~~FOR OFFICIAL USE ONLY~~

INSPECTOR GENERAL

U.S. Department of Defense

NOVEMBER 7, 2019

Evaluation of the V-22 Engine Air Particle Separator

INTEGRITY ★ INDEPENDENCE ★ EXCELLENCE

The document contains information that may be exempt from mandatory disclosure under the Freedom of Information Act.

~~FOR OFFICIAL USE ONLY~~

Results in Brief

Evaluation of the V-22 Engine Air Particle Separator

November 7, 2019

Objective

The objective of this evaluation was to determine whether the Naval Air Systems Command V-22 Joint Program Office developed an Engine Air Particle Separator (EAPS) to adequately protect the V-22 engine while operating in all desert environments.

Background

The V-22 aircraft combines the capabilities of a helicopter and an airplane. V-22 missions include transport of personnel and cargo, and recovery of personnel. The V-22 operates from ships and air bases, and performs missions requiring takeoff and landing at unprepared landing zones.

One significant mission requirement of the V-22 is to operate in desert environments. This can result in large amounts of soil on the ground being blown into the air and ingested into the V-22 engine, which can contribute to premature engine failure. The EAPS' purpose is to protect the V-22 engine by removing soil from the air that enters the engine.

The V-22 Joint Program Office, known as the Program Manager, Air 275 (PMA-275), at Naval Air Station Patuxent River, Maryland, manages the V-22 program.

The PMA-275 recognized that the EAPS was not removing enough soil from the air entering the engine and initiated two EAPS redesign efforts, in 2010 and 2011. However, the PMA-275 determined that neither redesign was a viable option. Specifically, the first EAPS redesign had inconsistent test results, and the second EAPS redesign adversely affected the ability of the V-22 to operate as an airplane.

Background (cont'd)

~~(FOUO)~~ [redacted]

In 2018, the PMA-275 initiated a third EAPS redesign effort. The goal of that effort was to increase the ability of the EAPS to separate soil from the air entering the engine by improving the existing EAPS components.

Finding

The PMA-275 did not develop an EAPS that protects the V-22 engine while operating in all desert environments. Specifically, the PMA-275 did not include a specification in the original EAPS design that required the EAPS to meet the engine manufacturer's specification for cleanliness of the air flowing into the engine. Despite two unsuccessful redesign efforts, the PMA-275's third EAPS redesign effort will also not meet the engine manufacturer's specification.

The third EAPS redesign is intended to remove more soil from the air flowing into the V-22 engine than the original EAPS; however, the soil ingested into the engine would be four times greater than the engine manufacturer's specification allows. While PMA-275 officials stated that it is not technically feasible to meet the engine manufacturer's specification for air quality in a desert environment, they could not provide analysis that demonstrated whether this redesign would adequately protect the engine.

Additionally, the PMA-275 intends to test the third EAPS redesign with soil that is not representative of all environments where the V-22 operates, relying instead on military standard soil compositions and soil concentrations based on testing from a single desert environment. This occurred because the PMA-275 is not taking advantage of the ability to tailor military standard soil samples.

As a result, the V-22 remains at risk despite more than nine years of EAPS redesign attempts. Additionally, the PMA-275 cannot be certain that the third EAPS redesign will correct long-standing problems with the V-22.

Results in Brief

Evaluation of the V-22 Engine Air Particle Separator

Recommendations

We recommend that the V-22 Joint Program Office Commander:

- Conduct a review of alternatives for the EAPS and V-22 engine so that the EAPS adequately protects the V-22 engine in all desert environments.
- Develop a plan to include a sampling of additional soils, whose compositions and concentrations are representative of those found in actual V-22 operational environments, in the testing for the EAPS and V-22 engine.

Management Comments and Our Response

The V-22 Joint Program Office Deputy Program Manager, responding for the V-22 Joint Program Office Commander, stated that the PMA-275 agreed that V-22 operations in desert environments are a critical capability for the program. However, he disagreed with our focus on only the V-22 EAPS subsystem, stating evaluating only one V-22 subsystem and not the overarching program strategy to enable safe operation of the V-22 during austere operations, does not capture the program's plan for addressing risk. The Deputy Program Manager described a multi-layered approach the program office was taking to address safe operation of the V-22 and stated that extensive research has led the PMA-275 to conclude that it is not technically possible to develop, integrate, and field an EAPS that is fully capable of protecting the V-22 engine from all possible soil types and concentrations for unlimited durations. The Deputy Program Manager stated that the PMA-275 intended to continue its plan to improve the EAPS subsystem as part of a multi-layered approach to address safe operation of the V-22, which includes testing that will characterize the performance of the V-22 engine and EAPS during desert operations.

Although the V-22 Joint Program Office Deputy Program Manager disagreed with our recommendation to conduct a review of alternatives for the EAPS and V-22 engine, several components of the multi-layered approach for improving the overall safety of the V-22 aircraft directly address concerns discussed in our finding. For example, the PMA-275 is developing a near real-time Cockpit Engine Health monitoring system and [redacted]. In addition, the PMA-275 plans to perform testing to characterize the performance of the V-22 engine and EAPS in desert environments and use the results of the testing to update the specification for the third EAPS redesign effort. Therefore, the recommendation is resolved but open. We will close this recommendation after we review the results of actions taken by the PMA-275.

Comments from the Deputy Program Manager did not address the specifics of our recommendation to develop a plan to include a sampling of additional soil compositions and concentrations; therefore, the recommendation is unresolved. However, we revised this recommendation to clarify our intent that the PMA-275 test soil samples which are representative of actual operational environments for testing of the V-22 EAPS and engine, instead of soil samples from all desert environments. We request that the V-22 Joint Program Office Commander provide comments on the revised recommendation no later than December 9, 2019.

Please see the Recommendations Table on the next page for the status of the recommendations.

Recommendations Table

Management	Recommendations Unresolved	Recommendations Resolved	Recommendations Closed
Commander, V-22 Joint Program Office	A.1.b	A.1.a	None

Please provide Management Comments by December 9, 2019.

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.

INSPECTOR GENERAL
DEPARTMENT OF DEFENSE
4800 MARK CENTER DRIVE
ALEXANDRIA, VIRGINIA 22350-1500

November 7, 2019

MEMORANDUM FOR AUDITOR GENERAL, DEPARTMENT OF THE NAVY

SUBJECT: Evaluation of the V-22 Engine Air Particle Separator
(Report No. DODIG-2020-006)

This final report provides the results of the DoD Office of Inspector General's evaluation. We previously provided copies of the draft report and requested written comments on the recommendations. We considered management's comments on the draft report when preparing the final report. These comments are included in the report.

This report contains one recommendation that is resolved, but remains open. Although the V-22 Joint Program Office Commander did not agree with the recommendation, his response and proposed alternative actions satisfied the intent. We will close this recommendation after we review the results of specific actions taken by the PMA-275 and the associated documentation.

This report also contains one recommendation that is considered unresolved, because the V-22 Joint Program Office Commander did not agree with the recommendation. We revised the recommendation and ask that the V-22 Joint Program Office Commander provide comments on the revised recommendation.

DoD Instruction 7650.03 requires that recommendations be resolved promptly. Therefore, please provide us your response concerning specific actions in process, as well as comments on the revised recommendation, no later than December 9, 2019. Your response should be sent to [redacted] If you arrange to send classified comments electronically, you must send them over the SECRET Internet Protocol Router Network (SIPRNET) to [redacted]

If you have any questions, please contact [redacted] We appreciate the cooperation and assistance received during the evaluation.

Randolph R. Stone
Assistant Inspector General for Evaluations
Space, Intelligence, Engineering, and Oversight

Contents

Introduction

Objective 1

Background 1

Finding. PMA-275 Did Not Develop an EAPS Specification That Protects the V-22 Engine When Operating in All Desert Environments 7

PMA-275 Did Not Develop an EAPS Specification That Protects the V-22 Engine When Operating in All Desert Environments 8

PMA-275 Officials Stated That Meeting the Rolls-Royce Specification for Air Cleanliness Was Not Technically Feasible 11

PMA 275 Intends To Test the Third EAPS Redesign With Soil Samples That Are Not Representative of All Environments Where the V-22 Operates 11

PMA-275 Is Not Taking Advantage of the Ability To Tailor Military Standards, and Is Relying on Testing Performed in Only One Desert Environment 13

PMA-275 Cannot Be Certain That the Third EAPS Redesign Will Correct the Long-standing Problems With the EAPS 14

Management Comments on the Findings and Our Response 14

Recommendations, Management Comments, and Our Response 15

Appendix

Scope and Methodology 18

Use of Computer-Processed Data 19

Use of Technical Assistance 19

Prior Coverage 19

Management Comments

The V-22 Joint Program Office Commander 20

Acronyms and Abbreviations 30

Introduction

Objective

The objective of this evaluation was to determine whether the Naval Air Systems Command V-22 Joint Program Office, known as the Program Manager, Air 275 (PMA-275), developed an Engine Air Particle Separator (EAPS) to adequately protect the V-22 engine while operating in all desert environments.

Background

V-22 Aircraft

The V-22 aircraft combines the takeoff and landing capability of a helicopter with the speed and range of an airplane. The V-22 has a cruise speed of 280 knots (299 miles per hour) and a maximum range of 860 nautical miles (989 miles) without refueling. The aircraft is 63 feet long, 22 feet high, and has a wingspan of 85 feet, including the propellers. The maximum takeoff weight is 52,600 pounds. See Figure 1 for a photograph of a V-22 landing on a paved surface.

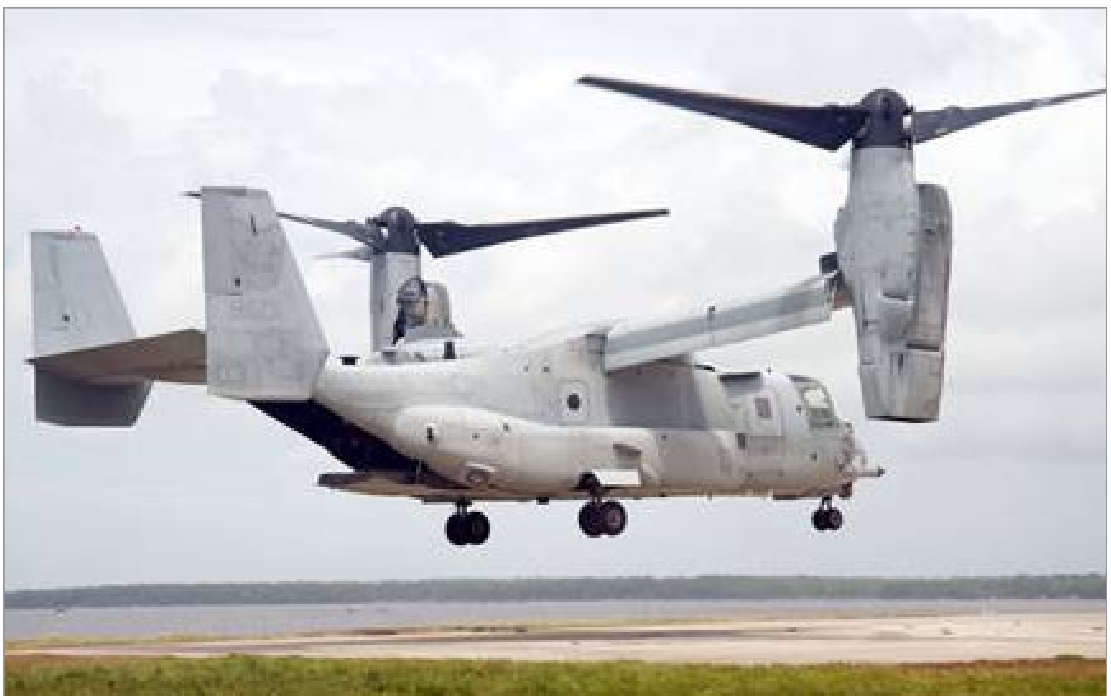

Figure 1. V-22 Landing at Marine Corps Air Station New River, North Carolina
Source: DoD Office of Inspector General (OIG).

V-22 Engine

The V-22 is powered by two Rolls-Royce Liberty AE1107C turboshaft engines.[1] Each engine delivers 6,200 shaft horsepower to a 38-foot-diameter, 3-blade propeller that provides lift for hovering and thrust for forward flight. The two engines are connected by a drive shaft that synchronizes the engines and provides power to both propellers in the event of a single engine failure.

The V-22 engine manufacturer, Rolls-Royce, defined a specification for air cleanliness that must be met for the V-22 engine (henceforth, referred to as the Rolls-Royce specification). Based on testing, Rolls-Royce defined an air cleanliness specification for the composition and concentration of soil that may be ingested by the V-22 engine, for an 11 hour period, without causing engine degradation.[2]

V-22 Program

The PMA-275, at Naval Air Station Patuxent River, Maryland, manages the V-22 program. Bell Helicopter Textron and Boeing Integrated Defense Systems, referred to as Bell-Boeing, are the contractors that jointly design and manufacture the V-22. There are currently two variants of the V-22 in operation within the DoD. The Marine Corps operates the MV-22, which began initial operation on June 13, 2007, and the Air Force operates the CV-22, which began initial operation on March 16, 2009. This report refers to both as the V-22.

V-22 Mission

The unique capability of the V-22 to function as both an airplane and a helicopter allows the aircraft to conduct various missions. The V-22 missions include transport of personnel and cargo, and recovery of personnel. The V-22 operates from ships and air bases, and performs missions requiring takeoff and landing at unprepared landing zones, including those in desert environments. For this report, "desert environments" refers to any dry, dust-covered area where soil can be blown into the air.

[1] A turboshaft engine is a jet engine that has an output shaft to provide power to the V-22 propellers. Rolls-Royce is the current manufacturer of the V-22 engine. The original design and manufacture of the engine was by Allison Engines which was acquired by Rolls Royce during development of the V-22.

[2] For this report, the term "soil" will be used to describe all dirt or sand-like substances that are on the ground around V-22 landing zones.

Reduced Visibility Landings

When the V-22 lands in a desert environment, the wind created from the propellers blows large amounts of soil into the air, limiting the crew's ability to see the landing site. Figure 2 shows a V-22 landing at Kirtland Air Force Base, New Mexico, where the aircraft is barely visible due to the soil in the air. The Marine Corps refers to these events as reduced visibility landings (RVLs), while the Air Force refers to them as low visibility approaches. For this report, we refer to both of these landings as RVLs

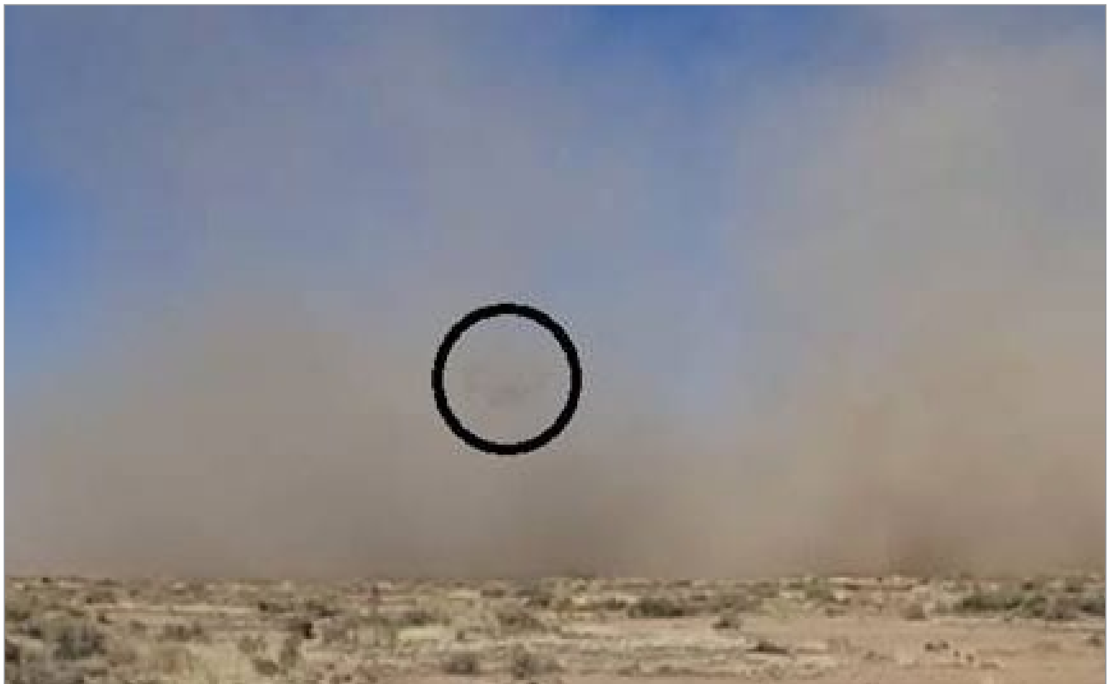

Figure 2. Example of an RVL at Kirtland Air Force Base With Aircraft Faintly Visible
Source: DoD OIG.

V-22 Engine Protection Provided by the EAPS

The large amount of soil that is blown into the air during an RVL can be ingested into the V-22 engine. To protect the V-22 engine from soil ingestion during an RVL, an EAPS is positioned in front of the engine. The EAPS creates a powerful vacuum force to remove soil from the air before the air enters the engine. If enough soil is not removed by the EAPS from the air flowing into the engine, it can cause damage to the engine and possibly engine failure. Figure 3 shows an EAPS installed on a V-22 engine that has been removed from the aircraft.

~~FOR OFFICIAL USE ONLY~~

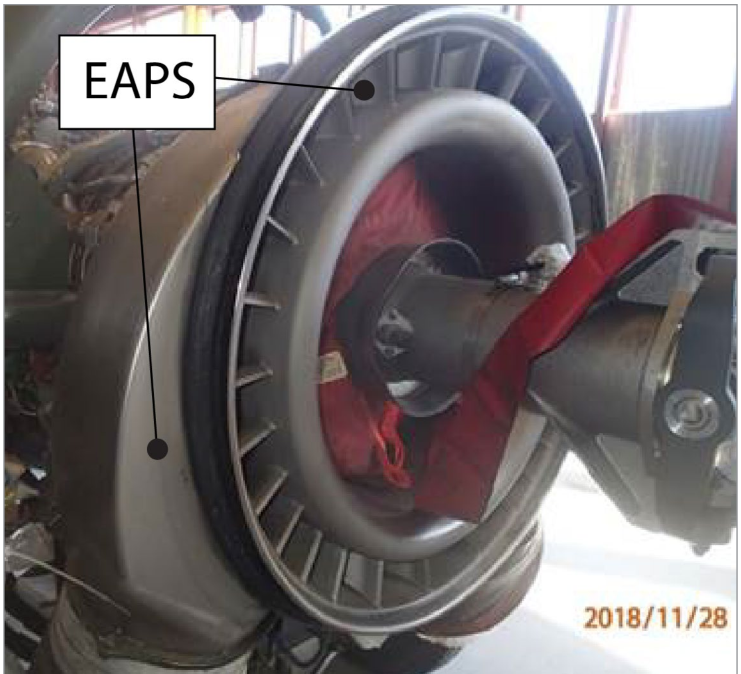

Figure 3. EAPS Installed on Engine Source: DoD OIG.
Source: DoD OIG.

EAPS History

The V-22 entered service for the Marine Corps on June 13, 2007, and for the Air Force on March 16, 2009, with the original EAPS design. The PMA-275 began to recognize problems with the V-22 aircraft operating in desert environments in 2010. Specifically, the PMA-275 identified a reduction in the amount of time that an engine could operate when flying in desert environments. The expected operational time for the V-22 engine was 500 hours before engine replacement; however, engines operating in the desert were experiencing operational times as low as 200 hours before engine replacement. The PMA-275 attributed the reduction in time that the engines could operate to the inability of the original EAPS to remove enough of the soil from the air entering the engine in desert environments.

~~(FOUO)~~ When the PMA-275 developed the specification for the original EAPS design, it did not require the EAPS to meet the Rolls-Royce specification in all desert environments. [redacted]. However, the PMA-275 did not include a similar specification for the EAPS to define the amount of soil the EAPS would remove from the air, and subsequently the concentration of soil that would remain in the air and be ingested into the V-22 engine. Because the PMA-275 did not

~~(FOUO)~~ include a specification in the original EAPS design requiring the EAPS to remove enough soil from the [redacted], the original EAPS did not meet the Rolls-Royce specification in desert environments. As a result, the PMA-275 initiated the first EAPS redesign.

In 2010, the PMA-275 contracted with Bell-Boeing for the first EAPS redesign with the objective of increasing the amount of time that engines could operate in desert environments by 50 percent. Initial flight testing of the first EAPS redesign resulted in inconsistent results. For example, one test showed an improvement in the amount of time that the engines could operate in desert environments, while another test showed a decrease.

~~(FOUO)~~ While the first EAPS redesign was ongoing, in 2011, the PMA-275 contracted again with Bell-Boeing for the second EAPS redesign with the objective of meeting all of the Rolls-Royce specifications for the V-22 engine when operating in desert environments. The second EAPS redesign involved using air filters in front of the engine to remove soil from the air. The PMA-275 included specifications that required the air filters to remove enough soil from the air to meet the Rolls-Royce specification. [redacted] The PMA-275 canceled the first EAPS redesign on December 6, 2012, as a result of the inconsistent test results mentioned earlier. The second EAPS redesign continued.

~~(FOUO)~~ [redacted].[3] While the redesign was ongoing, all V-22 aircraft retained the original EAPS design, which did not meet the Rolls-Royce specifications. [redacted]

[3] ~~(FOUO)~~ [redacted]

[4] ~~(FOUO)~~ [redacted]

(FOUO) In addition to the [redacted], the PMA-275 system safety risk assessment identified eight other engine rapid power loss events from June 2008 to May 2015, that were the result of the original EAPS not removing enough soil from the air flowing into the engines. An engine rapid power loss event occurs when an engine quickly loses a significant amount of power without warning. Although the eight engine rapid power loss events did not result in a catastrophic accident, the engines had degraded to a point where engine failure was possible. [redacted].[5]

The PMA-275 took immediate action to mitigate the risk by altering the operation of the V-22 to reduce the amount of time that the aircraft could operate in RVL situations. The PMA-275 also pursued three other mitigation efforts to improve the safety of the V-22 while flying in desert environments. The first effort was to redesign the EAPS so that it better protects the engine. The second effort was to make improvements to the engine in an attempt to allow the engine to better handle soil being ingested into it. The third effort was to implement an aircrew notification system, to make the crew aware of overall engine health and impending engine degradation while conducting RVLs so that the crew can take necessary precautions. While the PMA-275 is pursuing all of these efforts, this evaluation focused only on the first mitigation effort, the EAPS redesign.

Because the second EAPS redesign was in progress at the time that the safety risk was identified, PMA-275 personnel stated that the redesign effort continued as part of the risk mitigation. However, initial testing of the second EAPS redesign resulted in problems with the use of air filters. For example, the air filters disrupted the airflow into the engine when the V-22 was functioning as an airplane. As a result, overall airflow requirements of the V-22 engine were not being met. Bell-Boeing proposed several design change options in an attempt to correct the problems, but after reviewing the proposals, the PMA-275 decided to stop the second EAPS redesign on December 22, 2017, due to technical complexity.

After discontinuing the second EAPS redesign, the PMA-275 initiated a third EAPS redesign effort in 2018 with Bell-Boeing. The third EAPS redesign involves modifying the existing EAPS components to increase the ability of the EAPS to remove soil from the air before it flows into the engine. The third EAPS redesign is in the beginning stages of design. Therefore, we evaluated the PMA-275's third EAPS redesign specification.

[5] (FOUO) [redacted]

Finding

PMA-275 Did Not Develop an EAPS Specification That Protects the V-22 Engine When Operating in All Desert Environments

The PMA-275 did not develop an EAPS specification that protects the V-22 engine when operating in all desert environments. Specifically, the PMA-275 did not require the EAPS to meet the Rolls-Royce specification for air cleanliness. The PMA-275 initiated two EAPS redesign efforts that were unsuccessful. Furthermore, the PMA-275's third EAPS redesign also will not adequately protect the V-22 engine when operating in desert environments because the specification allows a soil concentration that is four times the amount that Rolls-Royce determined could enter the V-22 engine without degradation.

This occurred because PMA-275 personnel stated that meeting the Rolls-Royce engine specification was not technically feasible since the contractor for the second EAPS redesign (Bell-Boeing) attempted, but was unable, to meet the engine's specification for air cleanliness within the PMA-275's timeframe and budget. PMA-275 officials stated that although the third EAPS redesign will not meet the Rolls-Royce specification either, the third redesign will improve EAPS performance and better protect the V-22 engine.

Additionally, the PMA-275 intends to test the third EAPS redesign with soil samples of compositions and concentrations that are not representative of all environments where the V-22 operates. Specifically, the soil sample composition that the PMA-275 intends to use is a military standard composition that does not include all three soil components (sand, silt, and clay) commonly found in areas where the V-22 operates, such as Afghanistan. The soil sample concentration that the PMA-275 intends to use represents only one desert environment.

This occurred because the PMA-275 is not taking advantage of the ability to tailor military standards and is relying on testing performed in only one desert environment. Specifically, PMA-275 personnel stated that the composition of the soil samples that will be used for testing the third EAPS redesign are appropriate because the samples are identified in the draft revision to the "Department of Defense Joint Service Specification Guide Engines, Aircraft, Turbine" (JSSG-2007). However, the JSSG-2007 is a guide to specification development and states that it "must be tailored . . . to form the program-unique specification." Furthermore, the PMA-275 asserts that the concentration of the soil samples that will be used for testing the third EAPS redesign are appropriate because the samples represent a desert environment. However, the concentration of the soil samples represents only one desert environment and not all desert environments where the V-22 operates. Testing with soil samples that have a composition and concentration representative of all desert environments where the V-22 operates is necessary to ensure the success of the third EAPS redesign.

As a result, the PMA-275 has experienced performance problems over nine years due to the EAPS when operating the V-22 in desert environments; has attempted two EAPS redesigns that were unsuccessful; and has had to implement risk mitigation requirements that affect V-22 operational performance. Finally, the PMA-275 cannot be certain that the third EAPS redesign will correct the long-standing problems without determining what the effectiveness of the third EAPS redesign will be on the engine and without using representative soil samples to test the redesigned EAPS.

PMA-275 Did Not Develop an EAPS Specification That Protects the V-22 Engine When Operating in All Desert Environments

~~(FOUO)~~ The PMA-275 did not develop an EAPS specification that protects the V-22 engine when operating in all desert environments. [redacted]. The PMA-275 did not include a specification for the original EAPS design that required the EAPS to meet the Rolls-Royce specification. [redacted].[6] Although the third EAPS redesign may remove more soil than the original EAPS, the PMA-275 could not provide any analysis demonstrating the expected results [redacted] or whether the EAPS would remove enough soil to adequately protect the engine when operating in all desert environments.

[6] The PMA-275 defined certain environmental assumptions for the third EAPS redesign specification that must be used to evaluate the EAPS ability to remove soil from the air entering the engine. These environmental assumptions include concentration of the soil, defined based on an expected environment. The PMA-275 based these environmental assumptions on a given desert operational environment.

Rolls-Royce Determined the Concentration of Soil the V-22 Engine Could Ingest Without Degradation

~~(FOUO)~~ During engine design and development, Rolls-Royce determined the concentration of soil the V-22 engine could ingest without degradation. Specifically, in 1996, [redacted].

PMA-275 Developed the Original EAPS Design Without a Requirement for It To Meet the Rolls-Royce Specification

When the PMA-275 developed the original EAPS design, the PMA-275 did not include a specification for the amount of soil that the EAPS had to remove before the air entered the V-22 engine and did not include a requirement for the EAPS to meet the Rolls-Royce specification. However, the PMA-275 did determine that, given the conditions and environmental assumptions used to develop the third EAPS redesign specification, the original EAPS was capable of removing 84 percent of the soil from the air.

PMA-275 Attributed a Reduction in the Amount of Time That Engines Could Operate and Eight Rapid Power Loss Events to the Original EAPS

~~(FOUO)~~ In 2010, the PMA-275 attributed a reduction in the amount of time that engines could operate and eight rapid power loss events to the original EAPS not removing enough soil from the air entering the engine in desert environments. [redacted]. Specifically, in 2010, the PMA-275 identified a reduction in the amount of time that an engine could operate in desert environments. [redacted]. The PMA-275 attributed the reduction in time that the engines could operate to the original EAPS design not removing enough soil from the air entering the engine in desert environments.

~~(FOUO)~~ In addition, the PMA-275 conducted a system safety risk assessment in 2015 following [redacted].

~~(FOUO)~~ PMA-275 Revised the EAPS Specification for the Third Redesign To Require the EAPS To Remove [redacted] of Soil From the Air Before the Air Flows Into the Engine

~~(FOUO)~~ Although the second EAPS redesign, if successful, would have required the EAPS to meet the Rolls-Royce specification for air cleanliness, in 2018 the PMA-275 revised the air cleanliness requirement in the third EAPS redesign specification. [redacted]

PMA-275 Air Cleanliness Requirement in the Third EAPS Redesign Is Not Sufficient To Protect the V-22 Engine

~~(FOUO)~~ We reviewed the ability of the original EAPS design and the third EAPS redesign to meet the requirements of the Rolls-Royce specification for the V-22 engine. Under the PMA-275's conditions and environmental assumptions for the third EAPS redesign, [redacted]

~~(FOUO)~~ Although the third EAPS redesign may remove more soil than the original EAPS, [redacted] while operating in all desert environments or address the risks associated with RVLs. [redacted]

~~(FOUO)~~ However, the PMA-275 did not present any analysis to show that removing [redacted] of the soil from the air will provide enough improvement to adequately protect the V-22 engine.

PMA-275 Officials Stated That Meeting the Rolls-Royce Specification for Air Cleanliness Was Not Technically Feasible

The PMA-275 attempted two EAPS redesigns but PMA-275 officials stated that meeting the Rolls-Royce specification was not technically feasible. Specifically, the second EAPS redesign was the only attempt to meet the Rolls-Royce specification and it was unsuccessful. However, Bell-Boeing did propose several alternative designs in an attempt to correct the airflow problems with the second redesign, but the PMA-275 did not pursue any of the alternatives.

We asked PMA-275 officials why they did not pursue an alternative design for the third redesign that would meet the Rolls-Royce specification. PMA-275 officials stated that technical challenges, such as redesigning the V-22's structure and adding moving parts near the engine, could not be overcome within the timeframe and budget available. Therefore, the PMA-275 developed the third EAPS redesign specification to allow a soil concentration higher than the Rolls-Royce specification and lower than the current EAPS. The PMA-275 stated that although the third EAPS redesign will not meet the Rolls-Royce specification, the design will increase EAPS performance and provide greater protection for the V-22 engine because it will decrease the amount of soil that will be ingested into the engine.

Because the PMA-275 did not provide analysis supporting the selection of the air cleanliness requirements for the third EAPS redesign specification, it is not clear whether the third EAPS redesign will adequately protect the V-22 engine when operating in all desert environments. Without additional support for the specification selected for the third EAPS redesign, the PMA-275 cannot determine if the design will provide enough protection for the V-22 engine. Therefore, the PMA-275 should conduct a review of alternatives for the EAPS and V-22 engine so that the EAPS adequately protects the V-22 engine in all desert environments.

PMA 275 Intends To Test the Third EAPS Redesign With Soil Samples That Are Not Representative of All Environments Where the V-22 Operates

The PMA-275 intends to test the third EAPS redesign with soil samples of compositions and concentrations that are not representative of all environments where the V-22 operates. Specifically, the soil sample composition that the PMA-275 intends to use to test the third EAPS redesign does not include all three main components of soil. The soil sample concentration represents only one desert environment.

The soil sample composition that the PMA-275 intends to use to test the third EAPS redesign does not include all three main components of soil. Specifically, the composition of the soils that exist worldwide include three main components: sand, silt, and clay.[7] The environments where the V-22 operates have varying mixtures of these three components. For example, the soil composition at an operating location in New Mexico is 46.4-percent sand, 31.5-percent silt, and 22.1-percent clay; the soil composition at an operating location in Kuwait is 67.0-percent sand, 20.4-percent silt, and 12.6-percent clay; and the soil composition at an operating location in Afghanistan is 51.9-percent sand, 27.3-percent silt, and 20.7-percent clay.

PMA-275 officials stated that the third EAPS redesign will be tested using military standard soils identified in the draft revision of the "Department of Defense Joint Service Specification Guide Engines, Aircraft, Turbine" (JSSG-2007).[8] However, the soils that are included in the draft revision to the JSSG-2007 are not representative of desert environments where the V-22 operates. Specifically, the soils contained in the draft revision to the JSSG-2007 do not contain all three main components of soil. For example, one soil composition the PMA-275 intends to use to test the third EAPS redesign is 0.0-percent sand, 100.0-percent silt, and 0.0-percent clay and another is 100.0-percent sand, 0.0-percent silt, and 0.0-percent clay. None of the soil samples identified in the draft revision of the JSSG-2007 and planned for testing the third EAPS redesign contain all three of the main soil components, let alone in ratios representative of soils that exist in all desert environments where the V-22 operates.

During the original EAPS design, military standard soils were used to validate the design. The composition of these soils did not include all three components of soil. Within a year of the V-22's initial operational capability with the Air Force, the PMA-275 documented problems with the EAPS performance. Testing the original EAPS with soils that were representative of environments where the V-22 operates might have prevented some of the problems that occurred shortly after initial operational capability. Therefore, to minimize the risk of inadequate engine protection, the third EAPS redesign should be tested using soil samples with a composition that is representative of all environments where the V-22 operates.

The soil sample concentration that the PMA-275 intends to use to test the third EAPS redesign represents only one desert environment. To elaborate, soil concentration is the amount of soil that will be in the air that will be used to test

---

[7] Sand is classified as particles of soil that are between 50 micrometers and 2 millimeters in size, silt is classified as particles of soil that are between 2 micrometers and 50 micrometers in size, and clay is classified as particles of soil that are less than 2 micrometers in size.

[8] The Department of Defense Joint Service Specification Guide Engines, Aircraft, Turbine is approved for use by all Departments and Agencies of the Department of Defense and provides guidance for development of turbine engine specifications, including engine soil ingestion testing.

the third EAPS redesign. We learned that the PMA-275's third EAPS redesign specification requires testing to be performed with a soil concentration that is based on testing done by the Defense Advanced Research Project Agency.[9] The Defense Advanced Research Project Agency previously measured soil in the air during one V-22 RVL in a desert environment. However, the Defense Advanced Research Project Agency data was collected at only one location in the Arizona desert.

The concentration of soil in the air during an RVL depends on the location. The different locations where the V-22 operates are composed of different soils, which will affect the concentration of soil blown into the air during a landing. The test sample that the PMA-275 plans to use to determine the concentration of soil in the air during an RVL is from only one location. Because the PMA-275 did not consider other locations, the soil concentration requirement in the third EAPS redesign specification is not representative of all desert environments where the V-22 operates. The PMA-275 should consider additional factors in RVLs, including operating locations, to determine worst-case scenarios while developing soil concentration test requirements.

PMA-275 Is Not Taking Advantage of the Ability To Tailor Military Standards, and Is Relying on Testing Performed in Only One Desert Environment

The PMA-275 is not taking advantage of the ability to tailor military standards and is relying on testing performed in only one desert environment. Specifically, while the PMA-275 is using soil compositions from military standards, the PMA-275 is not taking advantage of the opportunity to tailor the JSSG-2007 to meet program-unique specifications. Although PMA-275 officials agreed that the soil samples are not representative of the soils where the V-22 operates, they stated that they are required to use military standard soils. The PMA-275 officials stated that the military standard soils they intend to use to validate the third EAPS redesign are acceptable, despite not being representative of all environments where the V-22 operates, because the soils are prescribed in the JSSG-2007. However, according to the JSSG-2007, "[the] specification is intended for Government and Industry program teams as guidance in developing program-unique specifications," and "must be tailored . . . to form the program-unique specification."

[9] The Defense Advanced Research Project Agency is a DoD Agency responsible for developing emerging technology for use by the military.

Additionally, PMA-275 officials stated that the concentration of the soil samples that will be used for testing the third EAPS redesign are appropriate because the soil concentration represents a desert environment. However, because the Defense Advanced Research Project Agency collected data at only one location, the soil concentration represents only one desert environment, not all desert environments where the V-22 operates. Therefore, the PMA-275 should develop a plan to include a sampling of additional soils, whose compositions and concentrations are representative of those found in actual V-22 operational environments, in the testing for the EAPS and engine.

PMA-275 Cannot Be Certain That the Third EAPS Redesign Will Correct the Long-standing Problems With the EAPS

~~(FOUO)~~ For more than 9 years, the V-22 has experienced performance problems due to the EAPS when operating in desert environments. Specifically, the Marine Corps and the Air Force continue to operate the V-22 in desert environments with the original EAPS design, which the [redacted]. The PMA-275 attempted two unsuccessful redesigns of the EAPS and has had to implement risk mitigation requirements. The PMA-275 is proceeding with a third EAPS redesign that does not satisfy the Rolls-Royce specification designed to ensure the V-22 engine operates without degradation. Without adequate analysis and testing with the appropriate soil compositions and concentrations, the PMA-275 cannot be certain that the third EAPS redesign will correct these long-standing problems. As a result, continuing with the specification for the third EAPS redesign, although a likely improvement, could still produce problems for the V-22 similar to those attributed to the original EAPS design.

Management Comments on the Findings and Our Response

V-22 Joint Program Office Commander Response

The V-22 Joint Program Office Deputy Program Manager, responding for the V-22 Joint Program Office Commander, stated that the PMA-275 agreed that V-22 operations in desert environments are a critical capability for the program; however, he disagreed with our focus on only the V-22 EAPS system, stating, "The approach by DODIG to evaluate only one V-22 subsystem and not the overarching program strategy to enable safe operation of the V-22 during austere operations, does not capture the program's plan for addressing risk." The Deputy Program Manager described the multi-layered approach the program was taking to enable safe operation of the V-22—an approach that does not rely on a single aircraft subsystem or mitigation step. Specifically, the PMA-275 is working to develop:

- a near real-time Cockpit Engine Health Monitoring System,
- [redacted]
- [redacted]
- engine improvements to increase resistance to sand ingestion power loss.

The Deputy Program Manager stated that as a result of extensive market research and technical development, the PMA-275 determined that it is not "technically possible" to develop, integrate, and field an EAPS that is fully capable of protecting the V-22 engine from all possible soil types and concentrations for unlimited durations. However, he stated that the PMA-275 intended to, "continue its plan to significantly improve the current EAPS system as part of the overarching program plan to address safe operation of the V-22 during austere operations." This plan includes testing that will characterize the performance of the V-22 engine and EAPS during RVLs, and will be used to update the EAPS system specification prior to the preliminary design review for the third EAPS redesign.

Our Response

We acknowledge the PMA-275's multi-layered approach to improving the overall safety of the V-22 aircraft during RVLs. Several components of this approach directly address concerns that are discussed in our finding. Although it is not clear what impact this multi-layered approach may have on the reliability of the V-22 engine, we recognize the PMA-275's plans to perform testing to characterize the performance of the V-22 engine and EAPS in RVLs and use the results to make further decisions regarding the third EAPS redesign.

Recommendations, Management Comments, and Our Response

Revised Recommendation

As a result of management comments, we revised Recommendation A.1.b to clarify the actions needed by the PMA-275 to improve the V-22 engine and EAPS testing.

Recommendation A.1

We recommend that the V-22 Joint Program Office Commander:

a. Conduct a review of alternatives for the Engine Air Particle Separator and V-22 engine so that the Engine Air Particle Separator adequately protects the V-22 engine in all desert environments.

V-22 Joint Program Office Commander Response

The V-22 Joint Program Office Deputy Program Manager, responding for the V-22 Joint Program Office Commander, disagreed with the recommendation. He stated that our evaluation's focus on only one component—the EAPS—did not take into account the overall effort that the PMA-275 is taking to increase the overall safety of the V-22 aircraft in RVLs. In his response, the Deputy Program Manager described the multi-layered approach that the PMA-275 is performing to reduce the overall risk during RVLs to the aircraft. For example, the V-22 Joint Program office is developing a near real-time Cockpit Engine Health monitoring system and [redacted]. In addition, he stated that the PMA-275 is planning to conduct testing that will determine the requirements of the V-22 engine and EAPS during RVLs that will be used to update the EAPS system specification prior to the preliminary design review for the third EAPS redesign effort.

Our Response

Although the Deputy Program Manager disagreed with the recommendation, the PMA-275's description of the multi-layered approach to improving the overall safety of the V-22 aircraft during RVLs and planned actions to conduct engine and EAPS testing, and use the results of those tests to update decisions regarding the third EAPS redesign effort satisfied the intent of the recommendation. Therefore, the recommendation is resolved but will remain open. We will close this recommendation after we review the results of the actions taken by the PMA-275 to address this recommendation.

b. Develop a plan to include a sampling of additional soils, whose compositions and concentrations are representative of those found in actual V-22 operational environments, in the testing for the Engine Air Particle Separator and engine.

V-22 Joint Program Office Commander Response

The V-22 Joint Program Office Deputy Program Manager, responding for the V-22 Joint Program Office Commander, disagreed with the recommendation. He stated that testing for all desert environments is not testable as described, as the V-22 operates worldwide in an infinite number of soil types and compositions. The Deputy Program Manager further stated that the sand and dust compositions that are intended to be used for testing are representative of the environments where the V-22 operates. He stated that the PMA-275 is developing a computer based model that will be capable of analytically evaluating the performance of the EAPS when subjected to alternative contaminant profiles and concentrations.

Our Response

Comments from the Deputy Program Manager did not address the specifics of the recommendation; therefore, the recommendation is unresolved. We acknowledge the PMA-275's plan to test the EAPS and engine using two soil samples and develop an analytical model that will be capable of evaluating alternate soil samples. However, we do not agree that the two soil sample compositions are representative of environments where the V-22 operates. Specifically, we evaluated the soil samples that the PMA-275 intends to use for testing and compared them to soils that exist in operating environments for the V-22. Our analysis showed that the samples that the PMA-275 intends to use are not representative of areas where the V-22 operates. While we see the development of an analytical model for the EAPS as a valuable tool for evaluating V-22 performance when subjected to soil compositions that were not tested directly, we believe that the model should be validated using soil samples that are representative of actual operating areas for the V-22.

We revised Recommendation A.1.b to clarify our intent that the PMA-275 should include soil samples which are representative of actual operational environments, instead of soil samples from all desert environments, for testing of the V-22 EAPS and engine in order to validate the analytical model. We request that the V-22 Joint Program Office Commander provide comments on the revised recommendation no later than December 9, 2019.

Appendix

Scope and Methodology

We conducted this evaluation from September 2018 through July 2019 in accordance with the "Quality Standards for Inspection and Evaluation," published in January 2012 by the Council of the Inspectors General on Integrity and Efficiency. Those standards require that we adequately plan the evaluation to ensure that objectives are met and that we perform the evaluation to obtain sufficient, competent, and relevant evidence to support the findings, conclusions, and recommendations. We believe that the evidence obtained was sufficient, competent, and relevant to lead a reasonable person to sustain the findings, conclusions, and recommendations.

We conducted a site visit to Naval Air Station Patuxent River, Maryland, to meet with the Naval Air Systems Command, V-22 Joint Program Office (PMA-275). Specifically, we obtained the following documentation:

- "Capability Development Document for V-22," February 23, 2007, which identifies the operating capabilities of the V-22.
- "Detail Specification for V-22," September 1, 2017, which contains the PMA-275 specification for the EAPS.
- "Military Turboshaft Engine, Rolls-Royce Model AE 1107C," February 22, 2002, which is the Rolls-Royce engine specification.
- Documentation of past redesign efforts to replace the EAPS.
- Documentation of the effects of the inability of the EAPS to protect the engine in desert environments.
- "V-22 Engine Air Inlet System Requirements Document," which details the specification for the third EAPS redesign.

We also conducted site visits to Marine Corps Air Station New River, North Carolina, and Kirtland Air Force Base, New Mexico, to meet with V-22 aircrew and maintainers. In addition, we observed operational profiles for the V-22 to obtain an overall orientation of operations and tactical landings. We also witnessed RVLs in the desert to gain a better understanding of the EAPS' function in those situations.

To determine whether the EAPS meets the Rolls-Royce specification for engine air cleanliness, we compared the EAPS specification in the "Detail Specification for V-22" to the Rolls-Royce specification for air cleanliness in the Military Turboshaft Engine, Rolls-Royce Model AE 1107C. We reviewed the specifications for past attempts to redesign the EAPS and compared them to the Rolls-Royce specification. We also compared the specification for the third EAPS redesign to the Rolls-Royce specification.

Finally, we worked with subject matter experts in soil science from the Army, Engineer Research and Development Center, Environmental Laboratory, to determine whether the types of soil being used for the V-22 EAPS design and testing were appropriate. The subject matter experts analyzed the soils that were used for testing the V-22 engine and EAPS and compared them to the soils that exist in environments where the V-22 operates.

Use of Computer-Processed Data

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

Use of Technical Assistance

We used soil scientists from the Army, Engineer Research and Development Center, Environmental Laboratory to assist in conducting this evaluation.

Prior Coverage

No prior coverage has been conducted on the V-22 EAPS during the last 5 years.

Management Comments

The V-22 Joint Program Office Commander

DEPARTMENT OF THE NAVY RESPONSE
TO DODIG DRAFT AUDIT REPORT ON
"Evaluation of the V-22 Engine Air Particle Separator"
PROJECT # D2018-D000PT-0202.000
Dtd 26 August 2019

Executive Summary:

PMA-275 does not concur with the recommendations put forth by the DODIG in Project No. D2018-D000PT-0202.000, "Evaluation of the V-22 Engine Air Particle Separator". The approach by DODIG to evaluate only one V-22 subsystem and not the overarching program strategy to enable safe operation of the V-22 during austere operations, does not capture the program's plan for addressing this risk. PMA-275 is using a systems engineering approach to meeting this goal which involves multiple, layered mitigation elements. This approach enables safe operation of the V-22, while not relying on a single aircraft subsystem or mitigation step. PMA-275's approach is working, as there have been no particulate-induced engine rapid power loss mishaps since implementing the latest mitigations over four years ago.

Part of PMA-275's approach to address safe operation of the V-22 during austere operations is improving the current EAPS as much as technically possible. PMA-275 performed extensive market research, technical development and evaluation of every design put forward. Based on this work, PMA-275 determined that it is not technically possible to develop, integrate and field an inlet air particle separator system capable of fully protecting the V-22 engine from all possible soil types and concentrations for unlimited durations. The V-22 engine OEM also reached this same conclusion, based on their technical evaluation of these potential designs. Fully protecting the V-22 engine from all possible soil types and concentrations for unlimited durations, however, is not required to achieve the program goal of safe V-22 operations in austere conditions. This goal is achievable through the measures currently in place and will be mitigated further as the program fields additional risk mitigation elements in development, including an improved EAPS. Based on the extensive work to date by both PMA-275, the engine OEM and the aircraft OEM, the program will continue its plan to significantly improve the current EAPS system as part of the overarching program plan to address safe operation of the V-22 during austere operations.

~~FOR OFFICIAL USE ONLY~~

Destruction of non-record documents containing controlled unclassified information, shall be destroyed by any of the means approved for the destruction of classified information or by any other means that would make it difficult to recognize or reconstruct the information.

Page **1** of **10**

The V-22 Joint Program Office Commander (cont'd)

While PMA-275 does not concur with the recommendations in this report, the program does agree that V-22 operations in austere environments is a critical capability for the program. The program also agrees that understanding the current EAPS capability is important especially as it pertains to improving the current design, and is included in the current development effort. We will continue to work with the engine and aircraft OEM to continue reducing the risks of operating V-22s in austere environments. The program is executing a plan, based on years of market research and technical work referenced in this response, as part of an overarching plan, which includes an improved EAPS, in addressing V-22 risk while operating in austere environments.

MARINO.JOHN.C[redacted] Digitally signed by MARINO[redacted] for

M. G. KELLY, COL, USMC
V-22 JOINT PROGRAM OFFICE (PMA275)

10/7/2019
Date

~~FOR OFFICIAL USE ONLY~~

Destruction of non-record documents containing controlled unclassified information, shall be destroyed by any of the means approved for the destruction of classified information or by any other means that would make it difficult to recognize or reconstruct the information.

Page **2** of **10**

The V-22 Joint Program Office Commander (cont'd)

Recommendation A.1.a: Recommend the V-22 Joint Program Office Commander conduct a review of alternatives for the Engine Air Particle Separator and V-22 engine so that the Engine Air Particle Separator adequately protects the V-22 engine in all desert environments.

NAVAIR Comments: ***Do not concur. PMA-275 would concur with an alternate recommendation:***

Recommend the V-22 Joint Program Office Commander continue executing the planned development and implementation of the suite of V-22 improvements, based on the NAVAIR risk assessment and exhaustive analysis of alternatives already completed, specifically aimed at reducing the risk to the V-22 aircraft when operating in austere environments.

1. The DoD OIG Project No. D2018-D000PT-0202.000, "Evaluation of the V-22 Engine Air Particle Separator", focused on the V-22 Engine Air Particle Separator (EAPS) system capability to protect the V-22 engine in all desert environments. This evaluation approach is narrowly focused on one V-22 subsystem and not the overarching goal of enabling safe operation of the V-22 during austere operations. Through extensive market research, development and technical evaluation, PMA-275 determined that it is not technically possible to develop, integrate and field an inlet air particle separator system capable of fully protecting the V-22 engine from all possible soil types and concentrations for unlimited durations. The engine OEM also reached this same conclusion, based on their technical evaluation of the potential designs. An improved EAPS system is part of a comprehensive a plan PMA-275 is executing to reduce the risk associated with the operation of the V-22 in austere environments. In contrast to a single technical solution, the current plan provides more robust protection, utilizing a systems engineering approach, and not solely reliant on any one mitigation measure.

In order to provide a categorical reduction to risk for V-22 operations in austere environments, the PMA-275 is working across multiple complementary lines of effort:

- Develop and field an improved EAPS system (Improved Inlet Solution (IIS))
- Develop and field a near real time Cockpit Engine Health Monitoring (CEHI) system
- Develop and implement updated training and operational guidance
- Develop and field Reduced Visibility Landing Assist Software
- Develop and field improvements to the V-22 engine
- Develop and field improved simulator visual database to more accurately depict brownout conditions.
- Field a reduced visibility visor for training use.
- Engine improvements increasing resistance to sand ingestion power loss

2. DoD OIG report Findings / Discussion:

Finding: **"**The PMA-275 did not develop an EAPS that protects the V-22 engine while operating in all desert environments. Specifically, the PMA-275 did not include a specification in the original EAPS design that required the EAPS to meet the engine manufacturer's specification

~~**FOR OFFICIAL USE ONLY**~~

Destruction of non-record documents containing controlled unclassified information, shall be destroyed by any of the means approved for the destruction of classified information or by any other means that would make it difficult to recognize or reconstruct the information.

Page **3** of **10**

The V-22 Joint Program Office Commander (cont'd)

for cleanliness of the air flowing into the engine. Despite two unsuccessful redesign efforts, the PMA-275's third EAPS redesign effort will also not meet the engine manufacturer's specification."

Discussion:
This finding mischaracterizes the V-22 engine model specification durability requirement pertaining to sand and dust ingestion. The V-22 engine sand and dust ingestion durability rating establishes sustained maximum continuous power endurance at a single specified contaminant ingestion profile over an extended period of hours. It does not characterize engine capabilities or limitations for other contaminant constituency profiles or during transient contaminant ingestion events such as Reduced Visibility Landings (RVL) with a duration of 35 seconds or less. The engine durability rating is neither an absolute "specification for air cleanliness that must be met for the V-22 engine" nor a contaminant ingestion threshold that can be tolerated "without causing engine degradation" as indicated throughout the DoDIG report.

PMA 275 acknowledges deficiencies with past V-22 aircraft specification separation efficiency requirements and verification methods dating back to 1980's Engineering & Manufacturing Development (EMD). Examples include:

- Original aircraft separation efficiency requirements were non-representative of V-22 austere operating environments and excluded fine particulates (<20 micron diameter)
- Qualification test excluded hydraulic blowers & associated installation effects
- Qualification test inaccurately assumed nominal, symmetrical scavenge flow conditions
- Qualification test did not control contaminant injection pattern factor / clocking

Legacy requirements deficiencies have been addressed during IIS requirements analysis & verification planning. Expanded inlet rig testing for the baseline EAPS and the new IIS configuration will take place from 2020 to 2022. Baseline test results will inform the planned system specification updates prior to preliminary design review for the IIS development project.

Finding: **"**The third EAPS redesign is intended to remove more soil from the air flowing into the V-22 engine than the original EAPS; however, the soil ingested into the engine would be four times greater than the engine manufacturer's specification allows. While PMA-275 officials stated that it is not technically feasible to meet the engine manufacturer's specification for air quality in a desert environment, they could not provide analysis that demonstrated whether this redesign would adequately protect the engine."

Discussion:
PMA-275 performed extensive market research, technical development and evaluation of every potential EAPS design put forward. Based on this work, PMA-275 determined that it is not technically possible to develop, integrate and field an inlet air particle separator system capable of fully protecting the V-22 engine from all possible soil types and concentrations for unlimited durations. The engine OEM also reached this same conclusion, based on their technical evaluation of the potential designs. These incompatibilities with V-22 engine operability

The V-22 Joint Program Office Commander (cont'd)

requirements, and safety impacts have been clearly documented[1].

Specifically:

- **Engine / Inlet Compatibility:** Wind tunnel testing of the inlet barrier filter configuration demonstrated unacceptable inlet pressure distortion (>2x engine distortion limits). This technical deficiency is incompatible with engine / inlet integration practice, is not airworthy, and would significantly increase operational safety risk. All inlet barrier filter design iterations subsequently developed and presented were technically evaluated and none were identified that could meet engine inlet distortion requirements. These conceptual engine / inlet compatibility solutions, including variable geometry inlet features, are technically & programmatically unviable for the following additional reasons:
    - Not Airworthy. Non-compliant with engine distortion & angularity limits.
    - Introduction of new critical single-point-of-failure modes (increased safety risk)

The statement "soil ingested into the engine would be four times greater than the engine manufacturer's specification allows" is inaccurate and mischaracterizes the engine model specification durability requirement pertaining to sand and dust ingestion. The updated engine air inlet / inlet particle separator system specification[2] efficiency threshold will limit engine particulate ingestion to a rate less than three times the engine durability specification at specified environmental conditions[3]. As previously stated, the engine particulate ingestion rating pertains to sustained maximum continuous power operation for an extended period of hours. This durability rating does not characterize engine capabilities or limitations during authorized RVL operational limits with time scales in the range of seconds, not hours.

PMA-275 system requirements analysis and risk management strategy align with extensive market research, analysis, testing, and organizational experience developed over 500K accumulated flight hours. Implementation of V-22 engine rapid power loss mitigation initiatives including the improved EAPS system are projected to reduce mishaps due to engine rapid power loss event frequency from current rating or "Remote" to "Improbable" and improve engine reliability by 43%. This represents a categorical reduction in system safety risk.

Supporting evidence:

---

[1] AIR 4.4/17-185 Recommendations for V-22 Inlet Barrier Filter Program (2017-04-12); Improved Inlet Solution TIM #8 Presentation (2017-10-30); V-22 Improved Inlet Solution (IIS) Technical Assessment (2017-11-02)

[2] "Engine Air Inlet / Inlet Particle Separator System Specification" Particulate Brownout Tech Report R110565-05, and NATOPS A1-V22AB-NFM-000 operational guidance.
901-947-489 superseded referenced "V-22 Engine Air Inlet System Requirements Document" as of System Requirements Review 2 in March 2019.

[3] Based on NAVAIR Propulsion & Power unsteady Large Eddy Simulation performance models (2019), DARPA "Sandblaster" Particulate Brownout Tech Report R110565-05, and NATOPS A1-V22AB-NFM-000 operational guidance.

FOR OFFICIAL USE ONLY

The V-22 Joint Program Office Commander (cont'd)

- The PMA-275 is developing an IIS to replace the current EAPS system. Completion of development is scheduled for 2023. The below activities are complete or in work and inform the design activity.

  - **Engineering Investigations (2013-2015):** PMA 275 and industry partners conducted Engineering Investigations (EIs) for both catastrophic events cited in the DoD OIG report. The EIs determined technical, environmental, and human contributing factors and established detailed failure mode progression timelines and contaminant analyses to inform a system safety risk assessment and corrective action planning. **(Action Complete)**

  - **Analysis of Alternatives / Market Research (2014-2018):** PMA 275 executed an exhaustive inlet particle separation analysis of alternatives, issued a Broad Agency Announcement / Request for Information, evaluated a portfolio of fielded and developmental inlet particle separators, and reviewed available prototype rig test data. The updated V-22 separation efficiency requirements are consistent with state-of-the-art inertial particle separator technology and the IIS specification documents these requirements to provide the improvement in system safety as stated above. **(Action Complete)**

    Analysis of Alternatives Summary:

    - V-22 inlet particle separation analysis of alternatives (2014): PMA 275 commissioned an independent trade study of six V-22 inlet particle separator configuration candidates. Final recommendation was an enhanced inertial separator system similar to the current IIS architecture.

    - V-22 inlet particle separation Broad Agency Announcement (BAA) / Request for Information (RFI) (2017): PMA 275 solicited inputs from industry & academia to inform V-22 Inlet Particle Separator requirements and architecture. Three actionable responses were received from industry and evaluated across 14 technical criteria. The two highest scoring responses recommended an enhanced inertial separator system similar to the current IIS development effort.

    - Other Experience / Market Research that support the current technical approach:
      - Evaluation of in service particle separators on military aircraft: V-22, H-60, CH-53K, CH-47.
      - Evaluation of developmental particle separation technologies for developmental military aircraft

  - **V-22 Improved Inlet Solution Modeling & Simulation Working Group (2018):** Independent, peer-reviewed aerodynamic and sand separation performance modeling working group to include NAVAIR and V-22 aircraft / engine OEM technical area

The V-22 Joint Program Office Commander (cont'd)

experts. This team will evaluate system Technical Performance Measures throughout system development. **(Action ongoing through development phase of EAPS redesign)**

- **Engine Particle Ingestion Testing (2020):** The relationship between engine particulate ingestion rate & performance deterioration rate is well established across the military turboshaft engine portfolio. Scheduled engine testing in 2020 to evaluate performance degradation trends and recovery options will inform IIS requirements analysis, design trade-offs, and qualification. **(Action ongoing, scheduled to Complete in CY 2020)**

- **Inlet Rig Testing (2020):** Upcoming V-22 Inlet Rig Test in 2020 will characterize baseline inlet performance and separation efficiency for a broader spectrum of contaminant profiles. Data will inform updates to the IIS system specification prior to preliminary design review. **(Action ongoing, scheduled to complete in CY 2020)**

- PMA-275 is developing a near real time **Cockpit Engine Health Monitoring** system. Initial software development and a field service evaluation of CEHI are complete. PMA 275 evaluated data from 1,347 operational sorties (including austere takeoff & landings) to establish AE1107C performance degradation and turbine flow capacity trends. The evaluation revealed no precursor symptoms of engine rapid power loss, substantiating effectiveness of the updated training and operational guidance described below. CEHI engine health monitoring provides aircrew with early warning of imminent engine surge or rapid power loss events and allows the aircrew time to take corrective action to reduce risk of engine failure. **(Action ongoing, fleet implementation scheduled for 2021)**

- ~~(FOUO)~~ [redacted]

- ~~(FOUO)~~ [redacted]

~~**FOR OFFICIAL USE ONLY**~~

Destruction of non-record documents containing controlled unclassified information, shall be destroyed by any of the means approved for the destruction of classified information or by any other means that would make it difficult to recognize or reconstruct the information.

Page **7** of **10**

The V-22 Joint Program Office Commander (cont'd)

- PMA-275 is developing **<u>Engine Improvements</u>** for the V-22 that reduce susceptibility to deposition of reactive sand on critical surfaces in the turbine, leading to rapid power loss events. The below activities are complete or in work and inform the design activity.

  - **Turbine Rig Testing (2018):** V-22 engine turbine rig testing, in partnership with industry and academia, established current turbine nozzle design sand deposition trends. Additional turbine rig testing scheduled in 2020 will evaluate new turbine nozzle prototypes to reduce or eliminate deposition of reactive sand on critical surfaces to mitigate engine rapid power loss. **<u>(2018 testing: Action Complete, follow on testing scheduled for CY 2020)</u>**

Conclusions or recommendations based solely on implementation of an improved EAPS are not sufficient to meet the requirements and/or operational effectiveness necessary. Consideration of the broader PMA 275 concept of operations and risk management strategy is required to assess the effectiveness of the solutions being developed and implemented. PMA-275 is utilizing a robust systems engineering approach in identifying and implementing corrective actions that are technically feasible and executable by leveraging our technology development portfolio across multiple work streams. The development and implementation of the above efforts is representative of the systems level approach and plan of action PMA-275 is executing to mitigate the risk of rapid power loss events. It reflects actionable technical and non-technical approaches to reduce risk to aircrew and aircraft operating in austere environments. IIS is one developmental work stream within the overall plan. Technical constraints and the inherent capabilities of inertial type particle separation systems necessitate this type of comprehensive mitigation plan, which provides a balanced approach.

<u>Finding:</u> **"**As a result, the V-22 remains at risk despite more than nine years of EAPS redesign attempts. Additionally, the PMA-275 cannot be certain that the third EAPS redesign will correct long-standing problems with the V-22."

<u>Discussion:</u>
Residual non-zero operational safety risk will remain following implementation of the improved EAPS. The additional PMA 275 risk reduction initiatives being executed in a systems engineering approach include: <u>Training & Operational Guidance</u>, <u>Reduced Visibility Landing Assist Software</u>, <u>Cockpit Engine Health Indication (CEHI)</u>, and <u>AE1107C Configuration Changes</u> are being developed to reduce the risk of a mishap in the RVL environment.

The improved EAPS program, like any research & development program, requires active management of requirements, design tradespace, resources, and risks. Technical baseline maturation is executed in accordance with NAVAIR systems engineering and the PMA 275 risk management processes to methodically reduce uncertainty regarding end-state operational suitability. System verification activities will include both rig and instrumented flight tests.

The V-22 Joint Program Office Commander (cont'd)

Recommendation A.1.b: Recommend the V-22 Joint Program Office Commander develop a plan to test the Engine Air Particle Separator and engine with soil compositions and concentrations that are representative of all desert environments where the V-22 operates.

NAVAIR Comments: ***Do not concur. PMA-275 would concur with an alternate recommendation:***

Recommend the V-22 Joint Program Office Commander execute the existing program plan to test the Engine Air Particle Separator with soil compositions and concentration levels that are representative of known operational environments which encompass the stressing cases of particle sizes and compositions, as well as conduct planned engine rig testing for soil types and concentrations that are known to cause rapid engine power loss events due to deposition of reactive sand in the turbine.

1. "Representative of **all** desert environments" requires actionable definition and is not testable as described, as the V-22 operates worldwide in an infinite number of soil types and compositions. Improved Inlet Solution rig test contaminant profiles were selected in accordance with the Joint Service Specification Guide Engines Aircraft Turbine to test the stressing conditions of the system to ensure operational effectiveness throughout the world. The sand and dust particle size distribution & constituents are representative of V-22 austere operating environments in the United States and Middle East, and reactive sands in Southwest Asia and North Africa. Contaminant concentration is based on DARPA Particulate Brownout Report R110565-05, the most conservative airborne sand & dust survey known to PMA 275. Alternative contaminant profiles & concentrations can be evaluated analytically following separation efficiency performance model validation. Baseline inlet rig and engine particulate ingestion tests are scheduled for completion in CY 2020. IIS rig testing is scheduled for 2022 completion, after completion of the Critical Design Review.

2. DoD OIG report Findings / Discussion

Finding: **"**Additionally, the PMA-275 intends to test the third EAPS redesign with soil that is not representative of all environments where the V-22 operates, relying instead on military standard soil compositions and soil concentrations based on testing from a single desert environment. This occurred because the PMA-275 is not taking advantage of the ability to tailor military standard soil samples."

Discussion:

IIS rig test contaminant profiles include Joint Service Specification Guide A4 (fine), CSPEC (coarse), and AFRL03. A4 & CSPEC sand and dust particle size distribution & constituents are representative of V-22 austere operating environments in the United States and Middle East. Industry & government analysis shows these selected qualification particle size distributions bracket known V-22 austere operating environments. AFRL03 sand composition is representative of reactive sands in Southwest Asia and North Africa. It has the right constituents (34% Quartz, 30% Gypsum, 17% Aplite, 14% Dolomite, 5% Salt) to cause deposition of sand on

The V-22 Joint Program Office Commander (cont'd)

critical surfaces in the engine turbine with a similar melting point to naturally occurring sands in the above regions.

Improved EAPS rig test contaminant concentration is based on DARPA Particulate Brownout Report R110565-05, the most conservative airborne sand & dust survey known to PMA 275. For context, this concentration is 37% higher than comparable Kirtland AFB measurements referenced in the previous Inlet Barrier Filter specification. Inlet particle separation efficiency is largely independent of airborne particulate concentration.

CY20 inlet rig test data will be used to validate & calibrate separation efficiency performance models, facilitating rapid, accurate analysis of system performance for alternative contaminant profiles & concentrations.

The PMA 275 test plan for the improved EAPS, to include the test contaminant profiles selected, represents an actionable test plan and provides for a realistic developmental timeline that balances representation of "all possible environments" with representation of the known / most likely and stressing operational environments.

Acronyms and Abbreviations

EAPS	Engine Air Particle Separator
JSSG	Joint Service Specification Guide
PMA-275	Program Manager, Air 275
RVL	Reduced Visibility Landing

Whistleblower Protection

U.S. Department of Defense

Whistleblower Protection safeguards DoD employees against retaliation for protected disclosures that expose possible waste, fraud, and abuse in government programs. For more information, please visit the Whistleblower webpage at http://www.dodig.mil/Components/Administrative-Investigations/Whistleblower-Reprisal-Investigations/Whisteblower-Reprisal/ or contact the Whistleblower Protection Coordinator at Whistleblowerprotectioncoordinator@dodig.mil

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

Congressional Liaison
703.604.8324

Media Contact
public.affairs@dodig.mil; 703.604.8324

DoD OIG Mailing Lists
www.dodig.mil/Mailing-Lists/

Twitter
www.twitter.com/DoD_IG

DoD Hotline
www.dodig.mil/hotline

~~FOR OFFICIAL USE ONLY~~

DEPARTMENT OF DEFENSE | OFFICE OF INSPECTOR GENERAL

4800 Mark Center Drive
Alexandria, Virginia 22350-1500
www.dodig.mil
DoD Hotline 1.800.424.9098

~~FOR OFFICIAL USE ONLY~~