[9] of the low-cost safety upgrades did not significantly contribute to achieving the stated safety objectives, the suite of upgrades collectively met all the risk reduction targets associated with the safety upgrade objectives. Appendix D contains additional information on the objectives.

Conclusion

NASA selected the safety upgrades based on the total of the risk reductions for a suite of upgrades rather than the percentage to be gained from an individual project. NASA acted appropriately because it needed to consider other programmatic factors such as cost and schedule.

[9]The two low-cost upgrades were the Main Landing Gear Tire/Wheel (estimate at completion of $11 million) and External Tank Friction Stir Weld (estimate at completion of $21 million).

Quantitative and Qualitative Analyses

NASA appropriately selected safety upgrades approved for implementation by using quantitative and qualitative analyses.[10] Although the SSP Development Office did not employ a standard analytical process, it used appropriate methods to evaluate each upgrade.

Space Shuttle Safety Upgrades Prioritization and Selection

The primary goal of the safety upgrade prioritization and selection process is to allocate resources to significant safety improvement opportunities. NASA based the Space Shuttle safety upgrades prioritization and selection process on the Space Shuttle operational risk model. This model establishes the relative risk contribution of each Space Shuttle hardware element to overall Space Shuttle risk and identifies the high-risk systems and components of each element. The SSP Development Office established and maintained the resulting comparative risk contribution baseline as a major tool for prioritizing safety upgrade candidates. However, the SSP Development Office used many different methods, both qualitative and quantitative, to ascertain risk and select potential candidates.

In addition to prioritizing upgrades based on safety improvement potential, the SSP Development Office also screened upgrades for how well they met SSP goals, affordability, technology readiness, and early implementation potential. For example, as part of prioritizing upgrades, the SSP Development Office would rank an upgrade proposal with modest risk reduction potential, but very high cost to implement, lower than a much less expensive proposal that offered similar risk reduction potential. The SSP Development Office uses the results of these analyses to develop a prioritized suite of safety upgrade candidates based on their ability to eliminate or reduce the potential for catastrophic loss.

Alternative Safety Upgrade Selections

Once the SSP Development Office develops the suite of highest priority proposed upgrades, it determines whether adequate resources exist. Because limited funds are available, the SSP Development Office prioritizes safety upgrades based not only on benefit and risk, but also on affordability. The SSP Development Office used the affordability prioritization factor to select two low-cost safety upgrades that were within the available funding limitations and provided the greatest safety benefit for the investment. NASA selected the Main Landing Gear Tire/Wheel and External Tank Friction Stir Weld safety upgrades as part of the suite of approved upgrades.

[10] Quantitative and qualitative analyses include but are not limited to preliminary hazard analyses, failure modes and effects analyses, system and subsystem hazard analyses, fault tree analyses, human factors analysis/assessments, peer reviews, and baseline hazard data such as discrepancy reports and in-flight/ground anomalies found in the Shuttle's Problem Reporting and Corrective Action database.

Probabilistic Risk Assessments

NASA used a probabilistic risk assessment[11] method, specifically the Quantitative Risk Assessment System,[12] to determine the risk reduction percentage for four of the five upgrade projects we reviewed. In recent years, critics of probabilistic risk assessment tools pointed out that sole reliance on this system can lead to an unsafe spacecraft because the system:

- tends to focus on component/subsystem/system failures,
- can result in a goal of improving the risk reduction percentages without improving the design,
- concentrates on catastrophic hardware failures while not identifying risks associated with crew injury/vehicle damage, and
- does not account for safety risks associated with the vehicle operational design/concept.[13]

In addition, the results of the probabilistic risk assessment method depend on the quality and completeness of the underlying engineering model,[14] the quality and quantity of the data introduced, and the competencies of the individual using the system. Therefore, we were initially concerned about NASA's use of the Quantitative Risk Assessment System. However, we reviewed the probabilistic risk assessments and found that the SSP Development Office did not rely solely on this analytical tool[15] to determine risk.

Conclusion

NASA appropriately used quantitative and qualitative analyses to prioritize and select safety upgrades. For example, the SSP Development Office used quantitative risk analyses to rank safety risks and to prioritize safety upgrades and considered qualitative factors and judgment in determining what assumptions, such as risk factors, to use in the Quantitative Risk Assessment System and how to interpret the results.

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[11]Probabilistic risk assessment is a general term given to methodologies that assess risk. Although probabilistic risk assessment methods are usually quantitative, these methods can be either subjective or quantitative.
[12]The Quantitative Risk Assessment System is a personal computer-based software tool used to perform a probabilistic risk assessment.
[13]Critics of the probabilistic risk assessment based their explanations on the "Proceedings of the 19th International Systems Safety Conference – 2001, Risk Probability Numbers and Human-Rated Spacecraft Systems Safety," published by the Systems Safety Society.
[14]The engineering model is incomplete and does not contain certain key attributes such as human error, procedural error, secondary failures/conditions, operationally induced errors, or environmentally induced errors.
[15]The SSP Development Office used other analyses which included preliminary hazard analyses, failure modes and effects analyses, fault tree analyses, human factors analysis/assessments, peer reviews, and an assortment of baseline hazard data.

Safety Upgrade Funding

NASA had adequately funded the safety upgrades approved for implementation to ensure completion of the modifications when needed. For FY 2002, NASA received $207 million for high-priority safety upgrades--$20 million more than the $187 million the Agency requested.[16] The FY 2002 President's Budget[17] contained a program estimate for safety upgrades of about $1.6 billion.[18] However, the FY 2003 President's Budget reduced the program estimate for safety upgrades to $1 billion. The decrease of almost $600 million resulted from NASA's reduction in and deferral of safety upgrade projects.

Deferral of Electric Auxiliary Power Unit

The SSP Development Office encountered significant technical challenges with the Electric Auxiliary Power Unit (APU) (see Appendix D for additional information on the Electric APU) project as the technical formulation phase progressed. Assumptions made for the initial estimate about the maturity of necessary technology, primarily the power cells, were incorrect, and significantly more technology development needed to be performed. The cost estimate to complete the project increased due to the inability to mature the technology, resulting in significant weight, mass, and cost growth. As a result, the most recent cost proposal was $667 million--more than three times the original estimate of $182 million. These cost increases primarily resulted from NASA's underestimate of the technological risk remaining for developing the unique batteries required for the Electric APU and from growth in requirements early in the project formulation phase. In June 2001, NASA deferred the Electric APU as an upgrade because of technical and budget issues, but continued to pursue it as a technology development effort. As of December 2001, NASA had spent $70.3 million on the Electric APU project.

Deferral of Space Shuttle Main Engine Advanced Health Management System Phase II

NASA provided a $55 million preliminary estimate at completion for the Space Shuttle Main Engine (SSME) Advanced Health Management System (AHMS) Phase II (see Appendix D) during the budget formulation before the Agency knew either the scope or content of the program. An official of the NASA Independent Program Assessment Office stated that budget formulation demands often result in submission of premature estimates. The official explained that project estimates at completion are often required from project managers during the formulation phase when technology, schedule, and cost requirements are not yet fully developed, and there are many unknowns. However, estimates at completion must be provided early in the

[16]The Manager, SSP Development Office is reviewing all projects to determine whether there is a potential for risk reduction or schedule acceleration if additional funds are allocated. However, the SSP Development Office has not made any decisions on how to use the additional $20 million.
[17]The President's FY 2002 budget, "A Blueprint for New Beginnings," February 28, 2001, outlined the President's vision for governing the Nation.
[18]This budget estimate was the total cost estimate from the beginning of the Space Shuttle Safety Upgrades Program through FY 2006.

formulation stage in order for NASA to secure funding for future years. The latest estimate at completion for the SSME AHMS Phase II was $179 million.[19] However, in September 2001, NASA deferred the SSME AHMS Phase II because of budget issues.[20]

NASA's Response to Cost Growth

NASA has responded to the growth in cost estimates by taking actions to improve cost management and cost estimating, including increasing its program evaluation capability by adding staff for the cost estimating function. In addition, the recent award of the Independent Program Assessment Contract to Booz Allen Hamilton is a step toward improving the Agency's independent assessment capability. The contractor will support the Lyndon B. Johnson Space Center Systems Management Office in providing full programmatic and institutional assessment capability.

Also, OMB and NASA are developing an agreement on the kinds of information NASA should provide to OMB for program approval, evaluation, and updates.[21] This agreement should result in a more appropriate measure of cost estimates.

Conclusion

NASA continues to invest in safety upgrades for the Space Shuttle. The SSP Development Office has received sufficient funds for FY 2002 to continue work on high-priority safety upgrades that NASA approved for implementation. However, if the probability of catastrophic failure is to decrease further, NASA will need to increase funding to complete safety upgrade projects that have been reduced, deferred, or cancelled.

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[19]As of December 2001, costs incurred for the SSME AHMS Phase II were $7.5 million.

[20]Partial funding for FY 2002 was provided for the SSME AHMS Phase II to complete the development and documentation of the detailed technical specifications, to complete hardware preliminary design, and to refine cost estimates for future consideration. The SSP Development Office's position is that the SSME AHMS Phase II will be deferred indefinitely after FY 2002 if an adequate funding source cannot be identified for the implementation effort.

[21]OMB indicated that this program agreement could be completed by late FY 2002.

Impact on Space Shuttle Flight Schedule

The safety upgrades have not adversely affected the Space Shuttle flight schedule. Also, in the near future, there should be no adverse effect because of the limited number of upgrades being performed and the reduced number of planned flights.

Mixed Fleet Study

NASA performed a Mixed Fleet Study in May 2001. NASA defines a mixed fleet as one configured with multiple combinations of the Cockpit Avionics Upgrade (CAU)[22] and the Electric APU[23] (which has been deferred). The purpose of the Mixed Fleet Study was to develop an option to reduce the time the fleet is flying in a mixed configuration due to incorporation of major safety and supportability upgrades while maintaining the Space Shuttle flight schedule. The purpose of reducing the mixed fleet operating time was to provide overall cost savings due to reduced multiple configuration support requirements, reduce the strain associated with limited resources working multiple configurations, minimize the need for maintaining and operating multiple manuals and processes, reduce the window of vulnerability/risk of errors with multiple processes and procedures, and reduce training requirements for operations and support. When the Electric APU was deferred in June 2001, the May 2001 Mixed Fleet Study became obsolete. The SSP Office will make integration decisions with respect to the CAU in late summer 2002, when it expects to complete a new Mixed Fleet Study.

Impacts on Flight Rates

While the President's budget for FY 2002 proposed an increase in NASA's overall budget, it recommended that Space Shuttle flight rates be reduced from seven to six a year. However, the President's budget for FY 2003 directs that NASA contain rising Space Shuttle costs, which are due primarily to personnel costs, aging infrastructure, and growing vehicle obsolescence. The FY 2003 budget also supports a recommendation made by the International Space Station Management and Cost Evaluation Task Force that NASA further reduce the Space Shuttle flight rate to five a year in FY's 2003 and 2004 and to four a year in FY's 2005 and 2006.

Conclusion

NASA used the Mixed Fleet Study to ensure that approved Space Shuttle safety upgrades minimized adverse effects on the Space Shuttle flight schedule. However, due to budget restrictions and technical problems, only one major safety upgrade (the CAU) that affects the

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[22]NASA's Program Management Council granted the CAU authority to proceed through the preliminary design review, which was held in April 2002. As a result of that review, the Program Management Council must decide by late summer 2002 whether to grant further authority to proceed.

[23]The SSME AHMS Phase I is a major safety upgrade, but because it does not affect modifications to the Orbiter, NASA did not consider the upgrade in the Mixed Fleet Study.

Mixed Fleet Study is being performed. NASA will not make decisions regarding the integration of the CAU safety upgrade until summer 2002. This decision will be supported by a preliminary design review and a new Mixed Fleet Study in order for NASA to determine the best time to integrate the upgrade.

Other Matters of Interest

Although we found that the Space Shuttle safety upgrades approved for implementation were adequately funded for FY 2002, the Congress and the Aerospace Safety Advisory Panel (the Panel) expressed concerns about deferred and future safety upgrades. The Panel reported that because of the budget shortfall, safety upgrades will not be adequately funded, and NASA's plans to replace the Space Shuttle will not be accomplished in the near future.

On April 18, 2002, the House Subcommittee on Space and Aeronautics held a hearing on the Space Shuttle and Space Launch Initiative Programs. The hearing examined NASA's plans to operate and maintain the Space Shuttle and NASA's strategy for developing a second-generation reusable launch vehicle to replace the Space Shuttle.

During the hearing, the former Panel Chairman testified that during his involvement with the Panel, he had never been as concerned for Space Shuttle safety as he currently was. The Panel reported in its "Annual Report for 2001" that current plans and budgets for the Space Shuttle were not adequate and that while safety continues to be well served presently, the basis for future safety has eroded. In addition, the former Chairman stated that nobody would know for sure when the safety margin had been eroded too far and that the current approach was planting the seeds for future danger. Appendix C contains additional details on the Panel's "Annual Report for 2001."

Despite the Panel's concerns, NASA's Associate Administrator for Space Flight assured Congress that sufficient funds were available to maintain the current levels of safety for the Space Shuttle. In addition, the Associate Administrator indicated that for the Space Shuttle to successfully continue accomplishing its goals, the SSP Office must implement upgrades that will increase flight safety and improve systems reliability. NASA has established a goal to have its currently approved safety upgrades implemented into the fleet by 2007. As a contingency, the Associate Administrator also asked the SSP Office to assess upgrade investments required to safely fly the Space Shuttle through FY 2020.

Appendix A. Objectives, Scope, and Methodology

Objectives

The overall objective was to evaluate NASA's management of Space Shuttle safety upgrades. Specifically, we determined whether NASA ensured that the approved safety upgrades: met established safety objectives, were selected based on quantitative analysis or other measurable methodology, were adequately funded to ensure completion of the modifications when needed, and minimized adverse impacts to the Space Shuttle flight schedule.

Scope and Methodology

We reviewed prior audits by NASA's Office of Inspector General, the General Accounting Office, and the National Research Council, applicable Federal laws and regulations, NASA budget and historical data, procedures and guidelines, management plans and independent assessments/reviews. We discussed the audit scope with program management officials at the Lyndon B. Johnson Space Center. We did not assess the reliability of computer-processed data, because we did not rely on it to achieve our objectives.

Management Controls Reviewed

We reviewed the processes the Space Shuttle Program Development Office used to determine the prioritization and selection of the Space Shuttle safety upgrades. Additionally, we examined the process and the independent cost estimates that were prepared on the selected safety upgrade projects. We considered the controls in place to be adequate.

Audit Field Work

We performed the audit field work from June 2001 through May 2002 at the Lyndon B. Johnson Space Center. We performed the audit in accordance with generally accepted government auditing standards.

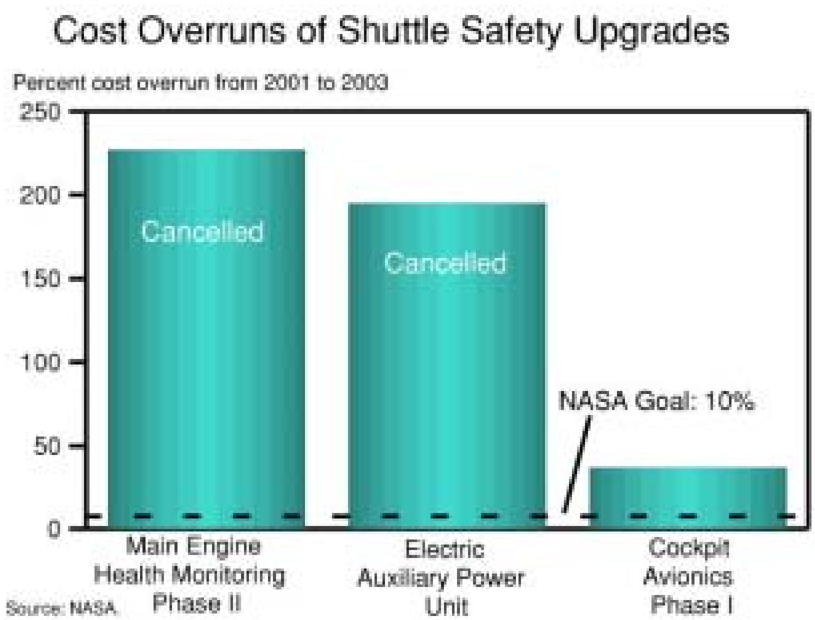
Summary of Prior Audits and Reviews

The Aerospace Safety Advisory Panel, the General Accounting Office, and the National Research Council have issued several reports and testimony on Space Shuttle safety upgrades, which are summarized in Appendix C.

Appendix B. NASA Fiscal Year 2003 Budget Status Report on Shuttle Safety Upgrades

The Office of Management and Budget (OMB) reviews programs throughout the Federal Government to identify strong and weak performers. The budget seeks to redirect funds where appropriate from lesser-performing programs to higher priority or more effective programs. Particularly, when low-performing programs are in priority areas, deficiencies will be addressed through reforms to improve performance. OMB rated the Space Shuttle Safety Upgrade Program ineffective and explained that the Program needed to address large cost overruns[24] and schedule delays to improve Space Shuttle safety through effective investments.

OMB's Overall Performance Rating. OMB's review concluded that NASA continues to invest in improving Space Shuttle safety, but some of the planned investments are experiencing significant problems (as depicted below). For example, the Electric Auxiliary Power Unit was the highest priority safety upgrade last year (fiscal year 2001), but delays, technical difficulties, decreasing safety benefits, and a tripling of its projected cost led NASA, with the support of its advisory committee, to cancel the project.



While the safety and schedule record of Space Shuttle operations has been very good and costs had come down considerably in the last decade, the Space Shuttle remains a very expensive vehicle to operate. In the last few years, Space Shuttle costs have begun to rise again, due to personnel costs, aging infrastructure, growing vehicle obsolescence, and a shrinking industrial base.

[24]See Footnote No. 3.

Appendix B

Improving Safety. OMB stated that NASA continues to invest in safety improvements for the Space Shuttle and increases investment in repairing aging Space Shuttle infrastructure. Planned safety upgrades will enhance safety during launch by 12 percent and will decrease the estimated risk of catastrophic failure during launch from 1 in 556 missions to 1 in 620 missions. Delays in the planned implementation of these upgrades continue to be a concern, so funding will be set aside specifically to accelerate the availability of planned upgrades.

Appendix C. Prior Audit Reports and Reviews

Aerospace Safety Advisory Panel

"Annual Report for 2001," March 2002. The Annual Report of the Aerospace Safety Advisory Panel (the Panel) presents results of activities during calendar year 2001. The Panel reported that budget cutbacks and shifts in priorities had severely limited the resources available to the Space Shuttle for application to risk-reduction and life-extension efforts. As a result, funds originally intended for long-term, safety-related activities have been used for operations. Thus, while safety continues to be well served at present, the basis for future safety has eroded. The Panel focused on the dichotomy between future Space Shuttle risk and the required level of planning and investment to control that risk. The report states that current plans and budgets were not adequate. The report also states it was not prudent to delay ready-to-install safety upgrades, thus continuing to operate at a higher risk level than is necessary. When risk reduction efforts, such as the advanced health monitoring for the Space Shuttle Main Engine, are deferred, astronauts are exposed to higher levels of flight risk for more years than necessary. These lost opportunities are not offset by any real life-cycle cost savings. The stock of some existing Space Shuttle components is not sufficient to support the program until a replacement vehicle becomes available. Some of the upgrades, in addition to improving safety, solve this shortfall by providing additional assets. If these upgrades are not going to be implemented, the program must plan now for adequate quantities of long lead-time components to sustain safe operations. Regarding specific safety upgrades, the Panel reported that it was unfortunate that the Space Shuttle Main Engine Advanced Health Management System Phase II had been deferred and that the Electric Auxiliary Power Unit would be assessed as a potential safety upgrade by the Space Shuttle Program after the related technology had further matured.

General Accounting Office Reports and Testimony

"Space Shuttle Safety Update on NASA's Progress in Revitalizing the Shuttle Workforce and Making Safety Upgrades," GAO-01-1122T, Testimony, September 6, 2001. In August 2000, the NASA Space Shuttle Program was at a critical juncture. Its workforce had declined significantly since 1995, its flight rate was to double to support the assembly of the International Space Station, and costly safety upgrades were planned to enhance the Space Shuttle's operation until at least 2012. Workforce reductions were jeopardizing NASA's ability to safely support the Space Shuttle's planned flight rate. Recognizing the need to revitalize the Space Shuttle's workforce, NASA ended its downsizing plans for the Space Shuttle Program and began to develop and equip the Space Shuttle fleet with various safety and supportability upgrades. NASA is making progress in revitalizing the Space Shuttle Program's workforce. NASA's fiscal year (FY) 2001 budget request projected an increase of more than 200 full-time equivalent staff through FY 2002. NASA has also focused more attention on human capital management in its annual performance plan. However, considerable challenges still lie ahead. Because many of the additional staff are new hires, they will need considerable training and will need to be integrated into the Space Shuttle Program. Also, NASA still needs to fully staff areas critical to Space Shuttle safety; deal with critical losses due to retirements in the coming years; and, most of all, sustain management attention to human capital reforms. Although NASA is making strides in revitalizing its workforce, its ability to implement safety upgrades in a timely manner is uncertain.

"Space Shuttle: Human Capital and Safety Upgrade Challenges Require Continued Attention," GAO/NSIAD/GGD-00-186, August 15, 2000. In response to a congressional request, The General Accounting Office (GAO) reviewed the workforce and safety issues facing NASA and its Space Shuttle Program, focusing on the: (1) impact of workforce reductions on the Space Shuttle Program; (2) challenges NASA faces in addressing workforce issues; and (3) status of planned Space Shuttle safety and supportability upgrades. Among other matters, GAO noted that in regard to safety issues, over the next 5 years, NASA plans to develop and begin equipping the Space Shuttle fleet with a variety of safety and supportability upgrades at an estimated cost of about $2.2 billion. Further, to implement the program successfully, NASA will have to overcome a number of programmatic and technical challenges, such as a demanding schedule and undefined design and workforce requirements.

"Space Shuttle: Upgrade Activities and Carryover Balances," Testimony, GAO/T-NSIAD-98-21, October 1, 1997. In response to a congressional request, GAO discussed the NASA Space Shuttle Program, focusing on: (1) the effect of a funding transfer from the Space Shuttle Program to the International Space Station Program on major Space Shuttle upgrade projects and the status of those projects, (2) the role carryover budget balances had in the transfer and in funding upgrades, and (3) funding for future upgrades. Concerning Space Shuttle upgrades, GAO noted that the $190 million funding transfer to the International Space Station Program did not adversely impact current or near-term upgrade projects; four current projects, which account for about 91 percent of the total funding provided for upgrade activities in FY 1997, could not have used the transfer funds; and even though they experienced technical problems and associated schedule slips, the projects' financial reserves were sufficient to fund the problems that were experienced. Furthermore, GAO reported that NASA has used carryover budget balances to fund upgrades in the past and plans to continue doing so in the future; that depending on the future upgrades selected, costs could range from hundreds of millions to several billions of dollars; and that NASA is defining an upgrade program to keep the Space Shuttle a viable space transportation system at least through about 2013 -- the planned mission life of the International Space Station. Finally, in addition to annual funding requests for safety and performance upgrades and the continued use of excess carryover budget balances, NASA plans to use any savings that are generated within the Space Shuttle Program to fund its upgrade activities; the extent to which these sources will be available in the future is uncertain; and funding needs for future upgrades will be driven by a number of questions related to issues such as how long the Space Shuttle will be required and whether viable alternatives can be developed to support space station operations and other human space flight requirements.

National Research Council

"Upgrading the Space Shuttle," Committee on Space Shuttle Upgrades, Aeronautics and Space Engineering Board, Commission on Engineering and Technical Systems, 1999. In May 1998, NASA asked the National Research Council (the Council) to examine the Agency's plans for further upgrades to the Space Shuttle system. The Council was asked to assess NASA's method for evaluating and selecting upgrades and to conduct a top-level technical assessment of proposed upgrades. NASA did not ask the Council to—and the Council's report does not—discuss the larger issue of whether the Space Shuttle should be upgraded. The report was limited to a review of NASA's approach to prioritizing and selecting upgrades and a top-level technical assessment of several representative proposed upgrades. The decision to implement many of the major proposed Space Shuttle upgrades must await a high-level national policy decision on when the Space Shuttle should be phased out in favor of some other launch vehicle (or vehicles). The report emphasized that although it may be tempting to delay making this decision until it becomes clear when a Space Shuttle replacement will be available, a timely decision is crucial for NASA to act efficiently either by phasing out its Space Shuttle upgrade program or by making the major investments necessary for the Space Shuttle to carry out its long-term mission reliably and efficiently.

Appendix D. Space Shuttle Safety Upgrades Objectives

National Space Transportation System (NSTS) 37400, "Space Shuttle Program Upgrades Management Plan," July 21, 2000, identifies the following safety upgrades objectives:

- major reduction in ascent catastrophic risk (targeting up to a 50-percent risk reduction);
- significant reductions in orbital and entry/landing catastrophic risk (targeting up to a 30-percent risk reduction); and
- major improvement in flight crew situational awareness for managing critical flight operational situations through cockpit modernization.

NASA derived the targets associated with the first two objectives by adding the individual risk reduction for each of the candidate upgrades that the Agency selected. However, because of budget constraints and technical limitations,[25] only two major upgrades are being pursued, the Cockpit Avionics Upgrade (CAU) (Figure D-1) and the Space Shuttle Main Engine (SSME) Advanced Health Management System (AHMS) Phase I. While two less costly safety upgrades, the External Tank Friction Stir Weld and Main Landing Gear Tire/Wheel, could not individually meet the safety objectives, the suite of proposed safety upgrades collectively met the established safety objectives. NASA has built the consideration of the safety objectives into the selection process.

Figure D-1. Cockpit Avionics Upgrade

Source: NASA

The CAU is a high-priority Space Shuttle safety upgrade. The project will provide new Orbiter cockpit avionics hardware and software to meet the man-machine interface requirements that will enhance overall crew safety. Orbiter cockpit displays and crew interface capabilities will be

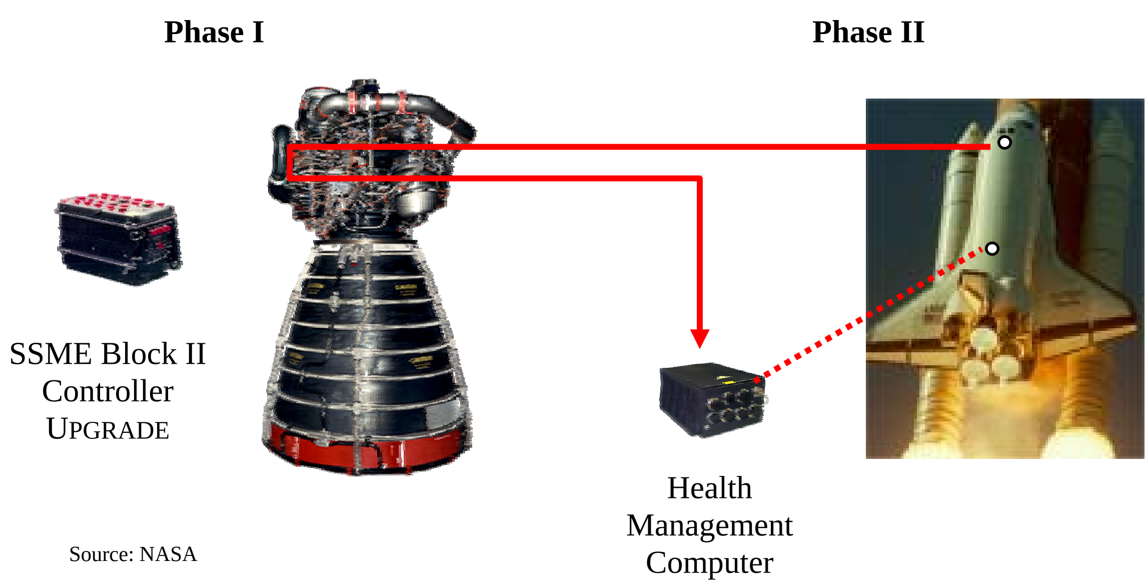
[25]The Electric APU was deferred in June 2001. It is now identified as a technology development effort with about $4 million in funding for fiscal year 2002.

significantly improved by replacing the existing integrated display processors with higher performance command and display processors. These units will provide expanded processing performance to enable dramatic improvements in information access and display capability as well as the implementation of new abort flight management and enhanced caution and warning software functions.

The CAU will increase crew situational awareness and decrease crew workload in the cockpit to enable more timely and accurate crew decisions. Excessive crew workload adversely affects the crew's situational awareness and impairs crew ability to diagnose and isolate system failures. Improving the crew's ability to manage information during critical flight operations will significantly benefit the safety and reliability of the Space Shuttle Program. The CAU is designed to significantly improve crew performance margins in safety-critical, high-workload scenarios and to mitigate risk of crew error throughout all critical flight operational phases (the third safety upgrade objective).

The SSME AHMS Phase I (Figure D-2) upgrade includes the contracted design, development, modification, certification, and delivery of 20 flight-advanced SSME controllers to include a high-pressure turbopump synchronous vibration redline capability,[26] new external communications interface, enhanced memory, and deletion of memory retention batteries.

Figure D-2. Advanced Health Management System



Source: NASA

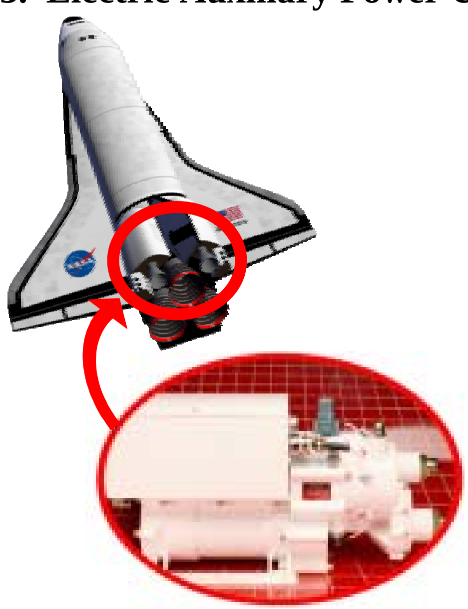
[26]The high-pressure turbopumps are the largest contributors to catastrophic ascent risk. The vibration redlines protect against bearing, impeller, and turbine blade failures within the SSME controller. The addition of a reliable catastrophic redline shutdown limit will result in a substantial reduction in both SSME and vehicle ascent risk.

Appendix D

The SSME AHMS Phase II upgrade will improve Space Shuttle safety by reducing the probability of catastrophic engine failures during the ascent phase of a Space Shuttle mission. This will be accomplished by the addition of new engine health management hardware and software, which will provide the capability to detect, diagnose and mitigate the effects of potentially catastrophic failures. The addition of the SSME AHMS Phase II capabilities will provide substantial reductions in catastrophic ascent risk above and beyond that achieved by Phase I. Additionally, Phase II will reduce the likelihood of having to abort the mission or, if an abort is required, will increase the probability that the abort will be less risky. However, in September 2001, because of limited funding, the SSME AHMS Phase II is in a deferred status until NASA increases the funding or makes a decision to formally cancel the project. The SSME AHMS is designed to reduce ascent risk by about 19 percent and reduce mission risk by about 9 percent (first safety upgrade objective).

The Electric Auxiliary Power Unit (APU) (Figure D-3) system was designed to replace the Orbiter's existing Hydrazine APU[27] with a battery. The Electric APU consists of a battery, associated 270-volt power, distribution and control, electro-hydraulic drive unit, and cooling system. All existing functional performance requirements of the existing Hydrazine APU will be met with the Electric APU, but without the highly toxic hydrazine fuel and high-speed turbo machinery and associated hazards. The Electric APU is designed to reduce mission risk by 15 percent and ascent risk by less than 1 percent (second safety upgrade objective). In June 2001, NASA deferred the Electric APU because of technical and budget issues.

Figure D-3. Electric Auxiliary Power Unit



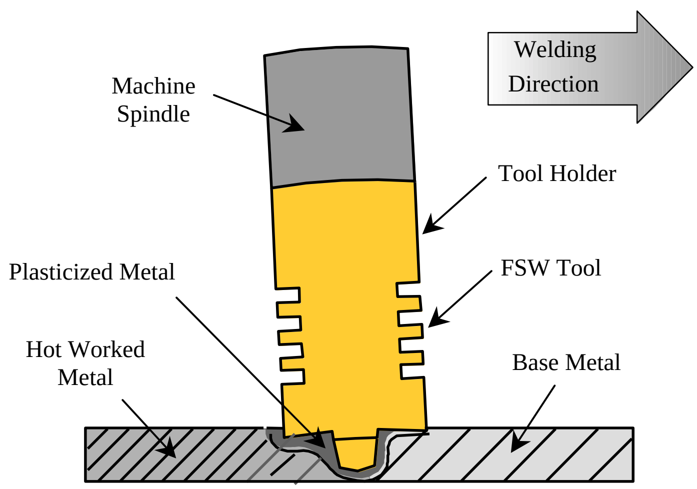
Source: NASA

REPLACE HYDRAZINE POWERED AUXILIARY POWER UNIT'S WITH ELECTRIC AUXILIARY POWER UNIT'S

[27]The Hydrazine APU is a highly toxic, explosive, flammable and corrosive system that utilizes a high-speed turbine to drive a pump shaft and pressurize the Orbiter hydraulic system.

Friction Stir Weld (Figure D-4) is a solid-state welding process utilizing a nonconsumable cylindrical tool, with a unique auger-type pin, which is rotated, plunged, and traversed along the weld joint using conventional milling equipment and backside support. Material around the tool is frictionally heated, plasticized, and extruded/forged to the back of the pin, where the material consolidates and cools under hydrostatic pressure conditions. The resulting wrought microstructure exhibits high strength and ductility. The Friction Stir Weld is designed to improve manufacturing reliability and was approved largely based on the potential to reduce the manufacturing defects in each external tank from about 100 per tank, which are experienced today, to none. This project is identified to reduce ascent risk by less than 1 percent (first safety upgrade objective).

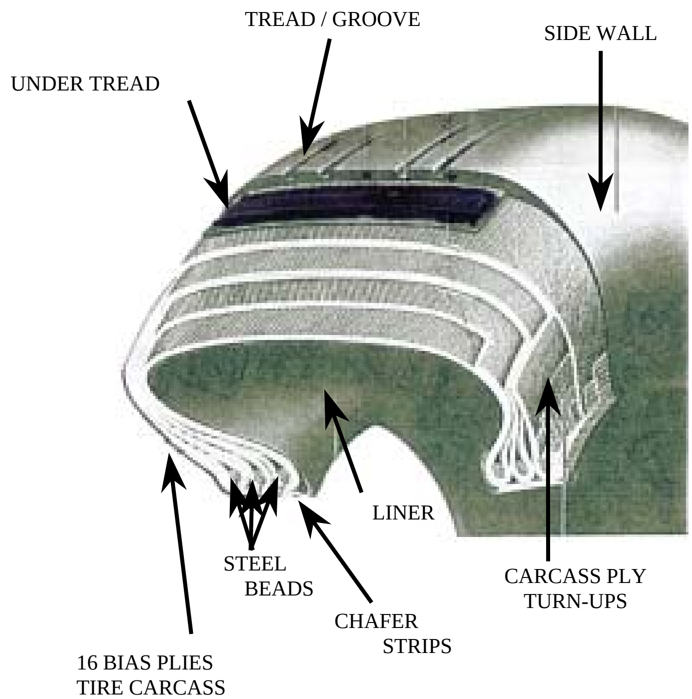
Figure D-4. Friction Stir Weld (FSW)



Source: NASA

The Main Landing Gear Tire/Wheel (Figure D-5) project will replace the existing Orbiter tire and wheel with an improved tire/wheel design that will add a safety margin for landing operations by increasing load capability with only minor changes to flight operations and ground processing. NASA approved the project based on expected improvements of gaining about a 20-percent margin in the tire load capability at touchdown, thereby reducing the risk of a tire blow-out on landing and potentially losing control during landing and roll out. This project is designed to reduce mission risk by less than 1 percent (second safety upgrade objective).

Figure D-5. Main Landing Gear Tire/Wheel



Source: NASA

Appendix E. Management's Response

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

June 12, 2002

Reply to Attn of: BD5

TO: W/Assistant Inspector General for Audits

FROM: M/Associate Administrator for Space Flight

SUBJECT: Management's Response to OIG's Discussion Draft Report on Audit of Space Shuttle Safety Upgrades, Assignment Number A-01-041-00

We appreciate the opportunity to review and provide comments to the draft audit report and commend your staff for the quality of work reflected in this report. As substantiated by your findings, significant efforts are underway by NASA and the Space Shuttle Program Office to fully recognize and integrate all aspects of human space flight within the confines of safety, mission, and budget. Many decisions are dependent on results of studies currently underway, including those related to safety upgrades with the probability of extending the life of the Space Shuttle through 2020. We appreciate your acknowledgement of this uncertainty by not making any recommendations in the draft report. Please consider this letter the official Agency response and issue the final report. If you have any questions, please contact Pat Ritterhouse, JSC Audit Liaison Representative, at 281-483-4220.

Frederick D. Gregory

cc:
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JM/J. Werner
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W-JS/D. E. Coldren
JSC/BD5/P. H. Ritterhouse
JSC/MA/R. D. Dittemore
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Appendix F. Report Distribution

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KSC/CC/Chief Counsel, John F. Kennedy Space Center

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Deputy Associate Director, Energy and Science Division, Office of Management and Budget
Branch Chief, Science and Space Programs Branch, Energy and Science Division, Office of Management and Budget
Managing Director, Acquisition and Sourcing Management Team, General Accounting Office
Senior Professional Staff Member, Senate Subcommittee on Science, Technology, and Space

Chairman and Ranking Minority Member – Congressional Committees and Subcommittees

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Senate Subcommittee on VA, HUD, and Independent Agencies
Senate Committee on Commerce, Science, and Transportation
Senate Subcommittee on Science, Technology, and Space
Senate Committee on Governmental Affairs
House Committee on Appropriations
House Subcommittee on VA, HUD, and Independent Agencies
House Committee on Government Reform
House Subcommittee on Government Efficiency, Financial Management and Intergovernmental Relations
House Subcommittee on Technology and Procurement Policy
House Committee on Science
House Subcommittee on Space and Aeronautics, Committee on Science

Congressional Member

Honorable Pete Sessions, U.S. House of Representatives

NASA Assistant Inspector General For Auditing
Reader Survey

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Report Title: **Space Shuttle Safety Upgrades**

Report Number: ______________________ Report Date: ______________________

Circle the appropriate rating for the following statements.

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A
1. The report was clear, readable, and logically organized.	5	4	3	2	1	N/A
2. The report was concise and to the point.	5	4	3	2	1	N/A
3. We effectively communicated the audit objectives, scope, and methodology.	5	4	3	2	1	N/A
4. The report contained sufficient information to support the findings in a balanced and objective manner.	5	4	3	2	1	N/A

Overall, how would you rate the report?

☐ Excellent ☐ Fair ☐ Very Good ☐ Poor ☐ Good

If you have any additional comments or wish to elaborate on any of the above responses, please write them here. Use additional paper if necessary. ____________

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How did you use the report? ____

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How could we improve our report? ____

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How would you identify yourself? (Select one)

- ☐ Congressional Staff
- ☐ NASA Employee
- ☐ Private Citizen
- ☐ Government: ________ Federal: _________ State: ________ Local: ________
- ☐ Media
- ☐ Public Interest
- ☐ Other: _________________________

May we contact you about your comments?

Yes: ______ No: ______

Name: ____________________________

Telephone: ________________________

Thank you for your cooperation in completing this survey.

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