IG-02-028

AUDIT REPORT

SPACE LAUNCH INITIATIVE: PRIMARY REQUIREMENTS FOR A 2[ND] GENERATION REUSABLE LAUNCH VEHICLE

September 30, 2002

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Acronyms

DOD	Department of Defense
FY	Fiscal Year
NPG	NASA Procedures and Guidelines
OMB	Office of Management and Budget
RLV	Reusable Launch Vehicle
SLI	Space Launch Initiative

September 30, 2002

W

TO: R/Associate Administrator for Aerospace Technology
AE/Chief Engineer
MSFC/DA01/Director, Marshall Space Flight Center

FROM: W/Assistant Inspector General for Audits

SUBJECT: Final Report on Audit of the Space Launch Initiative:
Primary Requirements for a 2nd Generation Reusable Launch Vehicle
Assignment Number A-01-049-00
Report Number IG-02-028

The subject final report is provided for your information and use. Our evaluation of your response has been incorporated into the body of the report. We consider management's proposed corrective actions responsive. The recommendations will remain open for reporting purposes until corrective actions are completed. Please notify us when actions have been completed on the recommendations, including the extent of testing performed to ensure corrective actions are effective.

We appreciate the courtesies extended to the audit staff. If you have questions concerning the report, please contact Mr. Dennis E. Coldren, Program Director, Space Flight Audits, at (281) 483-4773, Ms. Clara L. Seger, Program Manager, at (321) 867-4715, or Mr. James W. Linville, Auditor-in-Charge, at (256) 544-0971. The final report distribution is in Appendix H.

[original signed by]
Alan J. Lamoreaux

Enclosure

cc:
HQ/AI/Associate Deputy Administrator
HQ/B/Acting Chief Financial Officer
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NASA Office of Inspector General

IG-02-028 **September 30, 2002**
A-01-049-00

Space Launch Initiative: Primary Requirements for a 2nd Generation Reusable Launch Vehicle

Introduction

The Space Shuttle is America's first-generation reusable launch vehicle (RLV) and has been NASA's primary launch vehicle for access to space for the last 20 years. The Shuttle currently requires a significant portion of NASA's resources (about 22 percent of the $14.9 billion budget for fiscal year (FY) 2002), limiting the Agency's ability to pursue other initiatives in scientific exploration and development of space. In 1994, the President issued the National Space Transportation Policy that made NASA responsible for developing the technologies needed to build an RLV that would not only reduce the cost of access to space but also provide increased safety and reliability.

In 1999, NASA developed the Integrated Space Transportation Plan (Transportation Plan), the long-range investment strategy for the Government to accomplish its mission objectives. The Transportation Plan consists of three major programs: Space Shuttle Safety Upgrades; the Space Launch Initiative (SLI), also called the 2nd Generation RLV Program (Program);[1] and the 3rd Generation RLV Technologies and In-Space Transportation System. The Transportation Plan's comprehensive approach is based on national space policies, NASA's industry-led Space Transportation Architecture Studies conducted from 1998 through 2000, and lessons learned from various experimental technology demonstrators.[2] The 2nd Generation RLV Program currently represents an investment of about $4.85 billion for FY's 2001 through 2006.

The overall objective of the audit was to evaluate SLI planning and management. This report identifies a condition regarding determination of primary (Level 1)[3] requirements for the 2nd Generation RLV Program, which warrants timely action by NASA.

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[1]The SLI originally included all of the experimental vehicle programs (for example, the X-33, X-34, and X-37 Programs) and the 2nd Generation RLV Program. NASA cancelled the X-33 and X-34 Programs and incorporated the X-37 Program into the 2nd Generation RLV Program, which now represents the SLI.
[2]NASA initiated the DC-XA, X-33, X-34, and X-37 technology flight demonstrators from 1994 through 1999. The DC-XA crashed in 1995 during flight tests. NASA cancelled the X-33 and X-34 Programs in March 2001 after spending more than $1 billion and concluding that the programs would not provide sufficient contributions to SLI technology requirements to justify their cost.
[3]Level 1 requirements specify a capability or characteristic the system or architecture must have to meet clearly defined needs.

We will address other SLI issues in subsequent audit reports. Details on the objectives, scope, and methodology are in Appendix A. A summary of prior audit work that relates to the SLI is in Appendix B.

Results in Brief

NASA approved the Level 1 requirements for the 2nd Generation RLV Program without properly validating them, that is, NASA did not substantiate or verify that the requirements were appropriate and viable. As a result, the requirements, in particular those for safety and affordability, may not be valid or achievable. Invalid or unachievable Level 1 requirements can jeopardize the development of appropriate lower-level requirements, cause an inappropriate architecture selection,[4] lead to cost and schedule growth, and produce a launch vehicle that is not commercially viable.

Background

The NASA Office of Aerospace Technology manages the Agency's space transportation initiatives aimed at reducing the cost and improving the safety and reliability of access to space. Marshall Space Flight Center (Marshall) heads the 2nd Generation RLV Program with support from other NASA Centers. In February 2000, the Associate Administrator for Aerospace Technology approved the formulation process[5] for the 2nd Generation RLV Program. The overall goal of the Program is to substantially reduce technical and business risks associated with developing safe and reliable RLV's and providing affordable launch operations.

The 2nd Generation RLV Program follows a three-part strategy:

- Invest in technology development to provide needed technologies, and reduce risks in order to enable full-scale development of any new systems (FY's 2001 - 2005).

- Select a vehicle architecture and decide whether NASA will implement full-scale development of a 2nd Generation RLV (FY 2005).

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[4]NASA will select an approach, or architecture, for providing launch and in-space propulsion to meet space transportation requirements. The architecture is an integrated set of segments: Earth-to-orbit and on-orbit vehicles, mission planning capability, ground and flight operations, and ground-based and on-orbit support infrastructure.

[5]All NASA programs use a process called formulation to demonstrate readiness to begin implementation. Formulation is an iterative activity rather than a discrete set of linear steps. Formulation starts with customer requirements, strategic planning goals and objectives, and an authorization to begin the process, which is evidenced in the formulation authorization document.

- If the Agency decides in FY 2005 to implement full-scale development (FY's 2005 - 2010), then produce an operational 2nd Generation RLV by FY 2010.[6] If not, at the end of the current formulation phase, the 2nd Generation RLV Program could continue formulation, be restructured, or terminated.

Through the Program, NASA leads a team that includes the Department of Defense (DOD), primarily the U.S. Air Force, the aerospace industry, and academia to develop viable system architectures and technologies based on clearly defined system requirements.[7] An integral step in developing the architectures and technologies is the development of Level 1 requirements that reflect general launch needs that the 2nd Generation RLV is intended to satisfy. These requirements are derived from an understanding of NASA, DOD, and commercial mission needs and from deficiencies in the existing fleet of launch vehicles. System deficiencies include inadequate space transportation system safety and reliability and excessive space transportation user costs.

From the mission needs and system deficiencies, NASA developed the 2nd Generation RLV Program Level 1 Requirements Document (MSFC-RQMT-3221), September 4, 2001,[8] which identifies the capabilities or characteristics the architecture must have to meet mission needs. Those requirements form an integral part of activities including systems engineering, analyses, and trade studies in accordance with the 2nd Generation RLV Program Plan. Appendix C shows an excerpt of the Government Level 1 Requirements Document. The Government requirements, including requirements for safety (loss of crew of 1 in 10,000 missions) and affordability ($1,000 per pound to low-Earth orbit), currently reflect only NASA requirements. DOD requirements may be added in the future. The document does not include commercial Level 1 requirements because of proprietary and/or competition-sensitive concerns.[9]

[6] The decision to implement full-scale development has slipped to late FY 2006. Also, initial operational capability is no longer planned for 2010 but rather for early in the next decade.

[7] In February 2002, NASA and the Air Force concluded a joint Space Launch Requirements Study to determine how they could best coordinate efforts to meet their respective needs for a new generation of reusable launch systems. Marshall officials stated that, based on initial study results, the Air Force is not only reviewing available funding but is also considering establishing a program office similar to NASA's 2nd Generation RLV Program. As of September 2002, the Air Force and NASA were still exploring and pursuing alternatives for jointly developing a next generation RLV. The study results and future Air Force and NASA decisions based on the study could have a significant effect on NASA's current Level 1 requirements.

[8] The Associate Administrator for Aerospace Technology approved the Level 1 Requirements Document on November 6, 2001.

[9] Agency strategic planning has anticipated private ownership and operation of the next generation RLV, with NASA as a paying customer, but the feasibility of a commercial RLV depends on factors such as annual launch rate and market competition. These factors may not be addressed by NASA's Government requirements.

Validity of Level 1 Requirements

Finding. NASA approved the Level 1 requirements for the 2nd Generation RLV Program without properly validating them, that is, NASA did not substantiate or verify that the requirements were appropriate and viable. Validation has not occurred because the Agency had not established guidance to ensure that the proposed requirements were validated prior to approval. In addition, some Agency officials viewed the requirements as distant objectives (stretch goals[10]) that would be refined over time rather than mandatory thresholds. Consequently, the approved requirements may not be valid or achievable. In particular, several NASA groups[11] have questioned the validity and achievability of the requirements for safety (loss of crew of 1 in 10,000 missions) and affordability ($1,000 per pound to low-Earth orbit). Invalid or unachievable Level 1 requirements can jeopardize development of appropriate lower-level requirements, cause an inappropriate architecture selection, lead to cost and schedule growth, and produce a launch vehicle that is not commercially viable.

Guidance for Establishing Requirements

Office of Management and Budget (OMB). OMB's 1999 guidance[12] for NASA's FY 2001 budget included recommendations for the 2nd Generation RLV Program. The guidance states that NASA's requirements could make or break the affordability and commercial compatibility of new systems. Therefore, OMB placed a high priority on NASA's ensuring that premature requirements did not make final launch architecture options incompatible with the commercial market or affordability to NASA. According to OMB, trade studies[13] and independent evaluations were vitally important to differentiate between firm requirements and potential needs that could be pursued at a later time or in a different way. OMB strongly recommended that NASA use its contractors to perform trade studies and that NASA seek an external, independent review to help validate requirements before making final determinations.

NASA Guidance. NASA Procedures and Guidelines (NPG) 1000.2, "NASA Strategic Management Handbook," February 2000, states that the NASA Strategic Plan articulates the Agency's vision, mission, goals, and objectives. The Strategic Plan gives direction to

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[10]The Aerospace Technology Enterprise Strategic Plan, April 2001, states that the goals and objectives presented in the plan "stretch" beyond what is possible today, forcing the Agency to look beyond conventional concepts and evolutionary technologies.

[11]The NASA groups that questioned the requirements included the Office of Aerospace Technology, the Space Transportation Subcommittee of the Aerospace Technology Advisory Committee, and Program staff.

[12]This guidance known as a "passback" is OMB's December 6, 1999, response to NASA on the Agency's FY 2001 budget submission.

[13]Trade studies, a critical part of the systems engineering process, support decision makers by analyzing alternatives available to program/project managers and attempting to find solutions/designs that provide a better combination of cost and effectiveness. Thus trade studies provide an objective foundation for the selection of one or more approaches for the solution of an engineering problem.

the work of all NASA organizations and employees. The NPG assigns Enterprise[14] Associate Administrators the responsibility for establishing objectives, requirements, and metrics for Agency programs.

NPG 7120.5A, "NASA Program and Project Management Processes and Requirements," April 3, 1998, governs formulation, approval, implementation, and evaluation of all NASA programs and projects and assigns the following responsibilities:

- Associate Administrators are responsible for establishing Enterprise strategy, formulating programs, defining customer requirements and objectives, and recommending Lead Center assignments.

- Lead Center Directors have full program management responsibility and authority. Lead Center Directors delegate program management responsibility to program managers.

- Program managers are responsible for the total range of program activities including supporting the development and definition of detailed requirements.

The NASA Systems Engineering Handbook, Special Publication-6105, June 1995, provides guidance on performing systems engineering and addresses the development of mission needs statements and top-level requirements. The Handbook emphasizes the importance of selecting appropriate program/project requirements and thereby avoiding the acceptance of requirements that cannot be met and the selection of design concepts that cannot be built, tested, maintained, and operated.

Sufficiency of Support for Requirements

The 2nd Generation RLV Program Office obtained the Marshall Center Director's approval for the proposed Level 1 requirements and submitted them for final approval to the Associate Administrator for Aerospace Technology, who approved the requirements on November 6, 2001. However, neither the Marshall nor Headquarters officials had performed studies or analyses that supported the validity or appropriateness of the approved Level 1 safety and affordability requirements. Office of Aerospace Technology officials stated that program analysts were not available to perform the necessary analysis of the operational cost requirement ($1,000 per pound) and other requirements when the officials were reviewing and approving the Level 1 requirements. In addition, contractor trade studies did not provide anticipated documentation to support the validation or revision of the existing requirements.

Program officials expected contractor trade studies to provide sufficient analytical support to enable further refinement of program requirements. The Agency issued

[14]NASA conducts its programs through five Strategic Enterprises that constitute NASA's primary mission areas: Space Science, Earth Science, Biological and Physical Research, Human Exploration and Development of Space, and Aerospace Technology.

NASA Research Announcement 8-27 on March 7, 2000, and subsequently awarded contracts totaling about $18 million for the trade studies. The announcement solicited proposals that were to be initiated in FY 2000 as the first step in defining system requirements to meet the stated safety and cost goals. In addition, the proposals were to identify and commence initial risk reduction activities, such as technology demonstration. NASA expected those activities to ultimately enable a decision on the initiation of full-scale development of a 2nd Generation RLV architecture. Program officials stated that the contractors provided input on risk reduction activities as requested in the announcement, but the contractors did not provide sufficient documentation to support the validation or revision of the existing requirements.

Safety and Affordability Goals

The approved Level 1 safety and affordability requirements for a 2nd Generation RLV are essentially a restatement of the goals/requirements contained in the NASA and Aerospace Technology Enterprise Strategic Plans,[15] and other Agency documents. Appendix D explains the origin of the strategic goals, specifically: (1) achieve a probability of loss of crew for the total flight profile of a mission equal to a probability of 1 in 10,000 or less, and (2) deliver payloads into a low-Earth circular orbit with a recurring operational cost of $1,000 per pound or less.[16]

Although Level 1 requirements should specify a capability or characteristic the system or architecture must have to meet clearly defined needs, some Agency officials viewed the approved requirements as distant objectives (stretch goals) that would be refined over time rather than as mandatory thresholds. Management stated that milestones in the 2nd Generation RLV Program Integrated Master Schedule would facilitate further refinement of the requirements. These milestones include the initial architecture technology review in March 2002, the system requirements review in October 2002, and the nonadvocate review[17] tentatively scheduled for March 2003.

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[15]NASA established a Strategic Management System to provide the information and results to fulfill the requirements of the Government Performance and Results Act of 1993. The system includes the NASA Strategic Plan, which defines Agency missions and goals. NASA's five Enterprises also developed strategic plans to convey their unique strategic goals, objectives, and implementing strategies to address the requirements of the Agency's primary customers. These customers include the science and education communities, aerospace and non-aerospace industries, Federal agencies, and others.

[16]The probability of a loss of crew on the Space Shuttle (entire mission profile) is currently about 1 in 265 missions, and planned additional safety upgrades are expected to improve the probability to about 1 in 400 missions by 2006. The goal for loss of crew of 1 in 10,000 missions is a 25-fold improvement from the expected crew safety of about 1 in 400 for the Space Shuttle. The goal of $1,000 per pound of payload to low-Earth orbit is a 10-fold improvement from the current estimated cost of about $10,000 per pound for a Shuttle payload. The Enterprise and Agency strategic plans currently state the goals for safety and launch cost in terms of improving "by a factor of …"; earlier plans stated these goals in missions and dollars per pound, which is how NASA has stated the 2nd Generation RLV Program Baseline Level 1 requirements.

[17]The nonadvocate review is performed by a team of highly knowledgeable specialists (internal and external to NASA), outside the program or project's advocacy chain, to provide the NASA Program Management Council with an independent verification and evaluation of the program's or project's readiness to proceed.

Guidance Needed for Validating Requirements

NASA had not established guidance for the preparation of necessary support documentation and proper validation of proposed program requirements. Guidance, such as that developed by the DOD, is needed to ensure that an appropriate authority validates requirements prior to their approval.

DOD Instruction. DOD Instruction 5000.2, "Operation of the Defense Acquisition System," January 4, 2001, establishes a management framework for translating mission needs and technological opportunities, based on validated mission needs and requirements, into stable, affordable, and well-managed acquisition programs. The process includes validation of mission needs and requirements and specifies that the appropriate requirements authority shall validate requirements documents.

NASA Guidance. In accordance with NPG 7120.5A, Enterprise Associate Administrators are responsible for defining requirements, and program managers are responsible for supporting the development and definition of detailed requirements. The NPG however does not address the validation of requirements including the timeliness of analysis and adequacy of supporting documentation.

Similarly, although the NASA Systems Engineering Handbook, Special Publication-6105, provides some guidance on the development of mission needs statements and top-level requirements, the Handbook does not provide specific guidance on the process of validating proposed Level 1 requirements. The Handbook also does not contain guidance for program/project managers on the preparation of supporting documentation and on the development of the rationale for justifying the appropriateness of proposed requirements.

Concerns About the Requirements

Several NASA groups, both internal and external, have expressed concerns about the validity and achievability of the Level 1 requirements for the 2nd Generation RLV Program.

NASA Officials. NASA Headquarters and Marshall officials expressed concerns to us about the feasibility of current requirements primarily because of the magnitude of technology improvement needed to achieve them. Specifically, because they were concerned about both the validity of the affordability requirement of $1,000 per pound to low-Earth orbit and the metric (dollars per pound) used, Office of Aerospace Technology officials did not approve proposed Level 1 requirements until Marshall agreed to initiate a review of the affordability requirement and to consider restating it.[18] In addition, during the coordination of a draft of the NASA 2000 Strategic Plan, concerns by a senior Headquarters official about the $1,000 per pound cost goal led to a temporary change in

[18]Office of Aerospace Technology officials stated they were most concerned about use of the dollars per pound metric because of the need to provide numerous qualifiers such as launch rate, payload type, target orbit, etc.

the affordability goal to $2,000 per pound. The Office of Aerospace Technology did not agree with a $2,000 per pound goal and decided that it should remain $1,000 per pound because it was the original stretch goal that was intended to be aggressive to promote revolutionary technology development.

Program Office officials also had concerns about the feasibility of the proposed affordability requirement. They explained that after NASA awarded the contracts under NASA Research Announcement 8-30, the contractors requested that the Program Office provide a set of NASA-approved, top-level requirements as a baseline to work toward. Because of an overriding concern about a possible contractor work stoppage, Program Office officials considered it necessary to establish official program requirements. Therefore, despite concerns about the Level 1 requirements, the Program Office, the Marshall Center Director, and the Associate Administrator, Office of Aerospace Technology approved them.

Space Transportation Advisory Subcommittee. NASA established the Space Transportation Subcommittee of the Aerospace Technology Advisory Committee[19] to provide independent oversight of the Agency's Space Transportation programs. The subcommittee challenged the achievability of the Program's requirements during the November 2000 and October 2001 meetings of the committee. Minutes of the meetings included statements that the Program's requirements were not realistic and were impossible to meet in a 2nd Generation RLV and that the existing requirements documents should be cancelled.[20] The subcommittee provided written reports that addressed these concerns to the committee and to the NASA Advisory Council.

Program Office Technical Staff. The Program Office's technical staff identified numerous risks to achieving the Level 1 requirements for safety and affordability and entered them in the Program's risk management database.[21] As of December 2001, the staff had identified 279 risks, of which at least 110 were risks to achieving the Program's safety, reliability, and affordability requirements.

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[19]The committee consists of 15 to 25 members and 75 to 153 associate members with a balanced representation from industry, academia, and Government. The members have recognized knowledge and expertise in scientific, technological, and programmatic fields relevant to Aerospace transportation.
[20]NASA had previously issued a requirements document for the 2nd Generation Space Transportation Architecture in August 1999 and had included goals in the 2nd Generation RLV Program Formulation Authorization document in February 2000. Both documents included the safety and affordability requirements/goals that the Agency subsequently approved in November 2001 as Level 1 requirements.
[21]The risk management database is a computerized repository used to warehouse, plan, track, and report program risks. All personnel associated with the Program have the responsibility and authority to identify risks. The risk originator develops the risk statement, risk context, and initial estimates for the likelihood, consequence, and timeframe of the risk.

The following table shows three validated[22] Program risks with a high-risk exposure.[23]

Safety and Affordability Risks With a High-Risk Exposure		
Risk Number[2]	**Risk Title**	**Risk Statement[1]**
1	Crew Escape Systems	Given the current state of the art in crew escape systems and the current reliability of main propulsion systems, the possibility exists that the Level 1 requirement of 1 in 10,000 loss of crew may not be met.
6	Lightweight, Low-Cost Composite Cryotanks[3]	Because the current state of the art for lightweight, low-cost cryotank composite materials is inadequate, the possibility exists that the Level 1 requirement of $1,000 per pound launch cost may not be met.
10	Power Systems	Given the current state of the art of power systems in the areas of fault tolerant power architecture, nontoxic power generation, advanced peak power source, energy storage, and distribution, the possibility exists that the Level 1 requirements of 1 in 10,000 loss of crew and cost goal of $1,000 per pound may not be met.

[1]The "Risk Information Sheet" includes a risk statement that explains the risk.
[2]A sequential risk number is assigned to each identified risk in the database.
[3]Cryotanks are fuel tanks capable of maintaining liquid oxygen and/or hydrogen at extremely low temperatures--at least 160 degrees below 0 degrees Celsius.

We recognize that establishing appropriate requirements will not eliminate all risks on a program. On the other hand, not ensuring the appropriateness and viability of requirements can significantly increase programmatic risks.

Programmatic Effects of Requirements

Invalid or unachievable Level 1 requirements can jeopardize development of appropriate lower-level requirements, cause an inappropriate architecture selection, lead to cost and schedule growth, and produce a launch vehicle that is not commercially viable.

Lower-Level Requirements. Level 1 requirements form the basis for more detailed requirements in program and project documents, which, in turn, provide a framework for management decisions and activities. NPG 7120.5A states that requirements management entails the decomposition of higher-level requirements into implementable packages and communication of the more specific requirements to the implementing projects that

[22]Validated risks are those that have been approved by the Program and project risk management boards.
[23]Risk exposure, the product of the likelihood and consequence of occurrence, is used to classify and prioritize risks for reporting and management purposes. The Program classifies the risk level as high, moderate, or low.

support the Program. Therefore, inappropriate Level 1 requirements can lead to inappropriate Levels 2 and 3 requirements in the Program's and projects' systems requirements documents.

Architecture Selection. The current Level 1 requirements reflect general launch needs that the 2nd Generation RLV is intended to satisfy. Level 1 requirements dictate the architectural design leading to full-scale development of the 2nd Generation RLV. The process of assessing the cost and performance trade-offs of the 2nd Generation RLV architecture will lead to a set of Level 2 system requirements that will further define the 2nd Generation RLV architecture requirements. If the current Level 1 requirements are inappropriate, any resulting architectural design also could be inappropriate.

Cost and Schedule. If the cost-per-pound (affordability) requirement of $1,000 is unrealistically low, because of the technology advances needed to reach such a requirement, it may not be achievable under the current cost and schedule constraints. Similarly, if the launch cost requirement is unnecessarily low compared to the projected market prices of competitive launchers over the next 2 decades, cost and schedule would be adversely affected again. In either case, additional funds and time would be required to meet requirements that are unrealistic or inappropriate.

Competitive Vehicle. Besides a manned version of the 2nd Generation RLV, the Program may develop an unmanned version. An unmanned vehicle would compete with expendable launch vehicles, which are becoming less costly. If the cost per pound of $1,000 is higher than the average cost per pound on commercial expendable launch vehicles, then the 2nd Generation RLV would not be competitive. Although NASA officials expected the current trend of reduced launch costs to continue, it is not clear how much launch costs for expendable launch vehicles will decrease in the next 2 decades when a 2nd Generation RLV may be operational. This uncertainty contributes to the difficulty in establishing an appropriate affordability requirement for the 2nd Generation RLV. Appendix E contains details on current and expected payload launch costs.

Conclusion

In view of the lack of analytical support for the baseline Level 1 requirements and the acknowledged concerns of cognizant officials, NASA's approval of the requirements was premature. Because of the questionable validity of the two primary Program requirements, safety and affordability, NASA should verify the appropriateness and achievability of the baseline Level 1 requirements and revise them, if necessary. We acknowledge that the Agency's plans for review may eventually lead to more refined requirements.[24] However, the requirements at any given time should be supportable.

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[24]On May 2, 2002, Program and Marshall officials approved Revision A to the baseline Level 1 requirements and submitted it to NASA Headquarters for final approval. The proposed revision would reduce the safety and affordability requirements, making them much more achievable.

Recommendations, Management's Response, and Evaluation of Response

1. **The Associate Administrator for Aerospace Technology, in coordination with the Marshall Center Director, should promptly perform analyses to support the validation or revision of the Level 1 requirements for the 2nd Generation RLV Program.**

Management's Response. Concur. The Office of Aerospace Technology approved proposed Level 1 Requirements prior to completion of detailed analyses needed to determine their validity and achievability. Management recognized there were deficiencies in the process for approving the initial Level 1 requirements and has instituted a more thorough validation process for the current iteration of the requirements, Revision A. The Program is performing further analyses of the Level 1 requirements. Additionally, the Agency identified the Executive Council as the requirements discrepancy resolution forum. These actions should be completed along with the planned completion of the SLI Systems Requirements Review in March 2003. The complete text of management's response is in Appendix F.

Evaluation of Management's Response. Management's planned actions are responsive to the intent of the recommendation. The recommendation is resolved but will remain undispositioned and open until agreed-to corrective actions are completed. Management's response included additional comments to the finding in the report. We address selected management comments in Appendix G.

2. **The NASA Chief Engineer should establish and include in Agency directives (NPG 7120.5A, Special Publication-6105, and the NPG on Systems Engineering currently under development) guidance that:**

   - **requires the approval authority to verify that proposed requirements are appropriate and reasonably achievable within available resources before approving the requirements,**
   - **specifies responsibility and requirements for preparing supporting documentation and for validating proposed requirements, and**
   - **requires Enterprises and Centers to establish appropriate implementing guidance and procedures.**

Management's Response. Concur. The Office of the Chief Engineer will attempt to incorporate the recommended guidance into the revision of NPG 7120.5 now being drafted. If unable to accomplish this, interim guidance will be issued not later than March 2003, pending publication of the next revision of the NPG (published in approximately October 2003).

Evaluation of Management's Response. Management's planned actions are responsive to the recommendation. Management stated during our discussions that more detailed, implementing guidance on requirements validation will be included in the new Systems Engineering NPG now being drafted and scheduled for publication in October 2003.

The recommendation is resolved but will remain undispositioned and open until corrective actions are completed.

Appendix A. Objectives, Scope, and Methodology

Objectives

The overall objective was to evaluate Space Launch Initiative (SLI) planning and management. Specifically, we planned to assess the adequacy of:

- requirements determination and program planning, including metrics for measuring and reporting progress;
- decision criteria for major milestones;
- program schedule and funding, including planned reserves; and
- plans for risk reduction and related metrics.

This report identifies a condition regarding requirements determination that warrants timely action by NASA management. Conditions relative to the other objectives may be addressed in a separate report as needed.

Scope and Methodology

The audit included a review of Government and Agency guidance for strategic planning and program management. We reviewed NASA and Enterprise Strategic Plans and SLI Program documents. In addition, we interviewed program officials to understand the objectives and current status of the program. 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 following management controls:

- Office of Management and Budget Circular A-11, "Preparation and Submission of Budget Estimates," revised November 11, 2001.

- NASA Procedures and Guidelines (NPG) 1000.2, "NASA Strategic Management Handbook," February 2000, enables the Agency to establish strategy, make decisions, allocate resources, and manage programs safely, effectively, and efficiently.

- NPG 7120.5A, "NASA Program and Project Management Processes and Requirements," April 3, 1998, governs formulation, approval, implementation, and evaluation of all NASA programs and projects.

- MSFC-HDBK-3173, "Project Management and System Engineering Handbook," May 30, 2001, provides the basic processes and general guidance for the life cycle of all programs and projects managed at Marshall Space Flight Center (Marshall).

We determined that management controls for determining primary requirements for programs and projects needed to be strengthened as discussed in the report.

Audit Field Work

We performed field work for this portion of the audit from July 2001 through June 2002 at NASA Headquarters and Marshall. We conducted the audit in accordance with generally accepted government auditing standards.

Appendix B. Summary of Prior Audit Coverage

The Office of Inspector General has issued four reports that relate to the audit work on the Space Launch Initiative. These reports are summarized below (see also www.hq.nasa.gov/office/oig/hq/issuedaudits.html).

IG-01-021, "X-37 Technology Demonstrator Project Management," March 30, 2001. The X-37 vehicle is an advanced technology flight demonstrator that NASA will use as a platform for flight experiments to validate and mature technologies that lower the cost and improve the performance of future Earth-to-orbit or in-space transportation systems. We found several weaknesses in NASA's project management and recommended that corrective actions be taken to address inadequate planning and funding for X-37 launch requirements, use of a tailored Earned Value Management System[25] by the contractor, and deficiencies in risk management by NASA officials. Management concurred and has initiated or completed corrective actions on all 13 recommendations.

IG-00-029, "X-34 Technology Demonstrator," March 30, 2000. The $200 million X-34 Project was one of several existing and planned technology demonstrator (X-Vehicle) programs the Agency pursued to mature technologies needed for the next-generation reusable launch vehicle. To evaluate NASA's planned use of X-34 technologies, we reviewed strategic planning and the role the X-34 was to play in meeting Agency Space Transportation technology requirements. We recommended that NASA improve strategic planning, complete program documentation in a timely manner, revalidate flight test requirements, and eliminate unnecessary flight tests or engines. Management concurred and has initiated or completed corrective actions on the 16 recommendations.

IG-99-052, "X-33 Cost Estimating Processes," September 24, 1999. NASA used a cooperative agreement with a commercial firm for Phase II of the X-33 program to design, build, and fly a test vehicle. NASA did not prepare an independent Government cost evaluation to assess cost reasonableness and cost risk for the program. Further, NASA did not include a risk analysis to quantify technical and schedule uncertainties. We recommended that NASA improve its evaluation processes to ensure that decisionmakers are provided complete and accurate information, that sufficient resources are available, and that the final price is fair and reasonable. Further, the X-33 Program's estimate to complete should be updated to reflect cost uncertainties and determine how remaining work will be funded. Management concurred with all four recommendations and has completed corrective actions on three recommendations.[26]

[25] NASA Policy Directive 9501.3, "Earned Value Performance Management," revised August 3, 2002, establishes the requirement to apply earned value performance management to significant NASA contracts to ensure that contractor management systems provide the contractor and the Government project managers with accurate data to make responsible decisions.
[26] Although NASA cancelled the X-33 and X-34 Programs and incorporated the X-37 Program into the 2nd Generation RLV Program (see footnotes 1 and 2), many recommendations in the related audit reports remain valid because they relate to systemic weaknesses rather than specific project weaknesses.

Appendix B

IG-99-001, "X-33 Funding Issues," November 3, 1998. We evaluated NASA's X-33 funding concept to determine whether it adversely affected Agency reports and financial statements and whether it complied with congressionally mandated fund controls including the Anti-deficiency Act. NASA did not record obligations of funds in a timely manner, resulting in potential violations of fiscal statute. The Marshall Space Flight Center (Marshall) had unrecorded year-end obligations, costs, and liabilities totaling $22 million in fiscal year 1996 and $34 million in fiscal year 1997. We recommended that NASA review the funding and payment practices used on the X-33 Program and perform corrective actions to ensure that Marshall and Agency year-end financial reports accurately disclose the financial status of the X-33 program, including any contingent liabilities. NASA concurred with the two recommendations but has not completed corrective actions.

Appendix C. Government Level 1 Requirements

NASA developed Level 1 requirements for the 2nd Generation Reusable Launch Vehicle from an understanding of NASA, DOD, and commercial mission needs, and from deficiencies in the existing fleet of launch vehicles. NASA published these requirements in the Level 1 requirements document, effective September 4, 2001. An excerpt of the document, Section 7.0, "Government Level 1 Requirements" follows:

> **[A10]** Comply with all applicable NASA, Department of Defense (DOD), and civil flight safety requirements as defined in [A11] through [A14] and in accordance with the Human Rating Requirements, JSC – 28354, as applicable.
>
> **[A11]** Assure public safety.
>
> **[A12]** Achieve a probability of loss of crew for the total flight profile of a mission.
> a. Threshold — must equal a probability of 1/10,000 or less.
> b. Objective— should equal a probability of 1/10,000 or less.
>
> **[A13]** Assure safety of personnel on the ground (transportation employees and customers).
>
> **[A14]** Assure safety of high value assets.
>
> **[A30]** Deliver payloads into a low-earth circular orbit, as described in the NASA Design Reference Missions document.
> a. Threshold — must provide a recurring operational cost of $1,000/pound or less.
> b. Objective — should provide a launch price of $1,000/pound or less.
>
> **[A40]** Achieve a probability of loss of mission throughout the design life of the 2nd Generation RLV [reusable launch vehicle] architecture.
> a. Threshold — must provide a probability of 1/100 or less.
> b. Objective — should provide a probability of 1/200 or less.
>
> [A50] Provide the capability of supporting the Government missions defined in section 6.0 above.
> a. Threshold — must provide the capability of performing all primary missions at IOC [initial operating capability].
> b. Objective — should provide the capability of performing secondary missions at IOC.
>
> **[A60]** Achieve a probability of launching a Government payload within its scheduled launch opportunity.
> a. Threshold — must exceed a 90-percent probability that a payload will be launched within its specified opportunity.
> b. Objective — should exceed a 95-percent probability that a payload will be launched within its specified opportunity.

[A70] Provide a growth path to support the Government secondary missions that cannot be supported initially.

[A80] Provide an evolutionary growth path that will enable the future commercial development of space.

[A90] Provide a viable growth path to support the Government evolutionary mission to enable the future human and robotic exploration of space by FY 2017.

[A100] Provide an evolutionary growth path to support future DOD launch needs.

Appendix D. Origin of Safety and Affordability Requirements

The Level 1 safety and affordability requirements for a 2nd Generation Reusable Launch Vehicle (RLV), approved in November 2001 by the NASA Office of Aerospace Technology, are essentially a restatement of the goals contained in the Agency and Enterprise Strategic Plans (see footnote 15), the requirements established for the Integrated Space Transportation Plan, and the major goals contained in the Program Formulation Authorization Document. Marshall Space Flight Center and NASA Headquarters officials had no documented support for the appropriateness and achievability of the goals/requirements contained in all of the documents above.

Agency Strategic Goals. Agency strategic goals for safety and affordability, characterized as "stretch" goals, were established by a former NASA Administrator based on a vision for safe and affordable access to space. NASA officials stated that the affordability goal (reducing the cost of access to space from $10,000 to $1,000 per pound to low-Earth orbit) was established in the mid-1990's by the NASA Administrator as a target. Officials maintained that the affordability goal was always recognized as an optimistic, "stretch" goal that might not be achievable in the near term. Similarly, officials stated that the Agency's safety goal (loss of crew of 1 in 10,000 missions) was established by the Administrator in 1999.

Integrated Space Transportation Plan Level 1 Requirements. In August 1999, the NASA Chief Engineer issued a Level 1 Requirements document for the 2nd Generation Space Transportation Architecture. The purpose of the document was to establish Level 1 requirements for the Integrated Space Transportation Plan and for conducting associated tasks for Phase III of the NASA Space Transportation Architecture Studies. This effort represented the initial step in requirements/systems definition, technology prioritization, and technology development for the Integrated Space Transportation Plan. The document included requirements for safety (loss of crew of 1 in 10,000 missions) and affordability (reduce the cost of payloads to low-Earth orbit from $10,000 to $1,000 per pound) that NASA officials stated were based primarily on the Space Transportation goals presented in the Agency and Enterprise Strategic Plans.

Program Formulation Authorization. The Associate Administrator for Aerospace Technology issued the 2nd Generation RLV Program Formulation Authorization document, February 10, 2000, to begin the formulation process. The formulation authorization document includes safety and affordability goals that are consistent with the Agency and Enterprise Strategic Plans.

Details of payload launch costs information omitted

Appendix F. Management's Response

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

September 26, 2002

Reply to Attn of: R

TO: W/Assistant Inspector General for Audits

FROM: R/Deputy Associate Administrator for Aerospace Technology (Space Transportation)

SUBJECT: Final Comments to Draft Audit Report (A-01-049-00) of the Space Launch Initiative (SLI)

The following letter provides the consolidated response from the Marshall Space Flight Center (MSFC), the SLI Program Office, and the NASA Chief Engineer's Office, and the Office of Aerospace Technology (OAT) to the subject draft audit report dated June 26th, 2002.

The Office of Aerospace Technology (OAT), the Office of Chief Engineer, MSFC and SLI Program Office concur with the recommended actions.

Specifically, the HQ Office of Chief Engineer will incorporate the recommended actions for

- requirements approval authority, to verify the proposed requirements are appropriate and achievable,
- requirements documentation and validation responsibility, and
- the establishment of implementing guidance and procedures

into the appropriate NASA Policy and Guidelines per their respective revision schedules.

The completion date of recommended action 2 is dependent upon other document revision factors. The Office of the Chief Engineer will attempt to incorporate recommended Agency guidance on requirements into the revision of NPG 7120.5 now being drafted. However, if we are unable to accomplish this, we will issue interim guidance not later than March 2003, pending publication of the next subsequent revision of the NPG, approximately October 2003.

OAT recognizes that requirements validation includes both supporting analysis and customer feedback. OAT approved proposed Level 1 Requirements prior to completion of detailed analyses needed to determine their validity and achievability. The Enterprise also concedes that, prior to the approval of Level 1 Requirements (L1Rs) in November

Appendix F

2001, the NASA Enterprises and associated Offices were not given the opportunity to formally respond to the proposed SLI L1Rs. The Space Transportation Office recognized this deficiency and instituted a more thorough validation process for the current iteration (revision A) of L1Rs. Additionally, in July 2002, the Agency identified the Executive Council as the requirements discrepancy resolution forum.

The report warns of potential pitfalls if the program proceeds into implementation without firm L1Rs. It is agreed that, for a development/acquisition program, analytically validated L1Rs are critical. The SLI program is unique in that it is a focused technology development effort, guided by top-level goals, whose charter is to develop L1Rs for a 2nd Generation RLV for the Agency prior to a decision to proceed with a full-scale development program. It is intended to be a discovery process and thus the requirements development is iterative in nature. In essence, the SLI program *is* the validation tool for the Agency for the space transportation requirements of a 2nd Generation RLV.

See Appendix G, OIG Comment 1

The OIG Draft report questions the analysis supporting the validity and achievability of the approved safety and affordability L1Rs. As discussed above, the SLI program was chartered to assist the Agency through its uncertainty regarding the requirements of a 2nd Generation RLV. An unfortunate side effect of this uncertainty was the hesitancy of private industry to fully participate in the formulation phase of the program. SLI industry partners were leery of investing resources toward this effort without a firm NASA commitment. Thus, detailed analysis to determine the validity and achievability of L1Rs could not be continued without an established NASA posture. It should be noted that the *value* of the safety and affordability requirements had little bearing at the time on the direction of effort of SLI or its industry partners. Basically, architecture designers and systems analysts in this early phase were simply focusing on *significantly* reducing the cost and increasing the reliability of a 2nd Generation RLV. Given the criticality to the Agency to have the best information available for its space transportation investment decisions, it was the decision of OAT that approving the first iteration of Level 1 Requirements presented little if any risk to the Agency.

See Appendix G, OIG Comment 2

See Appendix G, OIG Comment 3

OAT believes that the SLI program does not fit within a standard Agency program mold and that latitude should be afforded during this unique requirements definition phase. At no time has the program proceeded forward without the guidance of senior Agency officials or the close scrutiny of internal and external stakeholders. It is our intent through this process that SLI will enable the Agency to continue vetting and debating, with hard data, the true requirements of a 2nd Generation RLV.

See Appendix G, OIG Comment 1

Therefore, based on the discussion above and the results of the Space Transportation Architecture Studies, the NASA Research Announcement (NRA) 8-27 and analysis performed under contract from NRA 8-30, it is OAT's position that the level of analysis related to the validity and achievability of 2nd Generation RLV safety and affordability requirements was adequate to support the conditional approval of the L1R Document in November, 2001, as an initial starting point in developing final requirements.

See Appendix G, OIG Comment 2

Lastly, the OAT would like to clarify the rationale of the Enterprise rejection of the request to relax the payload cost requirement of $1000/lb to $2000/lb. The issue with this requirement is not the value as much as it is the metric itself. The OAT is concerned with the nebulous nature of this cost requirement because of the need to provide numerous qualifiers such as launch rate, payload type, target orbit, etc. Through the iterative requirements definition process discussed above, the Enterprise will continue to work with the SLI program to establish a clearly defined cost requirement for a 2nd Generation RLV.

See Appendix G, OIG Comment 4

The OIG draft report recommended corrective action 1 is currently being performed and will be completed by the end of the Systems Requirements Review. The expected completion date for this action is concurrent with the end of the SLI Systems Requirements Review activities that are currently scheduled to conclude in March 2003.

Please call me at (202) 358-4644 if you have any questions.

Dr. John R. Rogacki

Concurrence:

J. F. Creedon

cc:
HQ/AE/K. Hudkins
HQ/JM/M. Myles
HQ/Q/D. Moore
HQ/R/S. Humphries
JSC/W-JS/D. Coldren
KSC/W-KSC/C. Seger
MSFC/DA01/A. Stephenson
MSFC/DE01/A. Roth
MSFC/M-DI/J. Linville
MSFC/RS40/T. Danne
MSFC/UP01/D. Smith

Appendix G. Evaluation of Management's Comments

The Office of Aerospace Technology response (see Appendix F) included comments relative to the finding in the report. Our evaluation of those comments follows:

Management's Comments. Management agreed that analytically validated Level 1 Requirements are critical for development/acquisition programs. However, the SLI Program is a unique, focused technology development effort responsible for establishing Level 1 Requirements through an iterative process. The SLI Program does not fit within a standard Agency program mold and, therefore, latitude should be afforded during this unique requirements definition phase.

1. OIG Comments. Although we understand the circumstances that led to the approval of the initial Level 1 Requirements in November 2001, we maintain our position that such approval was premature in the absence of adequate supporting documentation and a thorough validation process. Further, the iterative nature of the requirements development process during program formulation is typical of Agency programs and is not unique to the 2nd Generation RLV Program. Therefore, we reemphasize that approval of each Level 1 Requirements iteration should be based on an adequate supporting documented analysis by the Program and projects. The documentation is essential in order for the requirements approving authority to perform an effective review and validation of proposed requirements.

Management's Comments. The audit report questions the lack of analysis supporting the validity and achievability of the approved requirements. It is the position of the Office of Aerospace Technology that the level of analysis performed by the Space Transportation Architecture Studies, and contractors under two NASA research announcements was adequate to support the conditional approval of the Level 1 Requirements in November 2001 as an initial starting point in developing final requirements. Further, contractors were leery of investing resources toward this effort without a firm NASA-level commitment.

2. OIG Comments. Our primary concern with the initially approved Program Level 1 Requirements was the lack of a credible supporting analysis for the safety and affordability requirements. The analysis identified by management does not provide sufficient support for validation and approval of the Level 1 requirements. Further, although responsible Agency officials acknowledged their concerns about the validity of the proposed requirements, neither their level of confidence nor the conditional nature of the Office of Aerospace Technology approval was evident in the requirements document. When such concerns exist, we believe requirements approval authorities should disclose their level of confidence in achieving the proposed requirements and state in the requirements document the conditional nature of their approval. Program and project managers may be reluctant to make such candid disclosures, but it is critically important to ensure that subsequent programmatic decisions are valid. Finally, the need to obtain contractor participation does not justify issuance of an unsupported requirements document.

Management's Comments. The focus in the early phase of the Program was simply to significantly reduce cost and increase reliability of a 2nd Gen RLV rather than to specify a level of improvement. Therefore, providing the best information available at the time presented little if no risk to the Agency.

3. OIG Comments. Because of the level of concern that existed both within and outside the Agency regarding the validity of the initial Program requirements, we do not consider the data used by NASA as the best information available. Program requirements such as safety and affordability are directed to projects and subsequently to contractors that make cost and schedule decisions based on these requirements. Further, approving unrealistic requirements without documentation to show they are reasonably achievable with existing resources can create false expectations by the Congress and by Agency stakeholders. Therefore, we believe the approval of unvalidated and unrealistic requirements creates significant programmatic and credibility risk to the Agency.

Management's Comments. Management decided not to relax the payload cost requirement of $1,000/lb. to $2,000/lb. in response to concerns by a senior Headquarters official. Management explained that the rationale for rejecting the request was not the value of the requirement as much as it was the nebulous nature of the metric itself that necessitates qualifiers such as launch rate, payload type, target orbit, etc.

4. OIG Comments. Based on subsequent discussions with Agency officials, we revised the wording in the audit report to reflect the management's clarification.

Appendix H. Report Distribution

National Aeronautics and Space Administration (NASA) Headquarters

HQ/A/Administrator
HQ/AE/Chief Engineer
HQ/AI/Associate Deputy Administrator
HQ/B/Acting Deputy Chief Financial Officer
HQ/B/Comptroller
HQ/BF/Director, Financial Management Division
HQ/G/General Counsel
HQ/J/Assistant Administrator for Management Systems
HQ/JM/Director, Management Assessment Division
HQ/L/Assistant Administrator for Legislative Affairs
HQ/R/Associate Administrator for Aerospace Technology

NASA Advisory Officials

Chair, NASA Advisory Council
Chair, Aeronautics and Space Transportation Technology Advisory Committee

NASA Centers

JSC/AA/Director, Johnson Space Center
KSC/AA/Director, Kennedy Space Center
KSC/CC/Chief Counsel, Kennedy Space Center
MSFC/DAO1/Director, Marshall Space Flight Center

Non-NASA Federal Organizations and Individuals

Assistant to the President for Science and Technology Policy
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

Senate Committee on Appropriations
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 Audits
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Report Title: Final Report on Audit of the Space Launch Initiative: Primary Requirements for a 2nd Generation Reusable Launch Vehicle

Report Number: ____________________ **Report Date:** __________________

Circle the appropriate rating for the following statements.

	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 finding(s) in a balanced and objective manner.	5	4	3	2	1	N/A

Overall, how would you rate the report?

- ☐ Excellent
- ☐ Very Good
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- ☐ Fair
- ☐ Poor

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)

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May we contact you about your comments?

Yes: ______ No: ______

Name: ____________________________

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Thank you for your cooperation in completing this survey.

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