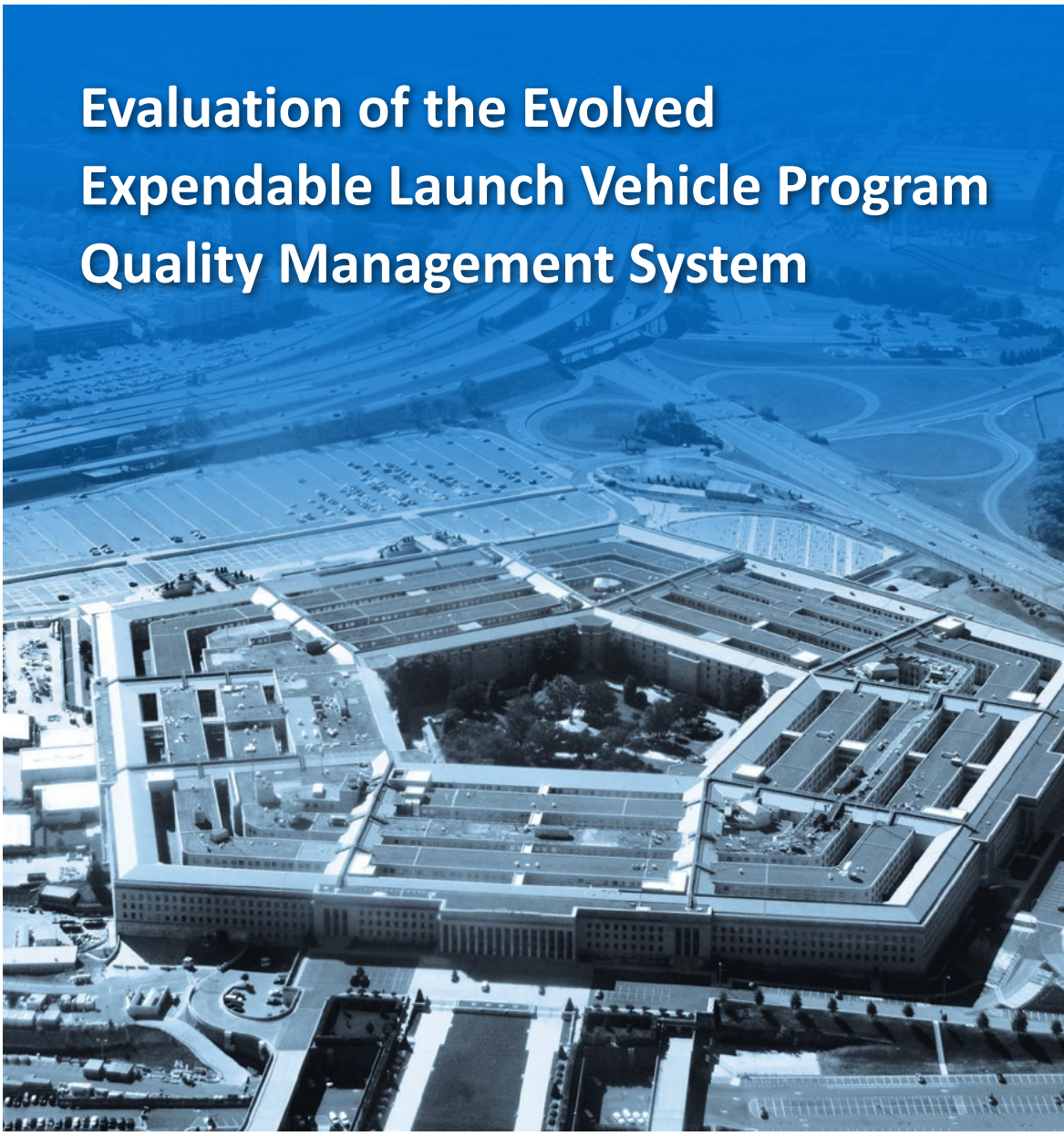
Report No. DODIG-2018-045

INSPECTOR GENERAL

U.S. Department of Defense

DECEMBER 20, 2017

Evaluation of the Evolved Expendable Launch Vehicle Program Quality Management System



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Results in Brief

Evaluation of the Evolved Expendable Launch Vehicle Program Quality Management System

December 20, 2017

Objective

We determined whether the DoD Evolved Expendable Launch Vehicle (EELV) prime contractors, United Launch Alliance (ULA) and Space Exploration Technologies (SpaceX), and the ULA major subcontractor, Aerojet Rocketdyne (AR), performed adequate quality assurance management for the EELV program. Specifically, we evaluated EELV contractors' compliance with the contractually required Aerospace Standard (AS) 9100C, "Quality Management Systems – Requirements for Aviation, Space, and Defense Organizations."

Background

The DoD created the EELV program in response to the National Defense Authorization Act for Fiscal Year 1994, which directed the Secretary of Defense to develop and submit to Congress a plan for the "modernization of space launch capabilities for the DoD or, if appropriate, for the Government as a whole." The EELV System Program Office (SPO) acquires launch services for U.S. military and intelligence spacecraft from ULA and SpaceX. AR provides ULA the RL-10 engine for use on the Delta IV and Atlas V. The EELV SPO delegates day-to-day contract and quality assurance management to the Defense Contract Management Agency (DCMA) through a memorandum of agreement (MOA).

Finding

We found that ULA, SpaceX, and AR did not perform adequate quality assurance management of the EELV program, as evidenced by the 181 nonconformities to

Finding (cont'd)

the AS9100C at the EELV contractor production facilities. For example, we found that ULA, SpaceX, and AR failed to comply with AS9100C, section 7.5.5, Preservation of Product.

At ULA, we found nonconformities related to Electrostatic Sensitive Device (ESD) protection in the avionics production area. We found ungrounded ESD workstations, untested wrist straps, missing ESD protective covers, non-ESD-approved containers and materials, and uncontrolled humidity levels. Inadequate ESD controls and mitigation could result in the premature failure of electronic components in the EELV system.

At SpaceX, we found an inadequately protected Merlin engine on the test stand. The Merlin engine exhaust ports and vent tubes should have been protected with specific covers. Furthermore, we found bottles of soda and personal items in FOD-controlled areas.

At AR, we found that the RL-10 engine test stand, used to test both the Delta IV and Atlas V second stage engine, had significant FOD issues, including loose bolts, nuts, tape, foil, tie wraps, and animal feces. Inadequate control of FOD significantly increases the risk of damage to EELV hardware, which can lead to costly rework and schedule impact.

ULA's, SpaceX's, and AR's inadequate quality assurance management could increase program costs, delay launch schedules, and increase the risk of mission failure.

Recommendations

We recommend that the Director, EELV SPO, and the Director, DCMA, conduct a root cause analysis and implement corrective actions for the 181 nonconformities identified during our evaluation and provide the DoD Office of Inspector General a copy of the root cause analysis and corrective action plan within 90 days of the issuance of this report.

Additionally, we recommend that the Director, EELV SPO, and the Director, DCMA, develop a corrective action plan to improve EELV quality assurance management to ensure

Recommendations (cont'd)

that the EELV contractors comply with all AS9100C requirements and provide the DoD Office of Inspector General a copy of the corrective action plan within 90 days of the issuance of this report.

Management Comments and Our Response

The Launch Enterprise (EELV SPO) Director agreed and the DCMA Director partially agreed with the recommendation to complete root cause analysis and corrective actions. The DCMA Director stated that minor nonconformities do not warrant formal root cause analyses and corrective action. However, both directors stated that the EELV SPO and the DCMA are actively working together with the EELV contractors as they conduct root cause analyses and develop corrective action plans. The EELV SPO and the DCMA stated that they will submit the root cause analyses and corrective action plans for the nonconformities within 90 days of issuance of the final report.

We do not agree with the DCMA Director's statement that minor nonconformities do not warrant formal root cause analyses and corrective actions. AS9100C states that "the organization shall take action to eliminate the causes of nonconformities in order to prevent recurrence."

We request that the Director, DCMA, provide additional comments in response to the final report that address performing root cause analyses and implementing corrective actions for all nonconformities. Therefore, this recommendation is unresolved and remains open. We will close this recommendation after we verify that the DCMA has performed root cause analyses and implemented corrective action plans for all nonconformities identified during our evaluation.

Comments from both the EELV SPO Director and the DCMA Director addressed all specifics of the recommendation regarding the development of a corrective action plan to improve EELV quality assurance management, and no additional comments are required. The EELV SPO and the DCMA stated that they will submit the overall corrective action plan to improve EELV quality assurance management within 90 days of issuance of the final report. Therefore, this recommendation is resolved but will remain open until we receive and evaluate a copy of the corrective action plan to improve EELV quality assurance management.

Please see the Recommendations Table on the following page.

Recommendations Table

Management	Recommendations Unresolved	Recommendations Resolved	Recommendations Closed
Director, Evolved Expendable Launch Vehicle, System Program Office	None	1 and 2	None
Director, Defense Contract Management Agency	1	2	None

Please provide Management Comments by January 5, 2018.

Note: The following categories are used to describe agency management's comments to individual recommendations.

- **Unresolved** – Management has not agreed to implement the recommendation or has not proposed actions that will address the recommendation.
- **Resolved** – Management agreed to implement the recommendation or has proposed actions that will address the underlying finding that generated the recommendation.
- **Closed** – OIG verified that the agreed upon corrective actions were implemented.


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December 20, 2017

MEMORANDUM FOR DIRECTOR, EVOLVED EXPENDABLE LAUNCH VEHICLE
SYSTEMS PROGRAM OFFICE
DIRECTOR, DEFENSE CONTRACT MANAGEMENT AGENCY

SUBJECT: Evaluation of the Evolved Expendable Launch Vehicle Program Quality Management System (Report No. DODIG-2018-045)

We are providing this report for review and comment. The Evolved Expendable Launch Vehicle (EELV) prime contractors, United Launch Alliance (ULA) and Space Exploration Technologies, and the ULA subcontractor, Aerojet Rocketdyne did not perform adequate quality assurance management of the EELV program as evidenced by the 181 nonconformities of the contractually required Aerospace Standard 9100C, "Quality Management Systems – Requirements for Aviation, Space, and Defense Organizations." This inadequate quality assurance management could increase program costs, delay launch schedules, and increase the risk of mission failure. We conducted this evaluation in accordance with the "Quality Standards for Inspection and Evaluation," published in 2012 by the Council of the Inspectors General on Integrity and Efficiency.

We considered management comments on a draft of this report when preparing the final report. Comments from the Director, Launch Enterprise, indicated concurrence with both recommendations. Comments from the Director, Defense Contract Management Agency, indicated partial concurrence with Recommendation 1 and concurrence with Recommendation 2. DoD Instruction 7650.03 requires that recommendations be resolved promptly. Therefore, we request the Director, Defense Contract Management Agency provide additional comments on Recommendation 1 by January 5, 2018. Please send a PDF file containing your comments to po-tad@dodig.mil. Copies of your comments must have the actual signature of the authorizing official for your organization. We cannot accept the /Signed/ symbol in place of the actual signature. If you arrange to send classified comments electronically, you must send them over the SECRET Internet Protocol Router Network (SIPRNET).

We appreciate the courtesies extended to the staff. [redacted]

Randolph R. Stone
Deputy Inspector General
Policy and Oversight

cc:
COMMANDER, SPACE AND MISSILE SYSTEMS CENTER
AUDITOR GENERAL OF THE AIR FORCE
INSPECTOR GENERAL OF THE AIR FORCE

Contents

Introduction

Objective

We determined whether the DoD Evolved Expendable Launch Vehicle (EELV) prime contractors, United Launch Alliance (ULA) and Space Exploration Technologies (SpaceX), and the ULA major subcontractor, Aerojet Rocketdyne (AR) performed adequate quality assurance management for the EELV program. Specifically, we evaluated EELV prime contractor compliance with the contractually required Aerospace Standard (AS) 9100C, "Quality Management Systems – Requirements for Aviation, Space, and Defense Organizations."

Background

The DoD created the EELV program in response to the National Defense Authorization Act for Fiscal Year 1994, which directed the Secretary of Defense to develop and submit to Congress a plan for the "modernization of space launch capabilities for the DoD or, if appropriate, for the Government as a whole." The EELV System Program Office (SPO) acquires launch services for U.S. military and intelligence spacecraft from ULA and SpaceX. AR provides ULA the RL-10 engine for use on the Delta IV and Atlas V. The EELV SPO delegates day-to-day contract management to the Defense Contract Management Agency (DCMA) through a memorandum of agreement (MOA).

EELV Contractors

The EELV program is composed of three launch vehicles designed and manufactured by two prime contractors, ULA and SpaceX. All three launch vehicles are available in various configurations and can be launched from either eastern or western launch sites.

ULA

Delta IV

The Delta IV launch vehicle is available in multiple configurations, tailored to suit specific payload size, weight, and orbit requirements. ULA manufactures and tests the Delta IV in Decatur, Alabama. AR, a subcontractor of ULA, manufactures and tests the Delta IV second stage RL-10 engine in West Palm Beach, Florida.

Atlas V

The Atlas V launch vehicle is available in multiple configurations, tailored to suit specific payload size, weight, and orbit requirements. ULA manufactures the Atlas V in Decatur, Alabama. AR manufactures and tests the Atlas V second stage RL-10 engine in West Palm Beach, Florida.

SpaceX

Falcon 9

The Falcon 9 launch vehicle and its Merlin main engines can be tailored to suit specific payload size, weight, and orbit requirements. SpaceX manufactures the Falcon 9 and its Merlin main engines in Hawthorne, California. Engine testing is performed in McGregor, Texas.

EELV Quality Management System Evaluation Criteria

AS9100C and AS9101D

AS9100C is the aerospace and Defense industry quality standard used during the design, manufacture, and test of DoD weapon systems. Safety, airworthiness, product conformity, and reliability are key outcomes of AS9100C compliance. AS9100C accounts for the complexity and diversity of the industry's supply chain and takes into consideration the complete life cycle of aerospace products. It is based on International Organization for Standardization (ISO) 9001 with nearly 100 additional quality assurance requirements specific to aerospace and Defense products.[1] Consequently, AS9100C is contractually required for the EELV program.

AS9100C is divided into five requirement sections:

- Quality Management System (QMS) – The organization shall establish, document, implement, and maintain a QMS and continually improve its effectiveness;
- Management Responsibility – Top management shall provide evidence of its commitment to the development and implementation of the QMS and continually improve its effectiveness;
- Resource Management – The organization shall determine and provide the resources as needed to implement and maintain the QMS, continually improve its effectiveness, and to enhance customer satisfaction by meeting customer requirements;

[1] ISO 9001 is the international standard that specifies requirements for a quality management system (QMS). Organizations use the standard to demonstrate the ability to consistently provide products and services that meet customer and regulatory requirements.

- Product Realization – The organization shall plan and develop the processes needed for product realization, consistent with requirements of other processes; and
- Measurement, Analysis, and Improvement – The organization shall plan and implement the monitoring, measurement, analysis, and improvement processes needed to demonstrate conformity to requirements, ensure conformity of the QMS, and continually improve the QMS.

AS9101D, "Quality Management Systems Audit Requirements for Aviation, Space, and Defense Organizations," details the requirement for conducting an AS9100C audit and includes the definition of a major and minor nonconformity.

As defined by the AS9101D, a major nonconformity is a nonfulfillment of a requirement that is likely to result in the failure of the quality management system or reduce its ability to ensure controlled processes or compliant products or services or both. A minor nonconformity is a nonfulfillment of a requirement that is not likely to result in the failure of the quality management system or reduce its ability to ensure controlled processes or compliant products or services.

AS9100C often refers to "processes" and "products." For this report, the "process" is the system of interrelated activities required to deliver the launch service, and the "product" is the EELV launch vehicles built and used to support National Security Space launches.

Quality Management System Evaluation

To evaluate the EELV quality assurance program, we performed a series of quality assurance evaluations of both EELV prime contractors ULA and SpaceX, and one ULA major subcontractor, AR. We evaluated the EELV contractors' policies and procedures for compliance with the AS9100C standard as follows:

- ULA Delta IV and Atlas V manufacturing, Decatur, Alabama, and ULA System Engineering and Program Management, Denver, Colorado;
- SpaceX Falcon 9 manufacturing, Hawthorne, California, and Falcon 9 booster and engine testing, McGregor, Texas; and
- AR Atlas V and Delta IV RL-10 engine manufacturing and test, West Palm Beach, Florida.

At each EELV contractor location, our evaluation team consisted of engineering and subject matter experts certified in the AS9100C standard. We documented all nonconformities to AS9100C on DoD Office Inspector General (OIG)-generated nonconformance forms. We shared these forms promptly with the SPO and EELV contractors, and they had an opportunity to provide feedback. At the conclusion of each evaluation, we provided the EELV SPO and contractor representatives with an exit briefing summarizing the AS9100C evaluation results.

Finding

The EELV SPO and the DCMA Need to Improve Quality Assurance Management of the EELV Contractors

We found that the DoD EELV prime contractors, ULA and Space X, and the ULA subcontractor, AR, did not perform adequate quality assurance management of the EELV as evidenced by the 181 nonconformities to the AS 9100C, "Quality Management Systems – Requirements for Aviation, Space, and Defense Organizations," at the EELV contractor production facilities. Inadequate quality assurance management could increase costs, delay launch schedules, and increase the risk of mission failure.

Discussion

AS9100C was created for the aerospace and Defense industry with safety, airworthiness, product conformity, and reliability as key outcomes. It accounts for the complexity and diversity of the aerospace and Defense industry's supply chain. The standard takes into consideration the complete life cycle of aerospace products and is based on ISO 9001 with nearly 100 additional quality assurance requirements specific to aerospace and defense products.

Adherence to a robust quality management system is a cornerstone of mission success for space launch vehicles. Consequently, AS 9100C is a contractual requirement for the EELV program. The EELV SPO is responsible for acquisition and mission success for all EELV missions. The EELV SPO entered into an MOA with the DCMA to conduct contract oversight of EELV prime contractors, ULA and SpaceX, and of one ULA major subcontractor, AR. The MOA states that it is the DCMA's responsibility "to ensure contractor compliance with contractual quality assurance requirements."

Results of the AS9100C Evaluation

We evaluated the EELV quality assurance program by verifying the EELV contractors' compliance with the AS9100C quality management standard. These evaluations identified 181 nonconformities to the AS9100C standard. To reduce duplication, we documented multiple nonconformities of the same AS9100C requirement on a single nonconformance form.

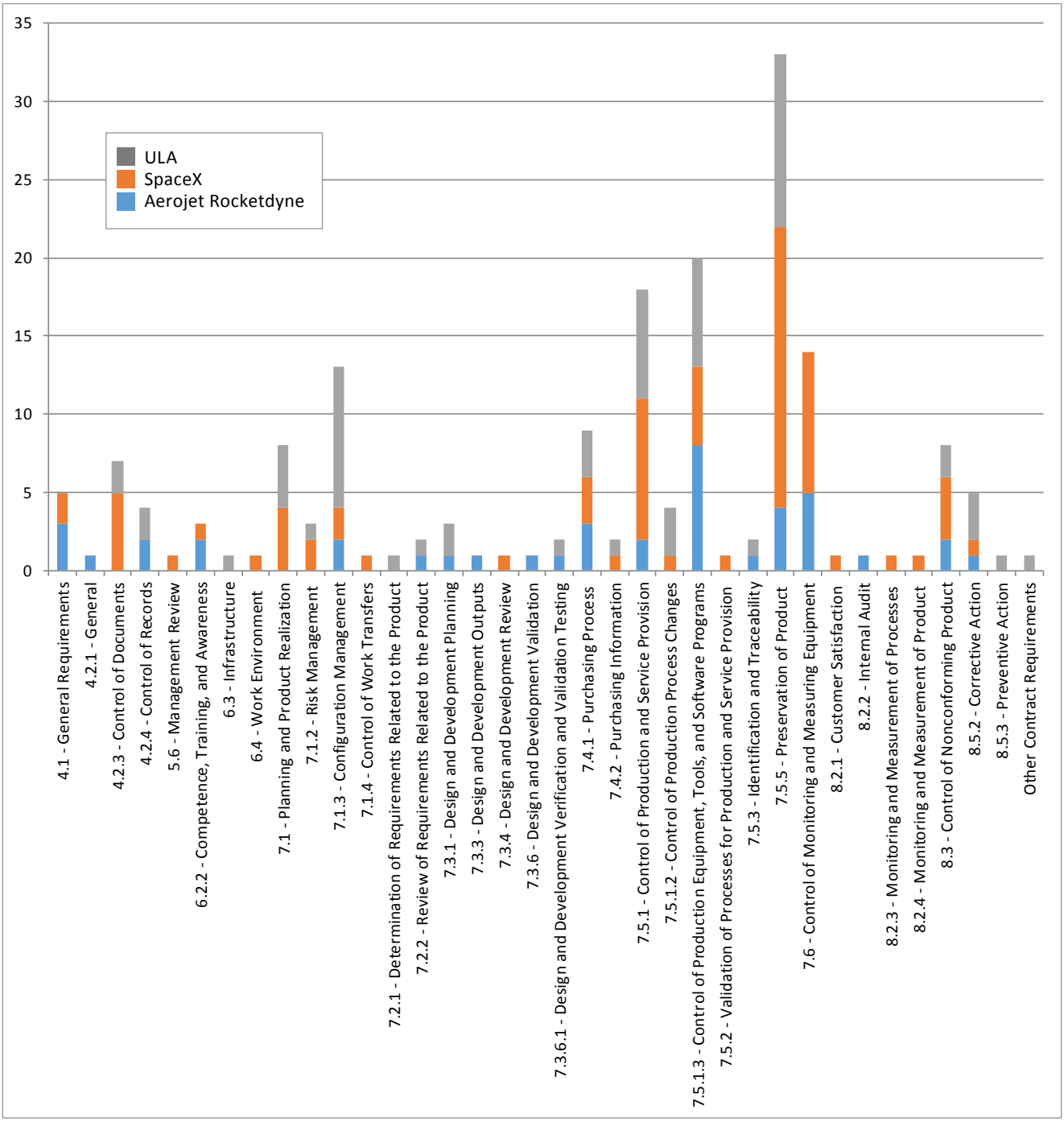
In accordance with the AS9101D's definitions of nonconformities, we classified 68 nonconformities as "major" and 113 as "minor." The table shows the breakdown of major and minor nonconformities for the EELV contractors.

Table. Major and Minor Nonconformities by Contractor

EELV Contractor	Major	Minor
ULA	21	43
SpaceX	33	42
Aerojet Rocketdyne	14	28
Total	**68**	**113**

The figure below depicts the number of nonconformities by category for each AS9100C requirement for the EELV contractors.

Figure. AS9100C Nonconformities by Category



Source: Compilation of Nonconformities from the Contractor Evaluations.

EELV AS9100C Major Nonconformities

As previously stated, AS9101D defines a major nonconformity as a nonfulfillment of a requirement that is likely to result in the failure of the quality management system or reduce its ability to ensure controlled processes or compliant products or services or both. These types of nonconformities likely will adversely affect EELV program cost, schedule, and mission success. Conversely, a minor nonconformity is a nonfulfillment of a requirement that is not likely to result in the failure of the quality management system or reduce its ability to ensure controlled processes or compliant products or services.

We submitted the major and minor AS9100C nonconformities to the EELV SPO for root cause and corrective action; however, this report discusses only major nonconformities, because a major nonconformity is likely to adversely affect EELV program cost, schedule, and mission success. The following sections describe, by AS9100C requirement category, examples of EELV major nonconformities identified during our evaluation.

Planning of Product Realization (7.1)

ULA did not comply with AS9100C, section 7.1, which requires it "to plan and develop the processes needed for product realization." Specifically, ULA's inertial navigation control unit, which is part of the guidance, navigation, and control system of the Atlas V launch vehicle, used reliability predictions based on commercial aircraft applications. These predictions do not account for the difference between commercial aircraft and space launch environments. Not adjusting the prediction calculation could cause inaccurate operation of the launch vehicle guidance system, thus effecting the trajectory and orbit of the EELV.

We also found that SpaceX failed to comply with AS9100C, section 7.1. SpaceX did not develop a software development plan, a software configuration management plan, or a software quality control plan for any Ground Support Equipment (GSE) software located at the McGregor, Texas, test facility. These software plans should detail how the EELV contractor develops and tests the software that operates the GSE that interfaces with flight hardware. Without these plans, software may be inadequately designed, tested, and introduced into the EELV test equipment. If the GSE software does not operate in a controlled and predicable manner, it may cause damage to the flight systems the GSE is testing.

Risk Management (7.1.2)

ULA failed to comply with AS9100C, section 7.1.2, which requires it to "establish, implement, and maintain a process for managing risk." Risk is an undesirable situation or circumstance that has both a likelihood of occurring and a potentially negative consequence. Risk Management is a process for managing risks. ULA tracks risk in a database called Risk, Issue, and Opportunity (RIO).[2] Our evaluation of the RIO database showed that 11 out of 26 risks related to either Atlas V or Delta IV launch vehicle were in "red" status, which indicates that risk mitigation was behind schedule. For example, the ULA risk identification number 2417 dated November 15, 2011, regarding the Electromechanical Actuator Thrust Vector Control (EMA TVC) states the system is not mature enough to proceed with system design. The EMA TVC is used to control the position of and to steer the rocket's engine. The EMA TVC risk was coded "red" because the risk should have been mitigated and closed no later than October 9, 2015. The EMA TVC risk was still open at the time of our evaluation. Failure to mitigate risk in a timely manner can lead to more costly and complex rework that cannot be implemented without major disassembly or reduction in performance of the EELV.

Configuration Management (7.1.3)

SpaceX failed to comply with AS9100C, section 7.1.3, which requires it to "establish, implement, and maintain a configuration management process." Configuration management is a controlled process to establish the baseline configuration of a product and any changes to that product. This process should occur during the entire life cycle of a product to provide visibility and control of its physical, functional, and performance attributes.

As part of the configuration management process, new or significantly changed aerospace products require a Physical Configuration Audit (PCA) and a Functional Configuration Audit (FCA). A PCA is a process to verify that the initial product conforms to the required physical specifications before additional product is manufactured. An FCA is a process to verify that the initial product meets specific functional, or performance requirements before additional product is manufactured.

SpaceX was not able to provide a documented process for PCAs or FCAs. Without a documented PCA and FCA process, there is a risk that the physical specification or performance of the initial product does not meet the required specifications. This can lead to nonconformities of all subsequently manufactured products and require rework of EELV procured Falcon 9 launch vehicles.

[2] The RIO database is used to track risk, issues, and opportunities for improvement.

Customer-Related Processes 7.2

Review of Requirements Related to the Product 7.2.2

AR failed to comply with AS9100C, section 7.2.2, which requires that, "[t]he organization shall review the requirements related to the product." We found that AR did not submit ULA contractually required data for the RL-10 engine. Specifically, AR did not provide ULA one contract deliverable (Shelf Life Control Plan). Furthermore, AR could not provide evidence that this critical program plan existed.

Critical program plans are necessary to ensure that the RL-10 engine specifications meet EELV system performance requirements. Not submitting critical program plans could increase the risk that engines do not meet EELV reliability requirements, which could have an adverse effect on EELV mission performance.

Design and Development (7.3)

Design and Development Review (7.3.4)

SpaceX failed to comply with AS9100C, section 7.3.4, which requires that "systematic reviews of design and development shall be performed in accordance with planned arrangements."

We found that SpaceX critical design review (CDR) records lacked engineering authorizations and approvals. A CDR is the final engineering review before production begins. Although the launch vehicle was in production, SpaceX could not provide evidence of engineering approval for the CDRs of the Merlin 1D vacuum engine and vacuum nozzle extension. We also found that the CDR for the "oxygen/nitrox relief panel" was approved on the contingency that CDR action items be resolved in parallel with the proceeding development. However, SpaceX could not provide evidence that it tracked or resolved these CDR action items. The lack of approval for CDRs increases the risk that an unapproved Falcon 9 design progresses into the production phase, and will ultimately lead to costly rework of the Falcon 9, or reduced Falcon 9 mission performance.

Purchasing (7.4)

Purchasing Process (7.4.1)

SpaceX failed to comply with AS9100C, section 7.4.1, which requires the organization to "evaluate and select suppliers based on their ability to supply product in accordance with the organization's requirements. Criteria for selection, evaluation, and re-evaluation shall be established." We found that SpaceX purchased equipment calibration services from a supplier that was not on the

SpaceX approved supplier list. The SpaceX purchasing and supplier management process audits and certifies that suppliers meet required SpaceX standards. SpaceX certifies the suppliers then adds them to the approved supplier list.

The purchase of products or services from an unapproved supplier could result in substandard products or services being incorporated into the EELV and effect mission reliability or performance. Specifically, the use of an unapproved equipment calibration service supplier introduces a risk that SpaceX test and measurement equipment may not meet EELV accuracy requirements. Properly calibrated measurement and test equipment is critical to ensure that accurate measurements are taken and tolerances are maintained during the manufacturing and test of the EELV.

Production and Service Provision (7.5)

Control of Production and Service Provision (7.5.1)

AR failed to comply with AS9100C, section 7.5.1, which requires it to "plan and carry out production and service provisions under controlled conditions" and requires "monitoring and control of utilities and supplies." Materials such as glues, sealants, and bonding agents that are used in the production of the EELV are considered flight hardware. These materials must be periodically tested to ensure that the products material characteristics (such as strength, density, conductivity) have not changed or deteriorated due to time or storage conditions. We found limited-life materials that were expired, not tracked, not labeled properly, or had no expiration dates.

We also found hazardous materials on the production line and in storage areas that were not labeled for identification and tracking purposes. Hazardous material that is not labeled is a health and safety concern to personnel working on the EELV production line. Furthermore, inadequate control of production and service provisions, such as the use of expired or uncontrolled limited-life material, may result in products that do not meet specifications. The production of nonconforming EELV products may require costly rework or, if the nonconformance is left uncorrected, may impact mission performance.

Control of Production Process Changes (7.5.1.2)

SpaceX failed to comply with AS9100C, section 7.5.1.2, which requires it to "control and document changes affecting processes, production equipment, tools, or software programs." We observed SpaceX technicians performing leak check steps on a Merlin engine turbo pump that were not in the work instructions. Leak checks ensure there is no fluid leaking from any part of the system, but should be accomplished exactly as written in a work instruction. We also

observed SpaceX technicians using tools and GSE with part numbers that were different from those specified in the work instructions. The technicians explained that the work instructions had not been updated to include the most recent requirements. SpaceX's failure to update work instructions caused the technicians to deviate from approved procedures. This could result in leak checks that do not accomplish the intent of the tests or leak checks that may damage flight systems. All work instructions should be up to date with engineering approval to reflect current practices.

Preservation of Product (7.5.5)

ULA, SpaceX, and AR failed to comply with AS9100C, section 7.5.5, which requires them to:

> preserve the product during internal processing and delivery to the intended destination in order to maintain conformity to requirements. As applicable, preservation shall include identification, handling, packaging, storage and protection. Preservation shall include . . . cleaning, prevention, detection and removal of foreign objects, special handling for sensitive products, marking and labeling including safety warnings, shelf life control and stock rotation, and special handling for hazardous materials.

At ULA, we found nonconformities related to Electrostatic Sensitive Device (ESD) protection in the avionics production area.[3] We found ungrounded ESD workstations, untested wrist straps, missing ESD protective covers, non-ESD-approved containers and materials, and uncontrolled humidity levels.[4] All of these conditions could lead to electrostatic discharge and subsequent damage to the EELV avionics. We found Foreign Object Debris (FOD), including cut-tie wraps, loose bolts, and tools. In the wire harness assembly area, ULA technicians were observed violating hardware contamination protocol by working using the wrong type of gloves.

At SpaceX, we found an inadequately protected Merlin engine on the test stand. The Merlin engine exhaust ports and vent tubes should have been protected with specific protective covers. However, we found several ventilation ports either unprotected or covered with strips of metallic tape. Furthermore, we found bottles of soda and personal items in FOD-controlled areas. We also found inaccurate tool control logs and toolboxes with undocumented and broken tools, and toolboxes missing required tools.

[3] ESD is the uncontrolled flow of electricity between two electrically charged objects caused by contact, an electrical short, or dielectric breakdown. This uncontrolled electrical discharge can cause permanent damage and malfunction in sensitive computer and electronic components.

[4] ESD wrist straps and smocks are used to prevent damage to ESD-sensitive hardware. They are required to be tested periodically to ensure that the proper static resistance is maintained.

In the SpaceX tubing production area, we observed SpaceX technicians performing a machining operation on a tube without inspecting the tube for FOD prior to installing it on flight hardware.

At AR, we found that the RL-10 engine test stand, used to test both the Delta IV and Atlas V RL-10 engines, had significant FOD issues, including loose bolts, nuts, tape, foil, tie wraps, and animal feces. In the production areas, tools were misplaced, were not signed out, and were not stored in their designated locations. Further, there were toolbox inventory logs that had not been updated to reflect the current toolbox inventory.

At all EELV contractor locations, we found numerous failures to preserve product. Inadequate ESD controls and mitigation could result in the premature failure of electronic components in the EELV system. Improper storage of product increases the risk of damage to flight hardware requiring costly rework. Inadequate control of FOD and tools significantly increases the risk of damage to EELV hardware, which can lead to costly rework and schedule impact.

Control of Monitoring and Measuring Equipment (7.6)

SpaceX failed to comply with AS9100C, section 7.6, which requires it to "determine monitoring and measurement to be undertaken and the monitoring and measuring equipment needed to provide evidence of conformity of product to determine requirements." It also requires "that environmental conditions are suitable for the calibration, inspection, measurement and testing being carried out."

We found that during tool calibration procedures, SpaceX technicians did not take into account environmental temperature of the calibration lab nor did they document temperature effects on the calibration results of measurement and test equipment. Accounting for temperature effects during calibration procedures is critical, because precision tools and fixtures change dimensions with temperature change. In addition, SpaceX did not specify calibration intervals for production tooling and fixtures that were used to verify that EELV products meet engineering requirements. Production tools and test equipment require calibration at appropriate intervals to ensure the accuracy of their measurements.

We also found that SpaceX did not always record calibration measurements and data generated during the calibration of inspection and test equipment. Recording calibration data is important to determine proper calibration intervals and to ensure that the previous measurements of the tool and test equipment were still within tolerance. If the calibration of the tool and test equipment is out of specification, then an audit must be conducted to determine which EELV component the tools or test equipment were used on. The EELV component would then need to

be inspected or tested to ensure the out-of-calibration tools or test equipment did not damage the launch vehicle. Furthermore, we identified 352 tools, measurement and test equipment items, with expired calibrations at the SpaceX McGregor facility. Although the calibration was expired and the calibration lab recalled the equipment, the equipment had not been returned to the lab and therefore may have been available for use on EELV systems.

Calibration of tools and test equipment is critical to ensure EELV products perform as intended. Specifically, the use of expired tools or expired measurement and test equipment during production of the EELV adds risk that required specifications may be inaccurate. Furthermore, EELV product acceptance may be based on inaccurate data, resulting in a non-conforming product.

Monitoring and Measurement (8.2)

Monitoring and Measurement of Product (8.2.4)

SpaceX failed to comply with AS9100C, section 8.2.4, which requires it to "monitor and measure the characteristics of the product to verify that product requirements have been met." In addition, AS9100C requires that "measurement requirements for product acceptance shall be documented and shall include criteria for acceptance and/or rejection."[5]

We found the borescope inspection criteria for product acceptance of the Composite Overwrapped Pressure Vessel (COPV) liner was not well defined regarding defect characteristics.[6, 7] The inspection procedure was outdated due to a change in the process, and contained photographs that were unusable for their intended purpose of determining defect size. This lack of clear product acceptance criteria resulted in more than 100 COPV units being identified as nonconforming and pending disposition. Without clear inspection criteria, the product may not meet required specifications.

[5] The acceptance evaluation process is the evaluation of an item's quality by comparing the results of measuring one or several product characteristics against specifications.

[6] An instrument used to inspect the inside of a structure through a small hole.

[7] A COPV is a vessel consisting of a thin, nonstructural liner wrapped with a structural fiber composite, designed to hold a fluid under pressure.

Control of Nonconforming Product (8.3)

ULA and AR failed to comply with AS9100C, section 8.3, which requires them to "ensure that product which does not conform to product requirements are identified and controlled to prevent its unintended use or delivery."

At ULA, we found 18 expired limited-life material items that were between 32 and 992 days past their expiration dates, but available for use on EELV flight hardware. This material should have been impounded and dispositioned. The use of expired limited-life items, such as glues and bonding agents, could result in product that does not meet specifications and may require costly rework.

At AR, we found an RL-10 engine test nonconformity that was not processed through the Material Review Board (MRB). The MRB is a process that determines appropriate disposition for hardware that contains a nonconformity. The MRB ultimately decides whether to: dispose of the nonconforming hardware, send the nonconforming hardware back to the production line to be reworked to appropriate standards, or accept the risk of the nonconforming hardware and approve its "use as is." The MRB also ensures that appropriate corrective actions are taken to prevent a reoccurrence of the nonconformity.

By bypassing the MRB, a proper engineering disposition and a root cause and corrective action analysis was not performed. Furthermore, since all nonconformities require MRB prime contractor approval, ULA would not have been notified of the nonconformity and any impact to EELV system performance would not have been addressed.

Conclusion

We determined that ULA, SpaceX, and AR were not performing adequate quality assurance management for the EELV program as evidenced by the 181 nonconformities to the AS9100C at the EELV contractor production facilities. This inadequate quality assurance management could increase costs, delay launch schedules, and increase the risk of mission failure.

Recommendations, Management Comments, and Our Response

Recommendation 1

We recommend that the Director, Evolved Expendable Launch Vehicle System Program Office, and the Director, Defense Contract Management Agency, conduct a root cause analysis and implement corrective actions for the 181 nonconformities identified during our evaluation and provide the DoD Office of Inspector General a copy of the root cause analysis and corrective action plan within 90 days of the issuance of this report.

EELV SPO Comments

The Director, Launch Enterprise, responding for the EELV SPO, agreed with the recommendation and stated that the EELV SPO and DCMA are actively engaged with the EELV contractors as they conduct root cause analyses and develop corrective plans. The Director further stated that AR has implemented corrective actions for all nonconformities, ULA has implemented corrective actions for all nonconformities except one, and SpaceX is in the process of implementing corrective actions. The EELV SPO will provide a copy of the analyses and corrective action plans to the DoD OIG within 90 days of the issuance of the final report.

Our Response

Comments from the Director, Launch Enterprise, addressed all specifics of the recommendation, and no further comments are required. Therefore, the recommendation is resolved, but remains open. We will close this recommendation after we receive the root cause analyses and corrective action plans.

DCMA Comments

The Director, DCMA, partially agreed with the recommendation and stated that the minor nonconformities do not warrant formal root cause analyses and corrective action. He also stated that many of the nonconformities have been corrected. The Director further stated that for the major nonconformities, the DCMA will work closely with the EELV Program Office to provide a summary of root causes and corrective action plans at each site. In addition, the DCMA will provide an overall corrective action plan to improve EELV quality assurance management within 90 days of the issuance of the final report.

Our Response

Comments from the Director, DCMA, partially addressed the specifics of the recommendation. Specifically, we do not agree with the DCMA Director's statement that minor nonconformities do not warrant formal root cause analyses and corrective actions. AS9100C does not differentiate between major and minor nonconformities in the requirement to implement corrective action. AS9100C, paragraph 8.5.2, "Corrective Action," states that "the organization shall take action to eliminate the causes of nonconformities in order to prevent recurrence." Ultimately, corrective action is ineffective without a formal root cause analysis. A formal root cause analysis is critical for understanding and solving the cause of the nonconformities, which prevents future nonconformities. Furthermore, AS9101D, paragraph 3.3, "Minor Nonconformity," states that a number of minor nonconformities against one requirement can represent a total breakdown of the system and thus be considered a major nonconformity.

The EELV SPO and DCMA provided conflicting responses to the recommendation. The EELV SPO agreed with our recommendation to conduct root cause analyses and implement corrective action plans for all nonconformities. However, the DCMA agreed to conduct root cause analyses and implement corrective action plans for only major nonconformities. We request that the Director, DCMA, provide additional comments in response to the final report that address performing root cause analyses and implementing corrective actions for all nonconformities. Therefore, the recommendation is unresolved and remains open. We will close this recommendation after we verify that the DCMA has performed root cause analyses and implemented corrective action plans for all nonconformities identified during our evaluation.

Recommendation 2

We recommend that the Director, Evolved Expendable Launch Vehicle System Program Office, and the Director, Defense Contract Management Agency, develop a corrective action plan to improve EELV quality assurance management to ensure that the EELV contractors comply with all AS9100C requirements and provide the DoD Office of Inspector General a copy of the corrective action plan within 90 days of the issuance of this report.

EELV SPO Comments

The Director, Launch Enterprise, agreed with the recommendation and stated that the EELV SPO and the DCMA have adjusted quality surveillance of ULA and AR. The Director further stated that the DCMA's quality surveillance of SpaceX has been implemented for SpaceX's first EELV mission and will be further refined as a result of the DoD OIG inspection. The EELV SPO will provide a copy of the corrective action plan to the DoD OIG within 90 days of the issuance of the final report.

DCMA Comments

The Director, DCMA, stated that the DCMA took the evaluation findings seriously, coordinated with the EELV SPO, and issued corrective action requests to each contractor following our site visits. The Director further stated that each contractor submitted corrective action plans, and they are implementing corrective actions. The DCMA will validate the implementation and effectiveness of the contractors' corrective actions, and evaluate and adjust its surveillance at each site. The DCMA will also inform third-party AS9100 certification auditors of potential contractor compliance issues, in an attempt to improve the value of the outside audits. The Director further stated that the DCMA will work with the EELV SPO to provide an overall corrective action plan to improve EELV quality assurance management within 90 days of the issuance of the final report.

Our Response

Comments from the Director, Launch Enterprise, and the Director, DCMA, addressed all specifics of the recommendation and no further comments are required. Therefore, the recommendation is resolved, but remains open. We will close this recommendation after we receive a corrective action plan to improve EELV quality assurance management and to ensure EELV contractors comply with all AS9100C requirements.

Appendix

Scope and Methodology

We conducted this evaluation from June 2016 through March 2017, in accordance with the Council of the Inspectors General on Integrity and Efficiency, "Quality Standards for Inspection and Evaluation." Those standards require that we plan and perform the evaluation to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our evaluation objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our evaluation objectives.

To evaluate the EELV quality assurance program we performed a series of quality assurance evaluations of both EELV prime contractors, ULA and SpaceX, and of one ULA major subcontractor, AR. We evaluated the EELV contractors' policies and procedures for compliance with the AS9100C standard as follows:

- ULA Delta IV and Atlas V manufacturing, Decatur, Alabama, and ULA System Engineering and Program Management, Denver, Colorado;
- SpaceX Falcon 9 manufacturing, Hawthorne, California, and Falcon 9 booster and engine testing, McGregor, Texas; and
- AR Atlas V and Delta IV RL-10 engine manufacturing and test, West Palm Beach, Florida.

At each EELV contractor location, our evaluation team consisted of engineering and subject matter experts certified in the AS9100C standard. We documented all nonconformities to AS9100C on DoD OIG-generated nonconformance forms. These forms were shared promptly with the SPO and EELV contractors, and they were given an opportunity to provide feedback. At the conclusion of each evaluation, we provided the EELV SPO and contractor representatives with an exit briefing summarizing the AS9100C evaluation results.

Use of Computer-Processed Data

We did not use computer-processed data to perform this audit.

Use of Technical Assistance

We used assistance from quality assurance engineers and quality assurance specialists with a background in Defense and aerospace systems and AS9100C. We established teams of 10 to 15 quality assurance engineers with an average of 10 years of quality assurance and audit experience.

Prior Coverage

During the last 5 years, the Government Accountability Office (GAO) and the DoD Office of Inspector General (DoD OIG) issued four reports discussing the EELV program. Unrestricted GAO reports can be accessed at http://www.gao.gov. Unrestricted DoD OIG reports can be accessed at http://www.dodig.mil/reports.html/.

GAO

Report No. GAO-13-317R "Launch Services New Entrant Certification Guide," February 2013

> GAO reviewed the Air Force Launch Services New Entrant Certification Guide and other requirements documents, interviewed Air Force officials responsible for implementing the Guide, and spoke with all four potential new entrants identified by the Air Force to discuss their perspectives on becoming certified under the Guide. The Air Force based its Guide on existing NASA policy and procedures with respect to payload risk classification and launch vehicle certification. Payloads are classified based in part on factors such as national significance, payload complexity and cost, and are assigned a risk tolerance level accordingly. The Air Force, NASA, and National Reconnaissance Office are working to coordinate and share information to facilitate launch vehicle certification efforts; however, each agency will determine for itself when certification has been achieved. As a result, some duplication and overlap of efforts could occur. The Air Force has also added other prerequisites to certification for new entrants that are not captured within the Guide, such as an approved implementation plan and a cooperative research and development agreement. According to the Air Force, these agreements are legal mechanisms intended to enable data sharing between the Air Force and new entrants, while protecting the interests of both.

Report No. GAO-14-337R "Space Launch Competition," March 2014

> This report addresses the following: (1) what insight did DoD have into launch costs under past EELV contracts? (2) How do recent changes to EELV contracts affect accounting for costs? (3) How is DoD compensated for costs when ULA sells launches to other customers? And (4) what are the implications if DoD requires competitors to submit offers using the same structure it currently uses with ULA or a commercial approach? GAO found that while the previous two-contract structure met DoD's needs for unprecedented mission success and an at-the-ready launch capability, the scope of its cost-reimbursement contract

limited DoD's ability to identify the cost of an individual launch, as, according to DoD, direct launch costs were not separated from other costs. Coupled with uncertainties and possible instability in the launch vehicle industrial base, EELV program costs were predicted to rise at an unsustainable rate.

Report No. GAO-15-623 "Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt an Incremental Approach to Future Acquisition Planning to Enable Incorporation of Lessons Learned," August 2015

The Air Force intends to make significant changes to its acquisition approach for acquiring launch services under the Evolved Expendable Launch Vehicle (EELV) program, which will alter its current access and insights into certain cost and performance data. The acquisition approach chosen for the first competitive launches offers some benefits to the government, including increased competition, but it could limit program oversight and scheduling flexibility. GAO found that while the Air Force is at risk of making decisions about future EELV acquisitions without sufficient knowledge. The Air Force plans to develop an acquisition strategy for the next phase of competitive launches before it has any actionable data from the first competitive launches. GAO recommends that, when planning for the next phase of competition for launches, the Air Force use an incremental approach to the next acquisition strategy to ensure that it does not commit itself to a strategy until data is available to make an informed decision. DoD concurred with the recommendation.

DoD OIG

Report No. DODIG-2015-086 "Air Force Is Developing Risk-Mitigation Strategies to Manage Potential Loss of the RD-180 Engine," March 2015

DOD-IG performed this audit in response to Congressional requests on the Evolved Expendable Launch Vehicle. We determined whether the Air Force implemented the recommendations in the RD-180 Availability Risk-Mitigation Study. The RD-180 Availability Risk-Mitigation Study identified 4 key findings with recommendations to manage concerns with the RD-180 engine. The Air Force did not specifically implement all recommendations made in the RD-180 Availability Risk-Mitigation Study; however, they developed risk-mitigation strategies to manage the potential loss of the RD-180 engine.

Management Comments

Evolved Expendable Launch Vehicle, System Program Office

DEPARTMENT OF THE AIR FORCE
SPACE AND MISSILE SYSTEMS CENTER (AFSPC)
LOS ANGELES AIR FORCE BASE, CALIFORNIA

25 October 2017

MEMORANDUM FOR DOD OFFICE OF THE INSPECTOR GENERAL

FROM: SMC/LE
483 N. Aviation Blvd
El Segundo, CA 90245

SUBJECT: Management comments on DoD-IG Report, Evaluation of the Evolved Expendable Launch Vehicle Program Quality Management System (Project No. D2016-D000PT-0169.000)

1. The Evolved Expendable Launch Vehicle (EELV) System Program Office (SPO) appreciates the DoD IG's thorough inspection of the EELV SPO and its prime contractors' compliance with AS9100C. The EELV program has maintained a rigorous focus on quality and mission assurance as a direct result of implementing the recommendations of the Broad Area Review following the launch failures in the late 1990s, and has achieved an outstanding record of 100% mission success with United Launch Alliance (ULA) and Aerojet Rocketdyne. This outcome was made possible through ULA's quality assurance processes, DCMA's oversight, and the EELV SPO's thorough mission assurance process. The EELV SPO and DCMA are actively working with SpaceX through the GPS III contract to obtain the same level of quality and mission assurance that has led to our long record of mission success.

2. The EELV SPO responses to the report Finding and Recommendations are as follows:

a. **Finding:** "The EELV SPO and the DCMA need to improve quality assurance management of the EELV contractors."

(1) **Management Comments:** Concur with the Finding. The EELV SPO and DCMA take this finding and the non-conformances seriously. Immediate corrective action was taken after each inspection event by working with our EELV contractors to address the non-conformances. Surveillance at ULA and Aerojet Rocketdyne has been refined, and implementing the corrective actions will shape the quality surveillance at SpaceX.

b. **Recommendation 1:** "Conduct a root cause analysis and implement corrective actions for the 181 nonconformities identified during our evaluation and provide the DoD Office of the Inspector General a copy of the root cause analysis and corrective action plan within 90 days of the issuance of this report."

INTEGRITY, SERVICE, EXCELLENCE

Evolved Expendable Launch Vehicle, System Program Office (cont'd)

(1) **Management Comments:** Concur with Recommendation 1. The EELV SPO and DCMA are actively engaged with the EELV contractors as they conduct root cause analysis and develop corrective action plans. Corrective actions for all findings at Aerojet Rocketdyne have been implemented and closed. ULA has implemented and closed all but one corrective action. Implementation and closure of corrective actions at SpaceX are in progress. A copy of the analyses and plans will be provided to the DoD IG within 90 days of the issuance of the final report.

c. **Recommendation 2:** "Develop a corrective action plan to improve EELV quality assurance management to ensure that the EELV contractors comply with all AS9100C requirements and provide the DoD Office of the Inspector General a copy of the corrective action plan within 90 days of the issuance of this report."

(1) **Management Comments:** Concur with Recommendation 2. The EELV SPO and DCMA have adjusted quality surveillance of ULA and Aerojet Rocketdyne as a result of the finding. DCMA's quality surveillance of SpaceX has been implemented for SpaceX's first EELV mission and will be further refined as a result of the DoD IG inspection. The EELV SPO will provide the DoD IG a copy of the corrective action plan within 90 days of the issuance of the final report.

3. Attached is a comment resolution matrix with recommended factual corrections. These comments do not impact our responses to your finding or recommendations.

4. Thank you for helping us strengthen our quality assurance process, the foundation of the EELV Program's mission assurance activities. Continuing to refine the EELV quality assurance management will ensure the program continues to provide assured access to space with 100% success.

[redacted]
Director, Launch Enterprise

Attachment:
Comment Resolution Matrix

cc: DCMA/LMD

Defense Contract Management Agency

DEFENSE CONTRACT MANAGEMENT AGENCY
3901 A. AVENUE, BUILDING 10500
FORT LEE, **VIRGINIA** 23801-1809

MEMORANDUM FOR DEPARTMENT OF DEFENSE DEPUTY INSPECTOR GENERAL
POLICY AND OVERSIGHT

SUBJECT: DCMA Comments to draft DoDIG draft report, Evaluation of the Evolved Expendable Launch Vehicle Program Quality Management System (Project No. D2016-DOOOPT-0169.000)

DCMA received the subject DoDIG draft report for review and comment on 03 October 2017. DCMA has reviewed the draft report and provides the below responses to the specific findings and recommendations. Addit iona lly, attached is a comment matrix with recommended factual corrections. These do not impact our responses to your findings or recommendations.

DoDIG Recommendation 1: We recommend that the Director, EELV SPO, and the Commander, DCMA, conduct a root cause analysis and imple ment corrective actions for the 181 nonconformities identified during our evaluation and provide the DoD Office of the Inspector General a copy of the root cause analysis and corrective action plan within 90 days of the issuance of this report.

DCMA Response: Partially Concur with Recommendation I. As indicated in the attached matrix, there were 70 Major nonconformitiesand I I I Minor. The Minor nonconformities do not warrant formal root cause analysis and corrective action and many have already been corrected and verified. For the Major nonconformities DCMA will work closely with the EELV Program Office to provide a summary of root-causesand corrective actions at each site as well as an overall corrective action plan to improve EELV quality assurance management within 90 days of the issuance of the DoDIG' s final report.

DoDIG Recommendation 2: We recommend that the Director, EELV SPO, and the Commander, DCMA, develop a corrective action plan to improve EELV quality assurance management to ensure that EELV contractors comply with all AS91OOC requirements and provide the DoD Office oflnspector General a copy of the corrective action plan within 90 days of the issuance of this report.

DCMA Response: DCMA took your findings seriously, coordinated with the EELV Program Office, and following your site audits , issued Corrective Action Requests to each contractor. Each contractor submitted corresponding Corrective Action Plans and they are well under way in implementing those corrective actions. DCMA will validate the implementation and effectiveness of the contractors' corrective actions, evaluate and adjust its surveillance at each site, and will inform 3rd party AS9100 certification auditors using OASIS of potential contractor compliance issues in an attempt to improve the value of these outside audits. Within

Defense Contract Management Agency (cont'd)

90 days of the issuance of the DoD IG's final report, DCMA will work with the EELV Program Office to provide an overall corrective action plan to improve EELV quality assurance management.

[redacted]
VADM, USN
Director

Attachmnent:
Comment Matrix

cc:
Director, SMC/LE

2

Acronyms and Abbreviations

AR	Aerojet Rocketdyne
AS9100C	Aerospace Standard
AS9101D	Aerospace Standard
CDR	Critical Design Review
COPV	Composite Overwrapped Pressure Vessel
DCMA	Defense Contract Management Agency
DoD OIG	DoD Office of Inspector General
EELV	Evolved Expendable Launch Vehicle
ESD	Electrostatic Discharge
FCA	Functional Configuration Audit
FOD	Foreign Object Debris
GAO	Government Accountability Office
GSE	Ground Support Equipment
ISO	International Organization for Standardization
MOA	Memorandum of Agreement
MRB	Material Review Board
NASA	National Aeronautics and Space Administration
PCA	Physical Configuration Audit
QMS	Quality Management System
RIO	Risk, Issue, and Opportunity
SMC	Space and Missile Systems Center
SpaceX	Space Exploration Technologies Corporation (used but not defined)
SPO	System Program Office
ULA	United Launch Alliance

Whistleblower Protection
U.S. Department of Defense

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For more information about DoD OIG reports or activities, please contact us:

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