

October 24, 2002



Acquisition

Fuel Cells of the V-22 *Osprey* Joint
Advanced Vertical Aircraft
(D-2003-013)

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Acronyms

EMD	Engineering and Manufacturing Development
FAA	Federal Aviation Administration
FSD	Full-Scale Development
IOT&E	Initial Operational Test and Evaluation
LRIP	Low-Rate Initial Production
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics



INSPECTOR GENERAL
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October 24, 2002

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION,
TECHNOLOGY, AND LOGISTICS

SUBJECT: Report on the Fuel Cells of the V-22 *Osprey* Joint Advanced Vertical
Aircraft (Report No. D-2003-013)

We are providing this report for information and use. This audit resulted from an allegation concerning the crashworthiness of the fuel cells or tanks installed on the V-22 *Osprey*. We considered management comments on a draft of this report when preparing the final report.

Management comments on the draft of this report conformed to the requirements of DoD Directive 7650.3 and left no unresolved issues. Therefore, no additional comments are required.

We appreciate the courtesies extended to the staff. Questions should be directed to Mr. John E. Meling at (703) 604-9091 (DSN 664-9091) (jmeling@dodig.osd.mil) or Mr. Jack D. Snider at (703) 604-9087 (DSN 664-9087) (jsnider@dodig.osd.mil). See Appendix O for the report distribution. The team members are listed inside the back cover.

David K. Steensma

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Office of the Inspector General of the Department of Defense

Report No. D-2003-013

October 24, 2002

(Project No. D2002AE-0065.001)

Fuel Cells of the V-22 *Osprey* Joint Advanced Vertical Aircraft

Executive Summary

Who Should Read This Report and Why? This report should be read by all who are interested in Marine Corps aviation, DoD acquisition processes, and aviation safety. The report discusses fuel cell safety considerations for the V-22 *Osprey* Joint Advanced Vertical Aircraft (V-22) used for flight testing.

Background. This audit resulted from allegations referred to the Office of the Inspector General of the Department of Defense by the Commandant of the Marine Corps on December 27, 2001. Of those allegations, four concerned the crashworthiness of the fuel cells or tanks installed on the V-22. Specifically, it was alleged by a Marine aviator that:

- the fuel cell installed in the V-22 was not able to withstand the required 10g (gravitational acceleration) impact;
- a fuel cell that could withstand the impact was developed but not installed because of structural issues affecting the weight of the aircraft;
- the V-22 design could have incorporated breakaway fuel cells, which break away on impact to prevent fires and explosions, but, instead, incorporated fuel cells that will burst and flood the cabin with fuel; and
- because the V-22 fuel cells did not pass the drop test, the V-22 fuel cell standards were lowered to incorporate a cell design that would work and still maintain a weight savings.

Appendix B of this report covers those four allegations. The Office of the Inspector General of the Department of Defense addressed the other allegations in a separate report, dated August 19, 2002.

On May 29, 2002, the Navy restarted engineering and manufacturing development (EMD) flight testing of the V-22 aircraft. As of October 2002, the program was in low-rate initial production. The Under Secretary of Defense for Acquisition, Technology, and Logistics (the Under Secretary) has not determined a date for the full-rate production decision.

Results. Safety risks for V-22 flight testing were not minimized because V-22 aircraft in use for EMD flight testing have noncrashworthy fuel cells. The V-22 fuel cells in the sponsons for the 4 EMD aircraft, the aft fuel cell in the right fuselage sponson for the 12 low-rate initial production aircraft in Lots 1 and 2, and all fuel cells in the fuselage sponsons for the 7 low-rate initial production aircraft in Lot 3 did not meet crashworthiness standards. Further, the V-22 fuel cells in the EMD aircraft and in the low-rate initial production aircraft in Lots 1, 2, and 3 did not meet ballistic live-fire requirements. For subsequent lots, the contractor developed sponson fuel cells that meet crashworthiness and ballistic requirements. The V-22 Program Office plans to install those compliant fuel cells at an average cost to the Government of about \$512,000 per aircraft on the 17 remaining low-rate initial production aircraft from Lots 1 through 3.

However, the V-22 Program Office does not plan to install crashworthy sponson fuel cells on V-22 aircraft used for EMD testing. As a result, the safety risk to aircrews of those aircraft will not be minimized if the aircraft are not retrofitted before further flight testing.

The Navy did not approve retrofitting the EMD aircraft with crashworthy fuel cells to minimize aircrew risk because those aircraft would be used only for flight testing. Consequently, on March 15, 2002, we requested that the Under Secretary determine whether the risk of flying the EMD aircraft with noncrashworthy fuel cells was acceptable. On April 3, 2002, the Under Secretary responded, stating that the benefits of returning to flight as scheduled to address other technical concerns outweighed the limited risk reduction attained by retrofitting the aircraft with crashworthy fuel cells. The Under Secretary also stated that he agreed with the assessment by the Commander, Naval Air Systems Command that the risk of conducting developmental testing with noncrashworthy fuel cells was within manageable flight test boundaries and with the Commander's decision to return to developmental testing with aircraft having noncrashworthy fuel cells. The Commander cited a system safety assessment of the V-22 as part of the basis for his decision; however, the V-22 Program Office and Boeing were not able to provide us with documentation that supported the system safety risk assessment.

On May 28, 2002, in response to an informal recommendation, the Under Secretary stated that the Navy had now formally documented its risk assessment process. However, when the Under Secretary made his decision, the risk assessment was not supported by documentation and the methodology used was flawed. On June 7, 2002, we informed the Under Secretary that the risk assessment raised a fundamental question concerning the evaluation methodology used because it did not consider the unique nature of the EMD testing and the EMD test aircraft. On July 12, 2002, the Navy provided the supporting data for the risk assessment, which was less than adequate. To have been a meaningful risk assessment, the methodology should have been revised to include a crash frequency probability based on the past performance of either the V-22 EMD test or other developmental aircraft. Further, the system safety risk assessment model should have been adjusted to account for the nonindependence between the "probability that the crash occurs over land" and the "probability that a crash is survivable." Using the crash frequency probability data that the Navy did provide and adjusting for the revised methodology, the safety risk assessment code would increase from undesirable or a medium safety risk to unacceptable or high safety risk. (See the Finding section of the report for the detailed recommendations.)

Management Comments. In response to the draft report, the Under Secretary stated that he has again concluded that the benefits of continuing to fly to address his other technical concerns outweighed the limited risk reduction attained by stopping the V-22 flight test program and retrofitting fuel cells with greater crashworthiness on the four EMD-only aircraft. The Under Secretary agreed that the Military Departments should use relevant methodology in their risk assessment procedures, including calculations of risk probability, and that risk assessments should be fully supported and documented. The Under Secretary stated that his office will ensure that the Military Departments' safety organizations review their procedures and update them, as appropriate. (See the Finding section of this report for a discussion of the management comments and the Management Comments section of the report for the complete text of the comments.)

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Source: Naval Air Systems Command V-22 Website

V-22 *Osprey* Joint Advanced Vertical Aircraft

Background

Allegation. The Office of the Inspector General of the Department of Defense received multiple allegations concerning the viability of the V-22 *Osprey* Joint Advanced Vertical Aircraft (the V-22). This audit resulted from allegations referred to us by the Commandant of the Marine Corps on December 27, 2001. The audit addressed four allegations concerning the crashworthiness of the fuel cells or tanks installed on the V-22. The Office of the Inspector General of the Department of Defense will address the other allegations in a separate report. See Appendix B for further details regarding the four allegations.

V-22 Aircraft. The V-22, a Navy Acquisition Category ID program, is a tilt-rotor, vertical take-off and landing aircraft, which operates as a helicopter for takeoffs and landings and, once airborne, converts to a turboprop aircraft. The V-22 is expected to operate in global and regional conflicts in support of operations ranging from peacetime engagements to conventional, high-intensity, general warfare. The V-22 has three variants: the Marine Corps variant to meet amphibious and vertical assault needs, the Navy variant to be used for rescue needs, and the Air Force variant for special operations missions. The V-22 *Osprey* will replace the Marine Corps CH-46E *Sea Knight* and the CH-53D *Sea Stallion*. Appendix C provides additional definitions of technical terms used in this report.

The V-22 Program started in December 1981 and was originally managed by the Army until it was transferred to the Navy in 1982. The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) approved the entry of the V-22 into low-rate initial production (LRIP) in April 1997, and delegated future V-22 production decisions to the Navy. However, in May 2001, the USD(AT&L) designated the V-22 as an Acquisition Category ID program, thereby rescinding the previous delegation. The V-22 Program Manager manages the V-22 acquisition program under the Program Executive Office, Air Anti-Submarine Warfare, Assault, and Special Mission Programs. Bell Boeing, a joint venture of Bell Helicopters Textron and the Boeing Company, teamed up to develop and produce the V-22.

Since the V-22 Program began in 1981, it has lost four aircraft. In June 1991, a full-scale development (FSD) V-22 aircraft experienced a vertical takeoff accident due to improper installation of sensors in the flight control system. In July 1992, a second FSD aircraft encountered a fatal accident because of drive shaft and engine failure resulting from compressor stall and fire. In April 2000, an LRIP aircraft experienced an excessive rate of descent and the effects of a vortex ring state that resulted in an asymmetrical loss of lift accompanied by a roll at too low an altitude to recover before ground impact. In December 2000, another LRIP aircraft crashed resulting from the loss of a hydraulic line combined with a flight control software malfunction. As a result of the mishaps and operational suitability issues identified in testing, the Secretary of Defense established an independent review of the V-22 Program by a group known as "The Blue Ribbon Panel." The Blue Ribbon Panel found no evidence of inherent safety flaws in the V-22 tilt-rotor concept and recommended that the program be continued, but restructured. The Blue Ribbon Panel determined that

the V-22 aircraft lacked the maturity needed for full-rate production or operational use and made recommendations for corrective action. Based on the Blue Ribbon Panel's recommendations, the USD(AT&L) restructured the V-22 Program and required extensive additional flight testing.

The Navy and the Air Force plan to acquire 397 and 40 aircraft, respectively, at an estimated cost of \$37.2 billion from FY 1982 through FY 2015. As of March 2002, the Navy had acquired or contracted for 40 V-22 aircraft consisting of FSD, engineering and manufacturing development (EMD), and LRIP aircraft, as shown in the following table and Appendix D.¹

V-22 Aircraft Under Contract or Delivered		
<u>Acquisition Phase</u>	<u>Aircraft Under Contract</u>	<u>Aircraft Delivered</u>
FSD	6	5 ²
EMD	4	4
LRIP Lot 1	5	5 ³
LRIP Lot 2	7	5 ⁴
LRIP Lot 3	7	0
LRIP Lot 4	<u>11</u>	<u>0</u>
Total	40	19

On May 29, 2002, the Navy restarted EMD flight testing of the V-22 aircraft. As of October 2002, the program was in LRIP; however, USD(AT&L) has not determined a date for the full-rate production decision.

V-22 Fuel Cells. The V-22 fuel cell is a flexible bladder that is shaped to fit the designated cavity in the V-22 aircraft and is designed to hold aircraft fuel. All fuel cells are to be self-sealing when penetrated by a 12.7 millimeter or .50 caliber armor-piercing projectile and meet a drop test requirement of 65 feet when filled with water.

The three V-22 variants have different fuel cell configurations. The Navy and Marine Corps variants have five fuel cells integrated into the wings and fuselage sponson:⁵ two wing feed cells, two forward sponson cells, and a right aft sponson cell. The Air Force variant has four additional cells in each wing.

¹Subsequent to the completion of our audit fieldwork, the Navy notified us that it had contracted for 20 LRIP aircraft for Lots 5 and 6. Our review included only those LRIP aircraft from Lots 1 through 4.

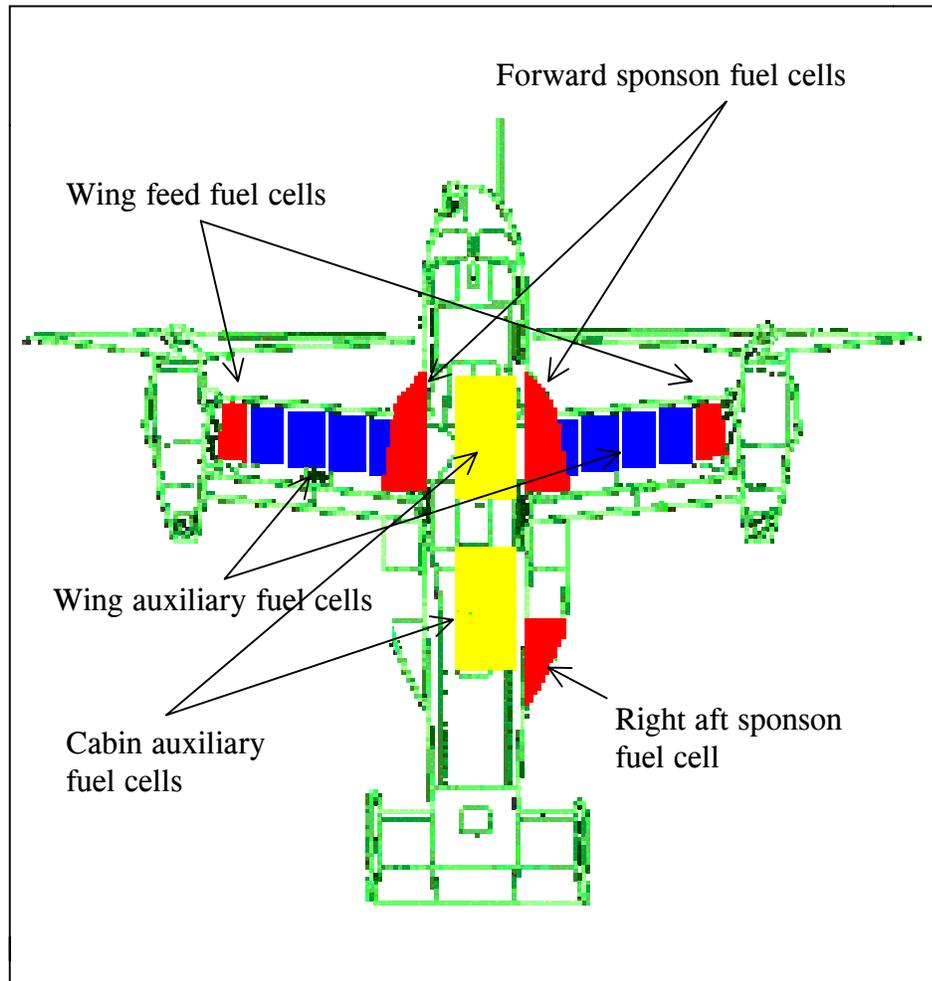
²Two of those aircraft crashed, one was used for live-fire testing, and two are display aircraft. One of the aircraft under contract was never built.

³One of those aircraft crashed.

⁴One of those aircraft crashed.

⁵A sponson is a projection from the side of the aircraft that holds the fuel cells and landing gear.

Each variant can carry additional auxiliary cells in the cabin for self-deployment missions. The following figure shows the fuel cell configurations.



V-22 Fuel Cell Configuration

Source: Naval Air Systems Command V-22 Website

Objectives

The primary audit objective was to review the documentation associated with developing, contracting, testing, and installing the fuel cells on the V-22 and the future funding for fuel cell improvements. See Appendix A for a discussion of the audit scope and methodology, and prior coverage related to the audit objectives.

V-22 Fuel Cell Crashworthiness and Ballistic Requirements

Safety risks for V-22 flight testing were not minimized because V-22 aircraft in use for EMD flight testing have noncrashworthy fuel cells. The V-22 fuel cells in the fuselage sponsons for the 4 EMD aircraft, the aft fuel cell in the right fuselage sponson for the 12 LRIP aircraft in Lots 1 and 2, and all fuel cells in the fuselage sponsons for the 7 LRIP aircraft in Lot 3 did not meet crashworthiness standards. Further, the V-22 fuel cells in the EMD aircraft and in the LRIP aircraft for Lots 1, 2, and 3 did not meet ballistic live-fire requirements. The Navy did not plan to remedy those conditions for the EMD test aircraft because they would be used only for flight testing. The V-22 Program Office issued a waiver for the LRIP aircraft to allow noncompliant fuel cells to be installed so that aircraft production would not be delayed. For subsequent lots, the contractor developed sponson fuel cells that meet crashworthiness and ballistic requirements. The V-22 Program Office plans to install those compliant fuel cells at an average cost to the Government of about \$512,000 per aircraft on the 17 remaining LRIP aircraft from Lots 1 through 3, but does not plan to install crashworthy sponson fuel cells on the V-22 aircraft used for EMD testing because:

- a formal safety risk assessment evaluated the fuel cell configuration to be a medium risk and
- the benefits of returning to flight outweighed the limited risk reduction attained by retrofitting the aircraft with crashworthy fuel cells.

However, the formal safety risk assessment was not supported by documentation before flight testing resumed and the methodology used was flawed. As a result, the safety risk assessment cannot be relied upon and the safety risk to aircrews of those EMD test aircraft will not be minimized if the aircraft are not retrofitted before further use in flight testing.

V-22 Fuel Cell Specifications

The following provides an overview of the military specifications associated with the V-22 fuel cells.

Navy Specification. Naval Air Systems Command specification document, SD 572-1, Revision C, "Detailed Specification for V-22 Engineering and Manufacturing Development," September 13, 1995, establishes the qualification requirements for the V-22 to enable the Army, Navy, Air Force, and Marine Corps to conduct combat missions requiring vertical and short-field takeoffs and landings. The specification states that the fuel cells will be manufactured in accordance with the contractor's specification that defines two types of fuel cell construction: nonextensible (high-strength fabric) and extensible (flexible

rubber). The sponson fuel cells will be self-sealing for the lower third and inboard wall of the cell. The contractor will establish the effects that weight and cost have on the aircraft to determine damage tolerance. When damage tolerance requirements cannot be met because of stringent contract weight, cost, or other penalties, the contractor is to identify such affected areas and propose deviations or waivers of specific requirements, subject to Naval Air Systems Command approval.

Further, the specification states that aircraft crashworthiness should meet the requirements of Military Standard 1290, "Light Fixed and Rotary Wing Aircraft Crashworthiness," July 21, 1977, to the maximum extent practical. Appendix A, "Test Methods," of the Standard states that fuel cells will be tested in accordance with DoD Military Specification MIL-T-27422B, "Tank, Fuel, Crash-Resistant, Aircraft," February 24, 1970.

Military Specification. DoD Military Specification MIL-T-27422B allows for crashworthy fuel cells that will be either self-sealing or non-self-sealing. A crashworthy and self-sealing fuel cell is designed to withstand a 65-foot drop without leaking and seal itself if a projectile penetrates the cell wall. Any rupture from the drop that results in spillage constitutes failure. Further, all gunfire wounds associated with ballistic live-fire testing must self-seal within a specified timeframe after being penetrated by an armor-piercing projectile up to 12.7 millimeters or .50 caliber.

V-22 Fuel Cell Compliance

The V-22 fuel cells in the fuselage sponsons for the EMD aircraft, the aft fuel cell in the right fuselage sponson for the LRIP aircraft in Lots 1 and 2, and all of the fuel cells in the fuselage sponsons for the LRIP aircraft in Lot 3 did not meet crashworthiness standards. Further, the V-22 fuel cells in the EMD aircraft and in the LRIP aircraft in Lots 1, 2, and 3 did not meet ballistic requirements.

V-22 Fuel Cell Development. The contract specifications for the V-22 aircraft allow the use of extensible or nonextensible fuel cells. To obtain a significant aircraft weight savings, Boeing and the Navy decided to use the extensible fuel cell construction in the fuselage sponson fuel cells of the V-22 aircraft, rather than the nonextensible fuel cell construction traditionally used in Navy helicopters. Boeing initially pursued using an extensible fuel cell developed by Fire Proof Tanks, a European company. However, because of the "Buy American" restriction of the Berry Amendment,⁶ Boeing did not use the European company to produce the extensible fuel cells. Consequently, Fire Proof Tanks licensed International Latex Company to produce the extensible

⁶The Berry Amendment, which Congress has included in various forms in DoD appropriations acts every year since 1941 and which the National Defense Authorization Act for FY 2002 codified, generally restricts DoD expenditure of funds for certain articles and items to American goods. The DoD Appropriations Act for FY 1968 added synthetic fabric and coated synthetic fabric to the Berry Amendment's list of protected articles. Fuel cells contain synthetic fabric.

fuel cells in the United States. Under this licensing agreement, International Latex Company manufactured the fuel cells installed on the 21 aircraft for FSD through LRIP, Lot 2. Specifically, Boeing used extensible fuel cells in the 5 FSD aircraft,⁷ the 4 EMD aircraft, and the 12 LRIP aircraft for Lots 1 and 2. For the 7 LRIP aircraft in Lot 3 and the 11 LRIP aircraft in Lot 4, Boeing used nonextensible fuel cells manufactured by American Fuel Cell and Coated Fabrics Company, and Engineered Fabrics Corporation, respectively. Appendix D lists the V-22 aircraft acquired from FSD through LRIP, Lot 4, and provides the results of testing performed on the fuel cells in those aircraft.

Crashworthiness and Ballistic Testing. The 4 EMD aircraft and the 19 LRIP aircraft in Lots 1, 2, and 3⁸ had wing fuel cells and breakaway valves that met crashworthiness and ballistic specifications. However, the fuel cells in the sponsons for the 4 EMD aircraft, the aft fuel cell in the right sponson in the 12 LRIP aircraft in Lots 1 and 2, and all fuel cells in the sponsons for the 7 LRIP aircraft in Lot 3 did not meet crashworthiness specifications. Further, the forward and aft fuselage sponson fuel cells in the EMD aircraft and the LRIP aircraft in Lots 1, 2, and 3 did not meet ballistic specifications. However, the sponson fuel cells for the LRIP aircraft in Lot 4 did meet crashworthiness and ballistic specifications.

Testing for Lots 1 and 2 Extensible Fuel Cells. The forward extensible fuel cells in the fuselage sponson used in the LRIP aircraft for Lots 1 and 2 passed the 65-foot drop test. However, the aft extensible fuel cell in the right fuselage sponson used in the Lots 1 and 2 aircraft experienced a 1.5 ounce per minute leak at the fittings after the 65-foot drop test. Further, none of the fuel cells in the Lots 1 and 2 aircraft passed the ballistic tests. Consequently, the contractor requested a waiver of the crashworthiness and ballistic qualification requirements for Lots 1, 2, and 3 aircraft for specific fuel cell part numbers. Even though the aft extensible fuel cell and all fuel cells in Lots 1 and 2 did not pass the drop test and the ballistic test, respectively, the V-22 Program Manager concluded that the fuel cells were acceptable for flight and approved the waiver, thereby accepting noncompliant fuel cells. Appendix E provides a copy of the waiver.

Although the extensible fuel cells were not a contributing factor to the April 2000 crash, the immediate post-crash fire generated interest in the issue of survivability as it related to the sponson fuel cells installed in the V-22. The Marine Corps concluded in its July 21, 2000, memorandum (commonly known as “JAGMAN Report”), “Investigation Into the Circumstances Surrounding the Class “A” Aircraft Mishap Involving an MV-22B Osprey Buno 165436 That Occurred on 8 April 2000 at Marana Northwest Regional Airport Near Tucson Arizona,” that the excessive forces resulting from gravitational acceleration encountered in the crash far exceeded the survivability requirements of the aircraft fuel system.

⁷The Navy planned to acquire six FSD aircraft; however, one was never built.

⁸Since the crashes, only 17 of those 19 LRIP aircraft remain.

Testing for Lot 3 Nonextensible Fuel Cells. For LRIP aircraft in Lot 3, Boeing subcontracted with a different contractor, American Fuel Cell and Coated Fabrics Company, for nonextensible cells in the sponson because the extensible cells used in Lots 1 and 2 experienced cost escalation and qualification difficulties. Consequently, the waiver for the Lot 3 aircraft no longer applied because the Lot 3 nonextensible fuel cells manufactured by American Fuel Cell and Coated Fabrics Company had different part numbers from the extensible fuel cells produced by International Latex Company for which the waiver applied. Furthermore, developmental testing indicated that the nonextensible cells manufactured by American Fuel Cell and Coated Fabrics Company did not pass the 65-foot drop and ballistic tests. Consequently, Boeing submitted a request for waiver of the crashworthiness and ballistic qualification requirements for Lot 3 fuel cells because the previous waiver applied to different fuel cell part numbers. The Navy did not approve the waiver. However, even though the Lot 3 nonextensible fuel cells manufactured by American Fuel Cell and Coated Fabrics Company did not pass the 65-foot drop and ballistic tests, the Navy considered the nonextensible fuel cells more crashworthy and ballistically acceptable than the extensible fuel cells used in Lots 1 and 2. Subsequently, the Navy accepted the Lot 3 nonextensible fuel cells because those fuel cells met the penetration and tear requirements of the Military Specification MIL-T-27422B.

Testing for Lot 4 Nonextensible Fuel Cells. Because the Lot 3 sponson fuel cells that American Fuel Cell and Coated Fabrics Company produced did not pass the drop and ballistic tests, Boeing contracted with Engineered Fabrics Corporation to design a nonextensible fuel cell that would withstand the 65-foot drop and ballistic tests for Lot 4. During testing in 2001, Boeing determined that the Lot 4 fuel cells complied with the crashworthiness and ballistic requirements in SD 572-1, Military Standard 1290, and Military Specification MIL-T-27422B. Consequently, Boeing plans to install nonextensible fuel cells manufactured by Engineered Fabrics Corporation in the sponson for the LRIP aircraft in Lot 4 and subsequent production aircraft.

Rework, Retrofit, Safety Risk, Resumption of Flight Test, Navy Evaluation Methodology, and Navy Support for Risk Assessment. The Navy plans to have Boeing retrofit or rework V-22 sponson fuel cells in Lots 1, 2, and 3 with the compliant nonextensible fuel cells manufactured by Engineered Fabrics Corporation.

Rework. Boeing was negotiating with the Navy for an engineering change proposal to rework the sponson fuel cells used in Lot 3 aircraft because those aircraft contain nonextensible fuel cells that:

- do not comply with military specifications,
- do not have an approved waiver for noncompliant fuel cells, and
- are installed on aircraft that have not been delivered to the Navy.

As of October 2002, the Navy had not approved Boeing's engineering change proposal even though it plans to have Boeing rework the sponson fuel cells used in Lot 3 aircraft and replace those fuel cells with compliant nonextensible fuel cells. Further, Boeing will install compliant nonextensible fuel cells in aircraft produced after Lot 3.

Retrofit. Although the Navy approved a waiver for crashworthiness and ballistic requirements for the LRIP aircraft in Lots 1 and 2, the Fuel Containment Branch at the Naval Air Systems Command and Boeing recommended to the V-22 Program Office that the EMD and Lots 1 and 2 aircraft be retrofitted with compliant nonextensible fuel cells, when they became available. Boeing also recommended that the aircraft be retrofitted with a larger access hole for fuel cell installation. In response, the Navy approved an engineering change proposal submitted by Boeing for retrofitting the sponson fuel cells in Lots 1 and 2 with compliant fuel cells. However, the Navy did not approve retrofitting the EMD aircraft because those aircraft would be used only for flight testing. Consequently, on March 15, 2002, the Deputy Inspector General requested that the USD(AT&L) determine whether the risk of flying the EMD aircraft with noncrashworthy fuel cells was acceptable (Appendix F).

On March 28, 2002, the Commander, Naval Air Systems Command issued a memorandum to the USD(AT&L) (Attachment in Appendix G), stating that the risk of conducting the flight testing of the EMD test aircraft with noncompliant sponson fuel cells was acceptable because:

- the test aircraft will operate in a controlled and structured developmental test environment,
- highly trained pilots will fly the test aircraft,
- the aircraft will be heavily instrumented and tracked with telemetry,
- the test squadron will provide significant oversight of the testing and conduct a safety assessment for each test plan and every flight, and
- no passengers will be carried on the aircraft.

Further, the Commander stated that his command had conducted a thorough system safety assessment of the V-22 as part of the V-22 Flight Readiness Review process, which included the fuel system and existing fuel cells on the test aircraft.

On April 3, 2002, the USD(AT&L) issued a memorandum (Appendix G) in response to our request. In his response, USD(AT&L):

- agreed with the assessment by the Commander, Naval Air Systems Command that the risk of conducting developmental testing with noncrashworthy fuel cells was within manageable flight test boundaries, and

-
- supported the Commander’s decision to return to developmental testing with aircraft having noncrashworthy fuel cells.

Further, the USD(AT&L) stated that the benefits of returning the V-22 to flight as scheduled to address his other technical concerns outweighed the limited risk reduction achieved by retrofitting the aircraft with crashworthy fuel cells that meet the 65-foot drop test.

On April 12, 2002, the V-22 Program Office, when asked, was still unable to provide us with documentation to support a system safety risk assessment⁹ of compliant and noncompliant V-22 fuel cells. Boeing had also been unable to provide documentation to support the system safety risk assessment concerning the use of compliant and noncompliant fuel cells on V-22 aircraft. Consequently, we believed that the decision of the USD(AT&L) merited further consideration.

On April 16, 2002, we issued a draft report to the USD(AT&L) recommending that he direct the Assistant Secretary of the Navy (Research, Development, and Acquisition) to require Boeing to install sponson fuel cells that comply with crashworthiness and ballistic standards in all existing V-22 aircraft, including the 4 EMD aircraft and the 17 LRIP aircraft from Lots 1 through 3, before flying those aircraft.

On May 6, 2002, the USD(AT&L) issued a memorandum (Appendix H) in response to our draft report. The USD(AT&L) stated that:

- all V-22 aircraft, except those used in EMD testing, will have crashworthy and ballistic compliant fuels cells installed in them, and
- a formal risk assessment, documented in a safety action record, evaluated the current fuel cell configuration in the aircraft to be used in EMD testing and assessed the risk as “1D (medium) risk.”

Further, the USD(AT&L) again concluded that the benefits of returning to flight as scheduled, to address other technical concerns, outweighed the limited risk reduction attained by retrofitting the aircraft with crashworthy fuel cells. However, the safety action record that the USD(AT&L) cited did not document and support the basis for assessing the safety risk as “1D (medium) risk” (undesirable risk) rather than “high risk” (unacceptable risk), the next higher level of safety risk. Consequently, we questioned the rigor of the risk assessment.

Safety Risk. On May 22, 2002, the Inspector General provided the USD(AT&L) with a draft information memorandum addressed to the Deputy Secretary of Defense. The draft memorandum:

- expressed concerns about flying EMD test aircraft with noncrashworthy fuel cells, and

⁹The system safety risk assessment assigns a risk level to a specific hazard, in this case the fuel cells, in terms of frequency of occurrence and severity related to injury, property damage, or effect on mission.

-
- recommended that the USD(AT&L) direct the Navy to only use aircraft with crashworthy fuel cells in flight testing or to conduct a formal system safety risk assessment to justify and document that the risk is only “medium.”

At the time of our draft memorandum, the Navy had not restarted its EMD flight testing of the V-22 aircraft.

On May 28, 2002, the USD(AT&L) issued a memorandum (Appendix I) in response to our draft information memorandum. The USD(AT&L) stated that the Navy:

- specifically addressed the fuel cell issue at a Flight Readiness Review on March 21, 2002, and
- assessed the marginal increased risk of using the existing fuel cells on EMD aircraft as medium risk compared to the fully compliant fuel cells that passed the 65-foot drop test.

Further, the USD(AT&L) stated that, subsequent to his April 3 and May 6, 2002, responses, the Navy formally documented its risk assessment process. He stated that this formal risk assessment should satisfy the recommendation in the draft information memorandum to document and provide increased rigor to the Navy’s assessment.

On May 28, 2002, we received the Navy’s formal system safety risk assessment of the EMD V-22 noncompliant sponson fuel cells (Appendix J); however, the Navy did not have documentation to support its risk assessment. After a preliminary review of the safety risk assessment, we contacted the V-22 Program Office on May 28, 2002, to express our concerns about the relevancy of the methodology used in the risk assessment and to request documentation that supported the assumptions made in the risk assessment. The V-22 Program Office requested that we prepare an e-mail addressing our concerns and related questions, including our request for supporting documentation.

On May 29, 2002, we analyzed the Navy’s formal system safety risk assessment and identified three areas of concern, as discussed in Appendix K. Those areas of concern included the probability of a crash, qualitative considerations, and data independence and variability.

Probability of a Crash. The system safety risk assessment did not base its crash frequency probability on past performance of the V-22 aircraft or other EMD aircraft. Specifically, the assessment’s crash frequency probability of 2 to 10 mishaps every 100,000 flight hours was inconsistent with the number of mishaps experienced and the technical challenges of the V-22. According to the V-22 Program Office, the V-22 has experienced 4 major mishaps to date in approximately 5,000 flight hours. Further, the estimate of 2 to 3 mishaps in 100,000 flight hours was based on historic Class A helicopter mishap rates for the Navy and Marine Corps. However, the risk assessment codes are based on the risk of aircraft and property damage and personal injury,

not just on “Class A” accidents in which a death or serious injury occurred. In addition, the Program Office used only baseline probability data for helicopters in its methodology and not baseline probability data that considered airplanes as well. To be meaningful, the methodology for the system safety risk assessment should have been revised to include a crash frequency probability based on the past performance of either the V-22 EMD test or other developmental fixed-wing or rotary aircraft.

Qualitative Considerations. The Navy did not plan to rigorously test the V-22 EMD test aircraft as part of the V-22 flight test program. The system safety risk assessment stated that:

- EMD testing will be conservative,
- EMD aircraft will have limited exposure compared to fleet aircraft, and
- EMD aircraft will not be transitioned to fleet use.

Because EMD testing is used to demonstrate system capabilities, and V-22 EMD test aircraft will be used throughout EMD testing, low-risk testing may be incompatible with making an adequate determination of the aerodynamic characteristics and operational limitations of the V-22. Further, in December 2000, the Defense Science Board criticized the V-22 Program for severely reducing the scope of developmental testing.

Data Independence and Variability. The independence and variability of probability factors used in the formula for the system safety risk assessment were questionable. The Navy should have considered dependencies among factors in making the safety risk level determination. For example, the “probability that a crash is survivable” and “probability that the crash occurs over land,” which the Navy showed as independent factors, are dependent factors. The factors are dependent because the probability of survivability is related to the environment in which a crash occurs. By presenting two dependent factors as independent factors, the Navy understated the numeric value of the safety risk assessment. Further, the assessment did not adequately address the variability of factors. The calculations in the system safety risk assessment addressed the variability in the number of crashes. However, the variability of other factors used in the Navy’s methodology, such as the “probability that the fuel tank is compromised during a crash condition,” was not addressed in the risk assessment.

Resumption of Flight Test. On May 29, 2002, the Navy resumed its flight testing of the V-22 EMD test aircraft, which had been grounded since December 2000.

Navy Evaluation Methodology. On June 7, 2002, the Inspector General issued a memorandum (Appendix L) to USD(AT&L) in response to his May 28, 2002, memorandum. The memorandum stated that the system safety risk assessment raised a fundamental question concerning the evaluation

methodology used because it appears that the unique nature of the EMD testing and the EMD test aircraft were not considered. At least one key factor seemed to be based on data from operational aircraft rather than EMD aircraft, which appeared to be a significant methodological error.

Also on June 7, 2002, we sent the V-22 Program Office an e-mail in which we:

- expressed our concerns about the support for the methodology used by the Navy in assessing safety risks for the V-22 EMD test aircraft;
- submitted questions concerning the USD(AT&L) flight decision documents, system safety risk assessment supporting documentation and methodology, and the V-22 EMD test program; and
- requested that the response be provided by June 14, 2002.

Navy Support for Risk Assessment. On July 12, 2002, the Navy provided a response (Appendix M) to our e-mail to support its system safety risk assessment. Our analysis of the Navy response is in Appendix N. Based on the data that the Navy submitted on July 12, 2002, to support the May 24, 2002, System Safety Risk Assessment, we again concluded that the methodology used to make the assessment was flawed. To have been a meaningful risk assessment, the methodology should have been revised to include a crash frequency probability based on past performance of either the V-22 EMD test or other developmental aircraft. Further, the system safety risk assessment model should have been adjusted to account for the nonindependence between the “probability that the crash occurs over land” and the “probability that a crash is survivable.” Using the crash frequency probability data that the Navy did provide and adjusting for the revised methodology, the safety risk assessment code would increase from undesirable or a medium safety risk to unacceptable or high safety risk.

Federal Aviation Administration Evaluation Methodology. On June 19, 2002, we contacted the Federal Aviation Administration (FAA) to determine its criteria and processes for certifying developmental aircraft. FAA representatives stated that the FAA does not have criteria or processes for certifying developmental aircraft. However, it does have criteria and processes for FAA type certification to determine aircraft airworthiness and for purposes of public use. The FAA conducts type certification after an aircraft has undergone developmental testing. Further, the FAA representatives stated that the FAA does not regulate aircraft development other than ensuring that developmental flights are conducted in geographic areas that ensure public safety. However, the FAA does conduct a risk assessment before releasing its pilots to test aircraft submitted for type certification.

Although the FAA does not regulate system configuration during developmental testing for commercial aircraft, commercial developmental aircraft have to meet FAA standards as closely as possible to obtain FAA approval for type certification. Further, the FAA representatives stated that the FAA was aware of a commercial tilt-rotor aircraft currently in development, the Bell

Agusta 609, and that during developmental testing, some aspects of the aircraft design may not be compliant with regulations. They also stated that the FAA routinely flies aircraft with noncompliant designs provided that an assessment does not indicate a safety-of-flight issue. Further, they stated that a noncrashworthy fuel cell in a developmental aircraft would not necessarily preclude the FAA from participating in flight evaluations.

Conclusion

According to the V-22 Program Office, the Navy plans to spend an average of about \$512,000 per aircraft to retrofit or rework the sponson fuel cells in the 17 remaining LRIP aircraft from Lots 1 through 3, with the contractor requiring 5 to 8 weeks to retrofit or rework each aircraft to make it compliant. However, the V-22 Program Office does not plan to install crashworthy sponson fuel cells on V-22 aircraft used in EMD testing. If the USD(AT&L) does not require the Navy to retrofit the noncompliant extensible fuel cells on the EMD flight test aircraft, the crew's survivability chances under crash conditions may be diminished. The increased risk could occur because the survivability of an extensible fuel cell is based on the cell's ability to expand under a crash condition and dissipate crash energy through its surrounding structure. However, if the fuel cell wall cannot stretch to relieve localized point loads, such as if areas of the fuel cell are restrained by the aircraft structure, the fuel cell may not be able to resist a puncture or it may tear, or both. Further, the probability that the extensible fuel cell may tear is increased over that of nonextensible fuel cells because the puncture and tear resistance of the extensible fuel cell is considerably less than that of the nonextensible fuel cell construction. In addition, if a V-22 aircraft with noncrashworthy fuel cells should experience a survivable crash, followed by a post-crash fire, the Navy would not have minimized the safety risk to the crew.

Further, the system safety risk assessment for the noncompliant sponson fuel cells on the V-22 EMD test aircraft, which the USD(AT&L) cited in his decision to not retrofit EMD test aircraft, should not have been relied upon for decision making because it was unsupported and the methodology used was flawed. Specifically, the safety risk assessment code would increase from undesirable or a medium safety risk to unacceptable or high safety risk if:

- the crash frequency probability was based on the past performance of either the V-22 EMD test aircraft or fixed-wing test aircraft, which was data provided by the Navy,¹⁰ and
- the system safety risk assessment model was adjusted to account for the nonindependence between the "probability that the crash occurs over land" and the "probability that a crash is survivable."

¹⁰Appendix N, Issue 3, Pages 53 and 54.

Recommendations and Management Comments

We recommend that the Under Secretary of Defense for Acquisition, Technology, and Logistics:

1. Reconsider his decision to fly the V-22 engineering and manufacturing development test aircraft without sponson fuel cells that comply with crashworthiness standards.

Management Comments. The Under Secretary of Defense for Acquisition, Technology, and Logistics stated that he has again concluded that the benefits of continuing to fly to address his other technical concerns outweighed the limited risk reduction attained by stopping the V-22 flight test program and retrofitting fuel cells with greater crashworthiness on the four EMD-only aircraft. For the complete text of the Under Secretary's comments, see the Management Comments section of this report.

2. Establish procedures to ensure that system safety risk assessments use a relevant methodology and are fully supported and documented.

Management Comments. The Under Secretary of Defense for Acquisition, Technology, and Logistics agreed that the Military Departments should use relevant methodology in their risk assessment procedures, including calculations of risk probability, and that risk assessments should be fully supported and documented. Further, the Under Secretary stated that his office will ensure that the Military Departments' safety organizations review their procedures and update them, as appropriate.

Appendix A. Scope and Methodology

We reviewed documentation dated from March 1986 to August 2002. To accomplish the audit objective, we:

- reviewed developmental test reports concerning the V-22 fuel cells;
- reviewed fuel cell test reports by the Commander, Operational Test and Evaluation Force and the Director, Operational Test and Evaluation;
- discussed V-22 fuel cell test and evaluation results with personnel in the Office of the Director, Operational Test and Evaluation; the V-22 Program Office; and at Boeing;
- discussed the V-22 development and production contracts with the Defense Contract Management Agency, the V-22 Program Office, and Boeing;
- discussed V-22 funding with personnel in the V-22 Program Office; and
- reviewed the Navy's formal system safety risk assessment of the EMD V-22 noncompliant sponson fuel cells

We performed this audit from January through August 2002 in accordance with generally accepted government auditing standards. We did not review the management control program because the audit was conducted in response to allegations referred to us by the Commandant of the Marine Corps; therefore, the scope was limited to the specific allegations.

General Accounting Office High-Risk Area. The General Accounting Office has identified several high-risk areas in the DoD. This report provides coverage of the DoD weapon systems acquisition high-risk area.

Use of Computer-Processed Data. We did not rely on computer-processed data to perform this audit.

Use of Technical Assistance. An operations research analyst and a mechanical engineer from the Quantitative Methods Division and the Technical Assessment Division, respectively, Office of the Assistant Inspector General for Auditing of the Department of Defense, assisted the auditors in reviewing fuel-cell test results and the system safety risk assessment for the V-22.

Prior Coverage

During the last 5 years, the General Accounting Office (GAO) and the Inspector General of the Department of Defense (IG DoD) have issued reports that reference DoD test waivers and limitations. Unrestricted General Accounting Office and Inspector General of the Department of Defense reports can be accessed at <http://www.gao.gov> and <http://www.dodig.osd.mil/audit/reports>, respectively.

General Accounting Office

GAO Report No. NSIAD-98-13, "Navy Aviation: V-22 Cost and Capability to Meet Requirements are yet to be Determined," October 1997

Inspector General of the Department of Defense

IG DoD Report on the Investigation of the Alleged Deletion/Falsification of Information from the MV-22 Osprey Aircraft Official Reports, August 19, 2002

IG DoD Report No. D-2000-174, "V-22 Osprey Joint Advanced Vertical Aircraft," August 15, 2000

Appendix B. Results of Allegations' Review

Of the four allegations concerning the V-22 fuel cells, we partially substantiated three, and did not substantiate one.

Allegation 1: The fuel cell installed in the V-22 was not able to withstand the required 10g (gravitational acceleration) impact.

Partially Substantiated. Although we were unable to substantiate the existence of a 10g impact requirement for any of the V-22 fuel cells, we did substantiate that fuel cells in the sponsons for the EMD aircraft, the aft fuel cell in the right fuselage sponson for the LRIP aircraft in Lots 1 and 2, and all fuel cells in the fuselage sponsons for LRIP aircraft in Lot 3 did not pass the 65-foot drop test as required by Military Specification MIL-T-27422B, "Tank, Fuel, Crash-Resistant, Aircraft," February 24, 1970. Subsequently, the contractor developed a fuel cell that met the specification requirements. Consequently, the Navy plans to have Boeing retrofit the LRIP aircraft in Lots 1 and 2 and rework the LRIP aircraft in Lot 3 with the compliant fuel cell.

Allegation 2: A fuel cell that could withstand the drop test was developed; however, it was not installed in the V-22 because of structural issues. Specifically, to install a fuel cell that would withstand the drop test, an access panel would have to be cut, which would affect the structural integrity of the stub wing. To compensate for the access panel, the aircraft structure would have to be modified thereby increasing the aircraft's weight.

Unsubstantiated. We were unable to substantiate that fuel cells meeting the drop test were not installed because of structural issues that required cutting an access panel. Instead, we determined that the Navy plans to have Boeing retrofit the LRIP, Lots 1 and 2, sponsons with nonextensible fuel cells, which meet the drop test and ballistic requirements. To install those nonextensible fuel cells, Boeing will have to modify the sponson access holes to accept the compliant nonextensible fuel cells. Because Boeing manufactured the sponsons for LRIP aircraft in Lot 3 to accept nonextensible fuel cells, the access holes on those sponsons do not require modification to install compliant nonextensible fuel cells.

Allegation 3: The designs of the CH-46E *Sea Knight* and the CH-53D *Sea Stallion*, which transport Marines, supplies, and equipment, incorporate fuel cells that break away on impact to prevent fires and explosions. However, the V-22 design incorporates fuel cells that will burst and flood the cabin with fuel, dramatically increasing the likelihood of a fire or an explosion, or both.

Partially Substantiated. We were unable to substantiate that the CH-46E *Sea Knight* and the CH-53D *Sea Stallion* incorporate fuel cells that break away on impact. However, we were able to substantiate that the V-22 design initially

incorporated a sponson fuel tank structure and cabin wall in the full-scale development aircraft that could crack and allow fuel to enter the cabin as a result of ballistic live-fire impact.

Breakaway Fuel Cells. According to the CH-46E *Sea Knight* and CH-53D *Sea Stallion* program offices, the designs of those two helicopters did not incorporate fuel cells that break away on impact. However, the fuel systems for the two helicopters did incorporate breakaway valves, which break away and close on crash impact. The V-22 fuel system also includes similar breakaway valves.

V-22 Fuel Cell Design. Ballistic live-fire tests of a flyable, full-scale development aircraft yielded cracking damage in the sponson fuel tank structure¹¹ and cabin wall that was significantly greater than expected. The damage was accompanied by fires under the fuselage floor and within the cargo and passenger areas of the fuselage. The damage resulted from the impact of an armor-piercing incendiary projectile. Subsequently, the sponson was redesigned and retested to make it more survivable. The Navy plans to have Boeing retrofit LRIP aircraft in Lots 1 and 2 and rework the Lot 3 aircraft with fuel cells that meet ballistic test requirements. Further, Boeing will install the compliant fuel cells in the LRIP aircraft in Lot 4 and future aircraft.

Allegation 4: At no time has the V-22 fuel cell passed the drop test. Consequently, the V-22 fuel cell standards were lowered to incorporate a cell design that would work and still maintain a weight savings.

Partially substantiated. Although we were unable to substantiate that the V-22 fuel cells had never passed the drop test, we did substantiate that the V-22 fuel cells in the sponsons for the EMD aircraft, the aft fuel cell in the right fuselage sponson for the LRIP aircraft in Lots 1 and 2, and all fuel cells in the fuselage sponsons for the LRIP aircraft in Lot 3 did not withstand the 65-foot drop test. However, the V-22 forward fuel cells in the sponson for the LRIP aircraft in Lots 1 and 2 passed the 65-foot drop test.

We were not able to substantiate that the V-22 fuel cell standards were lowered or made less stringent to incorporate a cell design that would work and still maintain a weight savings. However, for Lots 1, 2, and 3, the Navy approved a waiver request for relief from the drop test and ballistic specifications for the extensible sponson fuel cells, which Boeing originally selected for the aircraft because of their reduced weight. Subsequently, Boeing developed sponson fuel cells that met the drop test requirements. Consequently, the Navy plans to have Boeing retrofit LRIP aircraft in Lots 1 and 2 and rework the Lot 3 aircraft with the compliant fuel cell. Further, Boeing will install the compliant fuel cells in the LRIP aircraft in Lot 4 and future aircraft.

¹¹The fuel cells are located in the sponson outside the cabin walls.

Appendix C. Definitions of Technical Terms

Acquisition Category. An acquisition category is an attribute of an acquisition program that determines the program's level of review, decision authority, and applicable procedures. The acquisition categories consist of I, major Defense acquisition programs; IA, major automated information systems; II, major systems; III, programs not meeting the criteria for acquisition categories I, IA, or II; and IV, programs designated as such by the Army, Navy, and Marine Corps.

Acquisition Category ID. An Acquisition Category ID program is a major Defense acquisition program for which the milestone decision authority is the Under Secretary of Defense for Acquisition, Technology, and Logistics.

Acquisition Program Baseline. An acquisition program baseline is a document that contains the cost, schedule, and performance parameters for a program.

Allegation. An allegation is an assertion, claim, declaration, or statement that is made with or without supporting evidence and questions the existence of one or more facts.

Ballistic Live-Fire Test. To meet ballistic live-fire test requirements, the fuel cells must be self-sealing when penetrated by a 12.7 millimeter or .50 caliber armor-piercing projectile.

Class A Mishap. A Class A mishap is an accident in which a death or serious injury occurred.

Crashworthy Test. To meet the crashworthy test requirements, the fuel cell must be able to withstand a drop test of 65 feet when filled with water.

Developmental Test and Evaluation. Developmental test and evaluation is any testing used to assist in the development and maturation of products, product elements, or manufacturing or support processes. It is also any engineering-type test used to verify status of technical progress, verify that design risks are minimized, substantiate achievement of contract technical performance, and certify readiness for initial operational testing. Development tests generally require instrumentation and measurements and are accomplished by engineers, technicians, or soldier operator-maintainer test personnel in a controlled environment to facilitate failure analysis.

Engineering Change Proposal. An engineering change proposal is a proposal to the responsible authority recommending that a change to an original item of equipment be considered, and the design or engineering change be incorporated into the article to modify, add to, delete, or supersede original parts.

Engineering and Manufacturing Development. The engineering and manufacturing development phase of the acquisition process is to translate the most promising design approach into a stable, interoperable, producible,

supportable, and cost-effective design; to validate the manufacturing process or production process; and to demonstrate system capabilities through testing. Low-rate initial production usually occurs toward the end of the engineering and manufacturing development phase.

Extensible Fuel Cell. An extensible fuel cell is made of flexible material that expands to dissipate crash energy.

Full-Rate Production Decision. A full-rate production decision is a review normally conducted at the conclusion of low-rate initial production that authorizes entry into full-rate production and deployment.

Full-Scale Development. Full-scale development was an acquisition phase, which changed to the engineering and manufacturing development phase in the early 1990s. See the term engineering and manufacturing development for a definition of that phase.

Fuselage. A fuselage is the central body portion of an aircraft designed to accommodate the crew and passengers or cargo.

Low-Rate Initial Production. Low-rate initial production establishes an initial production base for the system, permits an orderly production rate increase sufficient to lead to a smooth transition to full-rate production, and provides production representative articles for initial operational test and evaluation and live-fire testing. This production effort concludes with a full-rate production decision review to authorize full-rate production and deployment.

Major Defense Acquisition Program. A major defense acquisition program is a program that the Under Secretary of Defense for Acquisition, Technology, and Logistics estimates will require an eventual expenditure for research, development, test, and evaluation of more than \$365 million (FY 2000 constant dollars) or procurement of more than \$2.19 billion (FY 2000 constant dollars), or one designated by the Under Secretary to be a major defense acquisition program.

Milestone Decision Authority. A milestone decision authority is the individual designated to approve entry of an acquisition program into the next acquisition phase.

Nonextensible Fuel Cell. A nonextensible fuel cell is made of high-strength flexible material that is able to absorb crash energy with minimal expansion.

Operational Test and Evaluation. Operational test and evaluation is the field test, under realistic conditions, of any item or key component of weapons, equipment, or munitions for the purpose of determining the effectiveness and suitability of the weapons, equipment, or munitions for use in combat by typical military users; and the evaluation of the results of such tests.

Program. A program is an acquisition effort funded by research, development, test and evaluation or procurement appropriations, or both, with the express objective of providing a new or improved capability in response to a stated mission need or deficiency.

Retrofit. Retrofit is a modification of a configuration item to incorporate changes made in later production items.

Rework. Rework is any correction of defective work, either before, during, or after inspection.

Safety Action Record. A safety action record is a summary of a single, identified hazard, including the chronological history of a hazard's identification and resolution. A safety action record is generated for hazards having the highest risk and is not the same as a system safety risk assessment.

Selected Acquisition Report. A selected acquisition report is a standard, comprehensive, summary status report of a major defense acquisition program, which is required for periodic submission to Congress. The report includes key cost, schedule, and technical information.

Sponson. A sponson is a projection from the side of the aircraft that holds the fuel cells and the landing gear.

System Safety Risk Assessment. A system safety risk assessment assigns a risk level to a specific hazard, in this case the fuel cells, in terms of frequency of occurrence and severity related to injury, property damage, or effect on mission.

Type Certification. Type certification is a process conducted by the Federal Aviation Administration to determine the airworthiness of a specific type of aircraft.

Vortex Ring State. Vortex ring state, also known as power settling, occurs when a very slow-flying helicopter or tilt-rotor in helicopter mode begins to descend into the disturbed air directly under its rotor system. This disturbed air is recirculated through the rotor system and results in a decrease in lift provided by that rotor disk. As rates of descent significantly increase, the pilot's instinctive reaction is to add power in an attempt to arrest his sink rate. However, when he adds power, he creates a greater volume of unstable air under the aircraft, which causes the rotorcraft to descend at an even faster rate.

Waiver. A waiver is a written authorization to accept a configuration item or other designated item, which, during production or after having been submitted for inspection, is found to depart from specified requirements, but nevertheless is considered suitable "as is" or after rework by an approved method.

Appendix D. V-22 Aircraft Configurations

Bureau Number	Build Number	Acquisition Phase	Sub-Contractor	Aft Sponson			Forward Sponsons		
				Fuel Cell Configuration	Crash-worthiness Test	Ballistic Test	Fuel Cell Configuration	Crash-worthiness Test	Ballistic Test
163911 ¹	1	FSD	FPT/ILC	NA ²	NA ²	NA ¹	NA ²	NA ²	NA ²
163912 ³	2	FSD	FPT/ILC	NA ²	NA ²	NA ²	NA ²	NA ²	NA ²
163913 ¹	3	FSD	FPT/ILC	NA ²	NA ²	NA ²	NA ²	NA ²	NA ²
163914 ⁴	4	FSD	FPT/ILC	NA ²	NA ²	NA ²	NA ²	NA ²	NA ²
163915 ⁴	5	FSD	FPT/ILC	NA ²	NA ²	NA ²	NA ²	NA ²	NA ²
163916 ⁵	6	FSD	FPT/ILC	NA ²	NA ²	NA ²	NA ²	NA ²	NA ²
164939	7	EMD	FPT/ILC	Extensible	Failed	Failed ⁶	Extensible	Failed	Failed ⁶
164940	8	EMD	FPT/ILC	Extensible	Failed	Failed ⁶	Extensible	Failed	Failed ⁶
164941	9	EMD	FPT/ILC	Extensible	Failed	Failed ⁶	Extensible	Failed	Failed ⁶
164942	10	EMD	FPT/ILC	Extensible	Failed	Failed ⁶	Extensible	Failed	Failed ⁶
165433	11	LRIP Lot 1	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165434	12	LRIP Lot 1	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165435	13	LRIP Lot 1	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165436 ⁴	14	LRIP Lot 1	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165437	15	LRIP Lot 1	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165438	16	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165439	17	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165440 ⁴	18	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165441	19	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165442	20	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165443	21	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165444	22	LRIP Lot 2	FPT/ILC	Extensible	Failed ⁷	NC ⁸	Extensible	Passed	Failed
165837	23	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰
165838	24	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰
165839	25	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰
165840	26	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰
165841	27	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰
165842	28	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰
165843	29	LRIP Lot 3	AMPUEL	Nonextensible	Failed ⁹	Failed	Nonextensible	Failed	Failed ¹⁰

(Continued on next page)

Bureau Number	Build Number	Acquisition Phase	Sub-Contractor	Aft Sponson			Forward Sponsons		
				Fuel Cell Configuration	Crash-worthiness Test	Ballistic Test	Fuel Cell Configuration	Crash-Worthiness Test	Ballistic Test
165844	30	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165845	31	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165846	32	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165847	33	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165848	34	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165849	35	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165850	36	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165851	37	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165852	38	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165853	39	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed
165956	40	LRIP Lot 4	EFC	Nonextensible	Passed	Passed	Nonextensible	Passed	Passed

¹Non-flyable aircraft is being used as a display.

²Data not available.

³Aircraft destroyed in live-fire testing.

⁴Aircraft crashed.

⁵Aircraft was never built.

⁶Navy documents show that the test failed; however, the Navy was unable to provide test data.

⁷Minor leakage around fitting following 65-foot drop. Boeing recommended this test to be considered passed. Naval Air Systems Command did not agree and categorized it as a failed test.

⁸The ballistic test for the aft fuel cell was not performed. Because the forward and aft fuel cells used the same materials and a similar design, the Navy decided that, if the forward sponson could not pass the ballistic test, the aft sponson fuel cell would not pass.

⁹Passed 65-foot drop test with some preproduction fittings, but later failed retest with production fittings.

¹⁰The contractor's testers determined that the fuel cells passed the ballistic test, but the Navy concluded that the fuel cell failed the ballistic test because the fuel cells leaked during ballistic testing.

Acronyms

AMFUEL	American Fuel Cell and Coated Fabrics Company
EEMD	Engineering and Manufacturing Development
EFC	Engineered Fabrics Corporation
FSD	Full-Scale Development
FPT	Fire Proof Tanks
ILC	International Latex Company
IOT&E	Initial Operational Test and Evaluation
LRIP	Low-Rate Initial Production
NA	Not Available
NC	Not Completed

Appendix E. Fuel Cell Waiver Request and Approval

REQUEST FOR DEVIATION / WAIVER				1. DATE (YYMMDD) 98-09-23	Form Approved OMB No. 0704-0186
<small>Public reporting burden for this collection of information is estimated to average 2 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and reviewing the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Information and Regulatory Affairs, Office of Management and Budget, Washington, DC 20503.</small>					2. PROCURING ACTIVITY NUMBER
<small>PLEASE DO NOT RETURN YOUR COMPLETED FORM TO EITHER OF THESE ADDRESSES. RETURN COMPLETED FORM TO THE GOVERNMENT ISSUING CONTRACTING OFFICER FOR THE CONTRACT/PROCURING ACTIVITY NUMBER LISTED IN ITEM 2 OF THIS FORM.</small>					3. DODAAC
4. ORIGINATOR		b. ADDRESS (Street, City, State, Zip Code)		5.	
a. TYPED NAME (First, Middle Initial, Last) Frank Reynolds		BELL-BOEING V-22 PROGRAM OFFICE 47123 JAMES RD., BLDG 3193 PATUXENT RIVER, MD 20670 - 1547		<input type="checkbox"/> DEVIATION <input checked="" type="checkbox"/> WAIVER	
7. DESIGNATION FOR DEVIATION / WAIVER		8. BASELINE AFFECTED		9. OTHER SYSTEM CONFIGURATION ITEMS AFFECTED	
a. MODEL/TYPE V-22	b. CASE CODE 77272	c. EYE DEMO. Fuel	d. DEVIATION NO. V-22-W-L0040	<input type="checkbox"/> FUNCTIONAL <input type="checkbox"/> ALLOWED <input checked="" type="checkbox"/> Initial product Baseline	<input type="checkbox"/> YES <input checked="" type="checkbox"/> NO
10. TITLE OF DEVIATION WAIVER Sponson Fuel Cells					
11. CONTRACT NO. AND LINE ITEM N00019-96-C-0054			12. PROCURING CONTRACTING OFFICER		
			a. NAME (First, Middle Initial, Last) Maria V. Meiton		
			b. CODE AIR-2.3.3		
			c. TELEPHONE NO. 301-757-5299		
13. CONFIGURATION ITEM NOMENCLATURE Sponson Fuel Cells			14. CLASSIFICATION OF DEFECT		
			a. CD NO. N/A	b. DEFECT NO. N/A	c. DEFECT CLASSIFICATION <input type="checkbox"/> MINOR <input checked="" type="checkbox"/> MAJOR <input type="checkbox"/> CRITICAL
15. NAME OF LOWEST PART/ASSEMBLY AFFECTED Sponson Fuel Cells			16. PART NO. OR TYPE DESIGNATION 901-366-105, 106 ^{EH EH} / 901-366-650105, 106		
17. EFFECTIVITY V-22 A/C D0011 through D0029			18. RECURRING DEVIATION/WAIVER <input checked="" type="checkbox"/> YES <input type="checkbox"/> NO		
19. EFFECT ON COST/PRICE None			20. EFFECT ON DELIVERY SCHEDULE None		
21. EFFECT ON INTEGRATED LOGISTICS SUPPORT, INTERFACE OR SOFTWARE No impact. Logistics will reflect EMD and LRIP Part numbers per IRR 901-1E38.					
22. DESCRIPTION OF DEVIATION / WAIVER This waiver requests relief from SD-572-1-1 paragraph 3.12.9.1.b (2) which requires qualification testing (for gunfire and drop) , and inspection / Acceptance standards per MIL - T - 27422B and MIL- STD- 801 for the Sponson Fuel Cells.					
23. NEED FOR DEVIATION / WAIVER a The Sponson Fuel Cells have not passed the qualification drop test or gunfire requirements of Mil-T-27422B. The Sponson Fuel Cells do not meet the acceptance and inspection standards of MIL - T - 27422 B and MIL- STD- 801. Request that inspection and acceptance criteria be defined as detailed in ILC Document 1072-70016 Dated 9/98 (attached). Revised acceptance criteria allows a limited number of areas of nonadhesion with quantity and location restrictions that exceed MIL-STD-801. Revised criteria also allows wrinkles in certain areas outside of MIL-STD 801 requirements.					
24. CORRECTIVE ACTION TAKEN Based on the anticipated usage of the aircraft involved the current fuel cells are acceptable for flight. Future A/C will be compliant to SD-572-1-1 requirements by incorporating IRR 901-1E38 implementing material changes and the use of a new supplier.					
25. SUBMITTING ACTIVITY					
a. TYPED NAME (First, Middle, Initial, Last) Frank Zincola		b. TITLE Senior Contracts Manager V-22 Contracts		c. SIGNATURE <i>Richard Savastone</i>	
26. APPROVAL / DISAPPROVAL					
a. RECOMMEND <input type="checkbox"/> APPROVAL <input type="checkbox"/> DISAPPROVAL					
b. APPROVAL <input type="checkbox"/> APPROVED <input type="checkbox"/> DISAPPROVED	c. GOVERNMENT ACTIVITY	SIGNATURE		DATE (YYMMDD)	
d. APPROVAL <input type="checkbox"/> APPROVED <input type="checkbox"/> DISAPPROVED	e. GOVERNMENT ACTIVITY	SIGNATURE		DATE (YYMMDD)	

DD Form 1694, APR 92 (Boeing version)

CCB CHANGE REQUEST/DIRECTIVE

1. TYPE OF CHANGE <input type="checkbox"/> CCP <input type="checkbox"/> DEVIATION <input type="checkbox"/> RAMEC <input type="checkbox"/> MGFEL <input checked="" type="checkbox"/> WAIVER		2. CHANGE NO V-22-W-L004 7.	3. DOCUMENT TRACKING NO. N/A
		4. JUST. CODE N/A	5. CCB NO. DATE: 99F-006 16 OCT 98
6. ORIGINATOR: NAVAIR / BELL-BOEING		7. NATURE OF CCB ACTION: <input checked="" type="checkbox"/> INITIAL REQUEST <input type="checkbox"/> URGENT <input type="checkbox"/> REVISION <input checked="" type="checkbox"/> ROUTINE <input type="checkbox"/> FOLLOW ON BUY <input checked="" type="checkbox"/> HANDCARRY <input type="checkbox"/> ADMIN REQUEST	
8. PROGRAM MANAGER SPONSORING THIS CHANGE (SIGNATURE AND DATE): BARBARA SMITH		9. CODE PMA-275A	10. PHONE (301) 757-5161
11. TITLE OF CHANGE Sponson Fuel Cells		12. TYPE OF IMPLEMENTATION: <input type="checkbox"/> EMD <input checked="" type="checkbox"/> PRODUCTION (LRIP) <input type="checkbox"/> ATTRITION OSIP NO.	
13. CONFIGURATION ITEMS AFFECTED AND EFFECTIVITY: LRIP Aircraft D0011 - D0029		14. TD CATEGORY - N/A <input type="checkbox"/> IMMED <input type="checkbox"/> ROUTINE <input type="checkbox"/> URGENT <input type="checkbox"/> RECORD	
15. OTHER CONFIGURATION ITEMS AFFECTED AND EFFECTIVITY None		16. TECHNICAL DIRECTIVE N/A TYPE NO.	
17. REFERENCES BB Ltr JPO-4560-98:BV dated October 12, 1998			
18. JUSTIFICATION <p>The Sponson Fuel Cells have not passed the qualification drop test or gunfire requirements of MIL-27422B. They also do not meet the acceptance and inspection standards of MIL-27422B and MIL-STD-801. Request that inspection and acceptance criteria be defined as detailed in ILC Document 1072-70016 dated 9/98 (as attached to the waiver request). The revised acceptance criteria allows a limited number of areas of non-adhesion with quantity and location restrictions that exceed MIL-STD-801. Revised criteria also allows wrinkles in certain areas outside of MIL-STD-801 requirements.</p>			
19. CCB MEMBERS		CODE	20. REMARKS (CCB CHAIRMAN ONLY)
ILS/FLEET SUPPORT - <i>ETO D. Barr</i>		AIR-3.1.2H	
SYSTEMS ENGINEERING - <i>CDR D. Schwartzburg</i>		AIR-4.1.2	
PRODUCTION MANAGEMENT			
AVIATION TRAINING			
CCB CHAIRMAN - Ms. M. Jansen / Ms. B. Smith <i>M. Jansen / B. Smith</i>		PMA-275D5 PMA-275A	21. (X) APPROVED <input type="checkbox"/> DISAPPROVED
			22. DATE 12/7/98

Appendix F. Office of the Inspector General of the Department of Defense Memorandum Concerning Noncrashworthy Fuel Cells



INSPECTOR GENERAL
DEPARTMENT OF DEFENSE
400 ARMY NAVY DRIVE
ARLINGTON, VIRGINIA 22202-4704

MAR 15 2002

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION,
TECHNOLOGY, AND LOGISTICS

SUBJECT: Noncrashworthy Fuel Cells on the V-22 *Osprey* Joint
Advanced Vertical Aircraft (Project No. D2002AE-0065)

During the course of our ongoing review of allegations about the fuel cells on the V-22 aircraft, it came to our attention from technical personnel at the Program Office that none of the sponson fuel cells on the four V-22 engineering and manufacturing development (EMD) aircraft (Build Numbers 7, 8, 9, and 10) have passed the 65-foot drop test. The military specification for the fuel cells requires that the V-22 fuel cells be crashworthy and self-sealing, and designed to withstand a 65-foot drop without leaking. Those four aircraft are scheduled to be used in flight testing in April 2002.

Our upcoming report will recommend that those four EMD aircraft be retrofitted with crashworthy fuel cells to meet the 65-foot drop test requirement before being used in flight testing. Because of the impending scheduled flight testing in April 2002, a timely and informed decision needs to be made as to whether the risk of flying the EMD aircraft with noncrashworthy fuel cells is acceptable.

We are in the process of completing our audit work and plan to issue the draft audit report by mid-April 2002. We bring this issue on flying EMD aircraft without compliant fuel cells to your attention because of its time sensitivity and importance. If you have any questions, please contact me or Mr. John E. Meling at (703) 604-9091 (jmeling@dodig.osd.mil).

A handwritten signature in cursive script, reading "Robert J. Lieberman".

Robert J. Lieberman
Deputy Inspector General

cc: Secretary of the Navy
Commandant of the Marine Corps
General Counsel of the Department of Defense
Assistant Secretary of the Navy (Research, Development,
and Acquisition)
Director, Operational Test and Evaluation
Director, Defense Contract Management Agency
Naval Inspector General
Commander, Naval Air Systems Command
Program Executive Officer, Air Anti-Submarine Warfare,
Assault, and Special Missions Programs
V-22 Program Manager

Appendix G. Under Secretary of Defense for Acquisition, Technology, and Logistics Memorandum Concerning Noncrashworthy Fuel Cells



ACQUISITION,
TECHNOLOGY
AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

03 APR 2002

MEMORANDUM FOR DEPUTY INSPECTOR GENERAL

SUBJECT: Non-crashworthy Fuel Cells on the V-22 Osprey Joint Advance
Vertical Aircraft (Project No. D200AE-0065)

This responds to your March 15, 2002, memo regarding your recommendation not to conduct V-22 development testing without crashworthy fuel cells that have passed the 65-foot drop test.

Attached is the Commander, Naval Air Systems Command's assessment of risk associated with testing the V-22 with its current aft sponson fuel cell configuration. I concur with his assessment and support his decision to return to developmental testing with the current fuel cell configuration.

I feel the benefits of returning to flight as scheduled to address my other technical concerns outweigh the limited risk reduction attained by retrofitting the aircraft with crashworthy fuel cells that have passed the 65-foot drop test prior to development testing. My POC is Mr. Gary Gray, Staff Specialist, (703) 697-0638

A handwritten signature in black ink, appearing to read "E.C. Aldridge, Jr." with a stylized flourish at the end.

E.C. Aldridge, Jr.

Attachment:
As stated



DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
ADM WILLIAM A. MOFFETT BUILDING
47123 BUSE ROAD, BLDG 2272
PATUXENT RIVER, MARYLAND 20670-1547

STANDARD FORM 64
28 Mar 02

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION,
TECHNOLOGY, AND LOGISTICS

SUBJECT: Noncrashworthy Fuel Cells on the V-22 Osprey Joint Advanced Vertical
Aircraft (DODIG Project No. D2002AE-0065)

The DODIG in a March 15, 2002 memo recommended that prior to flight tests V-22 aircraft used for developmental testing should be retrofitted with crashworthy sponson fuel cells that have passed a 65-foot drop test. The design of the sponson fuel cells in the V-22 aircraft that will be used for upcoming developmental testing was reviewed as part of the V-22 Flight Readiness Review (FRR) process. The V-22 Program Office and the Naval Air Systems Command V-22 Engineering Team determined that the risk was acceptable to conduct the planned flight test program with existing fuel system configuration which meets all crashworthy specifications, with the exception of the final 65-foot fuel cell sponson drop test.

The FRR determination concerning the sponson fuel cells was based the limited risk exposure in the controlled and structured developmental test environment in which the test aircraft will be operated. Highly trained pilots fly the test aircraft that are heavily instrumented and tracked with telemetry. The test squadron provides significant oversight of testing and a safety assessment is conducted for each test plan and every flight. Also, no passengers will be carried.

The Naval Air Systems Command has conducted a thorough system safety assessment of the V-22 as part of the FRR including the fuel system and existing fuel cells on the test aircraft. The determination concerning sponson fuel cells was the risk of conducting developmental testing with the existing fuel cells was within manageable flight test boundaries.

J. W. DYER
Vice Admiral, U.S. Navy

cc:
Program Executive Officer, Air Anti-Submarine Warfare, Assault, and Special
Missions Programs
Assistant Commander for Research and Engineering, Naval Air Systems Command
V-22 Program Manager

Appendix H. Under Secretary of Defense for Acquisition, Technology, and Logistics Memorandum Concerning Installation of V-22 Fuel Cells



ACQUISITION,
TECHNOLOGY
AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

06 MAY 2002

MEMORANDUM FOR DEPUTY INSPECTOR GENERAL

SUBJECT: Fuel Cells on the V-22 Osprey Joint Advance Vertical Aircraft
(Project No. D2002AE-0065)

This responds to your April 16, 2002, memo requesting comments on your draft audit report on Fuel Cells of the V-22 Osprey Joint Advanced Vertical Aircraft.

You recommended that I direct the Assistant Secretary of the Navy (Research, Development and Acquisition) to require installation of sponson fuel cells that comply with crashworthiness and ballistic standards in existing V-22 aircraft, including 4 engineering and manufacturing development aircraft and 17 low-rate initial production aircraft from Lots 1 through 3, before flying those aircraft.

All V-22 aircraft, Lot 1 and higher will have crashworthy and ballistic compliant fuel cells installed. The only exception will be aircraft used in engineering and manufacturing development (EMD) testing. A formal risk assessment process was used to evaluate the current fuel cell configuration in those aircraft. The risk assessment has been documented in a Safety Action Record (SAR). This risk was assessed as 1D (medium) risk.

I have again considered this risk, and still conclude that the benefits of returning to flight as scheduled to address my other technical concerns outweigh the limited risk reduction attained by retrofitting fuel cells with greater crashworthiness.

A handwritten signature in black ink, appearing to read "E.C. Aldridge, Jr." with a stylized flourish at the end.

E.C. Aldridge, Jr.

Appendix I. Under Secretary of Defense for Acquisition, Technology, and Logistics Memorandum Concerning Safety of V-22 Fuel Cells



ACQUISITION,
TECHNOLOGY
AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

28 MAY 2002

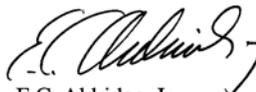
MEMORANDUM FOR DEPARTMENT OF DEFENSE INSPECTOR GENERAL

SUBJECT: Safety of the V-22 Osprey Joint Advanced Vertical Aircraft

This memo responds to your draft memorandum to the Deputy Secretary of Defense on fully compliant crashworthy fuel cells.

The Navy specifically addressed the fuel cell issue at a Flight Readiness Review on March 21, 2002. The Navy assessed the marginal increased risk of using the existing fuel cells on the Engineering and Manufacturing Development aircraft as medium risk compared to the fully compliant fuel cells that passed the 65-foot drop test.

On two prior occasions, I supported the Navy's assessment. Since that time, the Navy has formally documented its process. This formal risk assessment should satisfy your recommendation to document and provide increased rigor to the Navy's assessment.


E.C. Aldridge, Jr.

Appendix J. System Safety Risk Assessment of Engineering and Manufacturing Development V-22 Noncompliant Sponson Fuel Cells

FRA 2002-13

SYSTEM SAFETY FORMAL RISK ASSESSMENT

This risk assessment represents an additional effort in response to a memo to Deputy Secretary of Defense from Joseph Schmitz, dated 05/22/02. The initial activity for this hazard has been provided in Safety Action Record (SAR) 46-17 Crash Related Fuel Leak – Fuel Cell / Component Separation - March 1995.

Date: 24 May 2002

1. Type/Model/Series: EMD V-22 (Aircraft 7-10)

2. System/Subsystem: Fuel System

A. Assembly/Part: Sponson Fuel Tanks

3. Hazard Identification:

A. Risk Assessment Name: EMD V-22 Non-Compliant Sponson Fuel Cells

B. Description of Hazard:

Failure to adequately contain fuel following a mishap that could result in a post crash fire and aircrew fatal injury. This assessment evaluates the hazard associated with conducting Engineering and Manufacturing Development (EMD) flight test operations with extensible sponson fuel tanks.

The V-22 Bell-Boeing Engineering and Manufacturing Development Specification (SD-572-1) identified a crashworthy fuel system design based on MIL-STD-1290, with reduced requirements of MIL-T-27422B. Testing of EMD fuel tank configurations met these crashworthy specifications, with the exception of the sponson tanks that did not pass the 65-foot drop test requirement. Based on these test results, the program office continued to conduct development work on the fuel system in order to obtain a fully compliant crashworthy fuel system.

To assess the overall impact the extensible type fuel tanks have on the V-22 fuel system crashworthiness, it is important to recognize the fundamental differences between the extensible and non-extensible fuel tank approach to crashworthiness. Non-extensible MIL-T-27442B crashworthy fuel tanks absorb crash energy without substantial assistance from the surrounding structure. On the other hand, extensible type fuel tank construction dissipates crash energy through elastic deformation of the tank into gaps in the fuel tank cavity allowing loads to be transferred into all structural boundaries it contacts. If at the time of the crash, sharp edges or protrusions exist due to local structural failures then the probability that the bladder may tear is increased over that of non-extensible tanks. This is primarily due to the fact that the puncture and tear resistance of the extensible fuel tank is considerably less than that of the non-extensible tank construction. The exact degree of reduced capability is not easily quantified since the fuel tank qualification drop tests per MIL-T-27442 which use a 65 foot drop as a technique to verify crashworthiness are conducted for the tanks alone and not with the tanks installed in representative structure.

C. Hazard Classification:

- 1) Hazard Severity Code: I Catastrophic
- 2) Hazard Probability Code: D Remote
- 3) Risk Level: ID Medium

4. Explanation of severity/probability of this hazard:

- A. Hazard Severity: Catastrophic: This is based on the "worst credible" outcome, the likelihood that a post crash fire results in occupant fatality due to inability for occupants to egress the aircraft. In order for this hazard to be realized, a crash is required that is severe enough to release fuel from the tanks in the presence of an ignition source, yet not so severe that it would be a non-survivable crash.
- B. Hazard Probability: Remote (1/100,000 ft. hrs >Pr> .1/100,000 ft. hrs) -Unlikely but possible to occur in the life of an item. Qualitative & quantitative analysis is provided below:

Qualitative Considerations: Actual crash experience exists for the V-22. During Full Scale Development (FSD), the V-22 program suffered two major mishaps. Aircraft 4 crashed into a river at a velocity greatly beyond design criteria (in excess of 100ft/sec); as in other high-G impacts, performance of the fuel system crashworthiness features was not assessed in the mishap investigation. Aircraft 5 experienced a roll and came to rest inverted. The crash was survivable with no loss of crew. While it was not a high-end crash, the orientation of the crash was not anticipated. The impact force was sufficient enough to separate (peel back) the wing from the fuselage and initiate separation of the cockpit from the cabin structure. This wing failure mode had not been accommodated for in the FSD design and a midwing fire occurred. This failure mode was considered as part of the EMD redesign effort and, additional breakaway valves and flexible high-elongation lines have been incorporated into the aircraft to replace rigid fuel lines. The extensible tanks themselves performed well, remaining intact and they did not exhibit any leakage. In the most recent V-22 mishaps, involving production aircraft over land, the forces were beyond aircraft crashworthiness design requirements. A post-impact fuel-fed fire ensued. Analysis of the fuel system contribution to this incident was not conducted.

The EMD tank material construction was identical to FSD. However, the EMD tank is slightly thicker due to a heavier gauge power layer. Reconfiguration of the tanks occurred due to sponson redesign.

Developmental flight testing will be conducted in a controlled environment and a majority of the testing will be conducted over water on the east coast. The flight testing planned for the West Coast is related to the Multi-Mode Radar (MMR). This testing will be conducted during day VMC conditions and is considered low risk flying. Unlike fleet operational flying, the EMD flight test environment is structured and controlled. The

following factors will qualitatively reduce the probability of experiencing a Class A mishap during the EMD flight test program:

- A thorough subsystem and system level assessment was conducted to identify and mitigate risk associated with continued EMD flight operations.
- EMD aircraft are instrumented; aircraft 8 and 10 will utilize real time telemetry for every flight.
- Developmental Test (DT) flight test will be limited to DT flight crews only.
- Highly trained contractor/government flight crews with egress training currency.
- Significant oversight by test squadrons, Defense Contract Management Agency (DCMA) and the program office.
- A/C maintenance inspection intervals are very conservative compared to planned fleet operations.
- Testing approach is conservative (pilots will Return to Base (RTB) after first non-resettable caution).
- A Test Hazard Analysis will be performed for each test plan.

Quantitative Considerations: The probability of experiencing the identified hazard considers the likelihood that a survivable crash occurs, crash forces exceed the capability of the tanks, an ignition source is present and the occupants are not able to egress the aircraft. In order for this risk to be realized, a crash is required that is severe enough to deform the airframe yet not so severe that it would fatally injure the aircrew upon impact.

Assumptions:

Probability of a crash: (2-10/100,000 flight hours) - The historic Class A helicopter mishap rate for the Navy/Marine Corp has been about 2 to 3 per 100,000 hours. Class A mishaps are defined as those that exceed a 1 million dollar threshold in a/c damage and/or those that result in one or more fatalities. A lower rate of 2 mishaps/100,000 and higher rate of 10 mishaps/100,000 is presented to capture design maturity concerns that could result in a higher mishap rate than that associated with a production representative platform (reference 11)

Probability that a crash is survivable: (50%) - Historical evidence suggests that approximately 50% of all class A mishaps are non-survivable (Crash forces are beyond Mil-Std-1290 impact conditions).

Probability that the crash occurs over land: (50%) - Historical data indicates approximately 50% of Navy/Marine Corp mishaps occur over land. It is assumed that in the case of a water impact, the probability of the postcrash fire yielding a fatality is negligible.

Probability that the fuel tank is compromised during a crash condition: (50%) - The probability that an extensible tank is compromised will be a function of the magnitude of the crash. The V-22 landing gear is capable of attenuating impact velocities up to 24 ft/sec. The function of the landing gear system in a crash situation is to provide controlled loading and energy attenuation. Deceleration loads experienced by the extensible tanks during a 24 ft/sec crash are not anticipated to compromise the

integrity of the tank. Impacts beyond 24 ft/sec could impart significant loading to the extensible fuel cells. It is therefore conservatively assumed that fuel leakage will occur for impact velocities above 24 ft/sec. It is also assumed (and historically supported) that approximately 50% of the survivable mishaps will have an impact velocity of greater than 24 ft/sec.

Probability that an ignition source is present following a postcrash fuel spill: (100%) - The potential exists for fuel to be ignited by electrical sources or hot surface ignition. Because of the uncertainty associated with the post crash environment, a conservative approach is adopted and the probability of the presence of an ignition source is assumed to be 100%.

Probability that occupants are not able to egress the aircraft during a postcrash fire: (50%) - This accounts for the fact that in some cases, occupants will be able to egress the aircraft following a crash and subsequent postcrash fire. Safe egress during flight test is more likely than fleet operations due to fewer personnel and less cargo onboard. The assumption is that in 50% of the cases, egress routes will be blocked or debilitating injuries will prevent egress and aircrew fatalities will occur (i.e. crew/cabin occupants do not have adequate time to egress the a/c prior to succumbing to smoke inhalation or fire).

Hazard Probability Calculations

$2 \times .5 \times .5 \times .5 \times 1 \times .5 = .125$ events per hundred thousand flight hrs. = D (Remote)

$10 \times .5 \times .5 \times .5 \times 1 \times .5 = .625$ events per hundred thousand flight hrs. = D (Remote)

5. List of Sources and References:

1. SD-572-1C, Detail Design Specification for V-22 Engineering and Manufacturing Development, 13Sep95.
2. MIL-STD-882B, Standard Practice for System Safety Program Requirements, 28Jun87.
3. MIL-STD-1290, Light Fixed and Rotary Wing Aircraft Crashworthiness, 21Jul77.
4. MIL-T-27422B Military Specification, Tank, Fuel, Crash-resistant, Aircraft, 13Apr71.
5. V-22 SAR 46-17, Crash Related Fuel Leak- Fuel Cell/Component Separation, initiated 17Mar95
6. Flight Certification Rationale for V-22 Sponson Fuel Cells, FPT/DES/TLW/MRM/1404, FPT Industries, Sept. 24, 1996.
7. V-22 System Safety Working Group 22, 30Oct01, Patuxent River NAS, MD.

8. Aircraft Crash Survival Design Guide Vols. I-V. USAVSCOM TR 89-D-22E, dtd. December 1989.
9. The Naval Accident Environment, Helicopter Aircrew Survivability and Structural Response, Joseph W. Coltman, dtd. 16 October 1984.
10. Report of the Panel to Review the V-22 Program, 30Apr01.
11. US Navy Safety Center Internet web site, <http://safetycenter.navy.mil>

6. Background Material:

GENERAL CWFS BACKGROUND: Crashworthy Fuel Systems (CWFS) are designed to contain fuel during a survivable crash. , All current US Navy helicopter fuel systems, except the H-3 series and TH-57 B/C Jet Ranger aircraft, impose some CWFS requirements as defined in MIL-STD-1290, "*Light Fixed and Rotary Wing Aircraft Crashworthiness.*" MIL-STD-1290 specifies that fuel spillage during and after all survivable crash impacts of the severity of up to and including the 95 percentile survivable accident be minimized through the use of crashworthy fuel tanks, self-sealing breakaway valves, prudent fuel line routing, rollover vent system protection, etc. Crashworthy fuel tanks are defined in MIL-STD-1290 as those meeting MIL-T-27422B, the crashworthy fuel tank specification that calls out design characteristics and test requirements. Breakaway valves defined in MIL-STD-1290 should be utilized at all fuel tank to fuel line connections and other points in the fuel system where aircraft structural deformations could lead to fuel spillage. MIL-T-27422B requirements emanated from extensive fuel system crash tests conducted during the Vietnam War period when otherwise survivable helicopter crashes were resulting in fatalities exacerbated by fuel tank ruptures. Testing showed that tear and puncture resistance, standards for fitting pullout and 65 ft drop tests were the key factors in fuel tank ability to meet fuel system crashworthiness requirements of MIL-STD-1290.

V-22 CWFS BACKGROUND: The V-22 Bell-Boeing Engineering and Manufacturing Development Specification (SD-572-1, reference 1) calls for a crashworthy fuel system design based on MIL-STD-1290 and MIL-T-27422B. During the early stages of the V-22 program, to obtain a significant aircraft weight savings, Bell-Boeing and the Navy considered the use of an extensible fuel tank construction vice the non-extensible fuel tank construction typically used in other US Navy helicopter CWFS. Essentially, extensible tanks dissipate crash loads by locally elongating while non-extensible tanks absorb crash loads with minimal deformation. This fundamental difference in the design approach to achieve crashworthiness results in employment of materials in extensible tanks that at present are less puncture and tear resistant than materials used in non-extensible tanks. Extensible tanks may thus offer a lesser degree of crashworthiness than that of non-extensible tanks. There are tradeoffs among all of the crashworthiness factors, and even within the postcrash survival category, compromises must be made to avoid excessive adverse effects on mission capability. After considering overall aircraft requirements, a decision was made to employ extensible fuel tanks in the wing and sponsons. To this end and to acknowledge that a qualified extensible design could provide crashworthiness, SD-572-1, while retaining requirements for traditional MIL-T-27422B fuel tanks, added as an alternate tank the specific performance requirements that accommodated the unique mechanical properties of extensible fuel tanks. Specifically,

for extensible designs, the tear resistance, impact penetration, tensile strength/ultimate elongation, fitting strength and gunfire requirements were reduced from those of traditional MIL-T-27422B tanks. SD-572-1 retained requirements that the V-22 meet other CWFS requirements in accordance with MIL-STD-1290A

EMD V-22 FUEL TANK DESIGN STATUS: The following is information regarding the CWFS on EMD aircraft. Additionally, Table 1 provides a comparison of the SD-572-1 and MIL-T-27422B fuel tanks requirements.

- * Sponson Tanks (2 Fwd and 1 Aft)-Extensible Construction. Failed 65 ft. drop test (Not fully qualified to SD-572 crashworthy).
- * Total of 16 breakaway valves. Breakaway valves are fully qualified. The breakaway valves are located at all fuel tank to fuel line interfaces (7), BL 38 (2), twist capsule wing break (2), sponson vent lines (3) and APU fuel line (2). The locations and the design of the breakaway valves meet the requirements of MIL-STD-1290.
- * Frangible fittings, rollover provisions, high elongation hoses, etc are utilized as part of the postcrash fuel containment approach.

TABLE I

COMPARISON OF RELEVANT SD-572-1 AND MIL-T-27422B FUEL TANK REQUIREMENTS

REQUIREMENT	SD-572-1	MIL-T-27422B
Constant Rate Tear	40 ft.-lbs	400 ft.-lbs.
Impact Penetration (Throat Size)	20 in.-square	4.0 in.-square
Fitting Strength [secure to tank structure]	Shall elongate a minimum of 250% prior to failure	200 lb load attached to fitting and dropped from 20ft.
Composite Material Strength	Tensile strength and ultimate elongation shall not be less than 90lbs.-in. and 350%	4 in. diameter plunger shall be forced into the center of the panel at a rate of 20in. per minute until failure

In addition to V-22 program risk assessments, both the Panel to review the V-22 Program (Blue Ribbon Panel, reference 10) and the DOD IG reviewed the V-22 program and examined the crashworthiness of the fuel system. The Blue Ribbon Panel completed their review in April 2001, recommending the program office retrofit all operational aircraft at the first opportunity. The panel did not believe the marginal additional risk associated with the non-compliant fuel system warranted the grounding of the aircraft. In a memo to USD(AT&L), the DOD IG recommended that the EMD aircraft (7-10) be retrofitted

with the Lot IV fuel tanks prior to resuming flight testing. The System Safety Working Group addressed the retrofit of qualified fuel tanks into all aircraft. Their risk assessment was discussed with the program office at the time and the decision was made to retrofit the fleet aircraft, but not the EMD aircraft. This decision was based on the limited exposure of the EMD aircraft compared to fleet aircraft. This position was reconfirmed during the Return to Flight (RTF) and Flight Readiness engineering reviews.

7. Risk Reduction Alternatives:

Option 1: Continue to conduct EMD flight test operations with non-compliant sponson fuel cells.

System Safety Risk Assessment Code is ID (Catastrophic, Remote Probability).

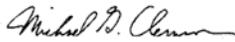
Option 2: Retrofit a/c with sponson fuel tanks that are fully qualified in accordance with the requirements of MIL-T-27422B and MIL-STD-1290. The residual risk will remain at a ID level due to indeterminate factors associated with a postcrash environment. This qualitative classification is appropriate given the programmatic definition of D probability risk (Remote - Unlikely but possible to occur in the life of an item).

The current program plan does not account for the retrofit of the Lot IV configuration qualified fuel tanks into the EMD aircraft. The EMD aircraft are "hand built" aircraft specifically designed to conduct flight-testing, not for standard fleet operations and will not be transitioned to fleet use. EMD aircraft require structural modifications to support installation of fully qualified fuel tanks. Four LRIP aircraft (21-24) will be added to the DT program. The existing configuration for aircraft 21 and 22 passed the drop test, with the exception of minor leaking from the single aft sponson tank (1.5 oz per minute). Aircraft 23 and 24, currently at Amarillo, TX, will have the fuel tanks replaced prior to flight, due to the timing and availability of the Lot IV tanks, limited modifications required and concurrent rework opportunities. All fleet aircraft will be equipped with the Lot IV fuel tanks as part of the Block A upgrade.

8. Potential Consequences of Risk Acceptance Without Action: ID Catastrophic, unlikely but possible (Medium Risk).

9. Contractor Concurrence:

PREPARED BY:



Michael G. Clemmons
Boeing Product Safety Manager

DATE: 5/29/02

P.O. CONCURRENCE:

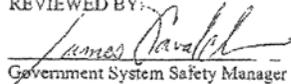

M. Tyach
Bell-Boeing Program Office

DATE: 5/28/2002

10. Government System Safety Concurrence:

Government Comments/Recommendations:

REVIEWED BY:


Government System Safety Manager

DATE: 5-24-02

11 Government Risk Acceptance:


V-22 Class Desk

DATE 5-28-02

Appendix K. Initial Analysis of V-22 System Safety Risk Assessment

Our initial analysis of the Navy's formal system safety risk assessment of the engineering and manufacturing development (EMD) V-22 noncompliant sponson fuel cells (Appendix J) and our concerns about that risk assessment follow. We conducted the analysis on May 29, 2002. To correlate our concerns, we include, as applicable, the heading from the system safety risk assessment in Appendix J and, in parentheses, the applicable report page number.

Navy Risk Assessment Guidance

Naval Air Systems Command Instruction 5100.11, "Research and Engineering Technical Review of Risk Process and Procedures for Processing Grounding Bulletins," September 3, 1999, provides guidance on engineering technical review of risk when coordinating an engineering recommendation involving potential grounding of aircraft. The Instruction states that a key element in understanding and managing a specific hazard is a risk assessment of the potential hazard. The risk assessment assigns a risk level to the hazard and is expressed in terms related to the operation of the platform or system in question. The risk level is a function of the:

- severity of the hazard, including catastrophic, critical, marginal, and negligible; and
- frequency of occurrence of the hazard, including frequent, probable, occasional, remote, and improbable.

The combination of those two factors form the hazard environment that must be assessed. Severity is expressed in terms of degree of injury, property damage, or effect on mission. Frequency is expressed either in qualitative terms, such as remote, or quantitative terms, such as probability of occurrence or failure rate; for example, catastrophic-remote or 1D. Once those two parameters are defined, a system safety risk analysis matrix is used to identify potentially unsafe conditions. The resultant four risk levels in the matrix are:

- unacceptable or a high safety risk;
- undesirable or a medium safety risk;
- acceptable with review or low safety risk; and
- acceptable without review or very low safety risk.

Although use of the matrix is inherently subjective, the process accepts data from the evaluation of inputs supplied by flight test results, original equipment

manufacturers, analysis, and laboratory results from engineering investigations. Often, suitable data is not available to quantify frequency or severity; therefore, a subjective analysis is required. In those cases, the matrix still provides a consistent framework and a systematic approach for assessing and managing risk.

Concerns With V-22 EMD System Safety Risk Assessment

Hazard Classification. (Page 32) The Navy assigned a safety risk assessment code of 1D catastrophic-remote (undesirable or a medium safety risk) for the fuel cells installed in the V-22 engineering and manufacturing development (EMD) test aircraft. The next higher code would have been 1C catastrophic-occasional (unacceptable or high safety risk).

Probability of a Crash: (2-10/100,000 flight hours). (Page 33) The probability factors associated with a crash do not appear to be reasonable. The system safety risk assessment did not base its crash frequency probability on past performance of the V-22 aircraft or other EMD aircraft. Specifically:

- The assessment's crash frequency probability of 2 to 10 mishaps every 100,000 flight hours seems inconsistent with the number of mishaps experienced and the technical challenges of the V-22. According to the V-22 Program Office, the V-22 has experienced 4 major crashes to date in approximately 5,000 flight hours.
- The estimate of 2 to 3 mishaps in 100,000 flight hours was based upon historic Class A helicopter mishap rates for the Navy and Marine Corps. However, the risk assessment codes in Naval Air Systems Command Instruction 5100.11 are based on the risk of aircraft and property damage and personal injury, not just on "Class A" accidents in which a death or serious injury occurred.
- Crash frequency data from other EMD aircraft would have been more representative than crash frequency data from operational aircraft.
- In making its probability projections, the Navy used only baseline probability data for helicopters and not baseline probability data that considered airplanes as well as helicopters. Specifically, the V-22 flies like an airplane and takes off and lands like a helicopter; but the V-22 cannot autorotate and land in the event of an engine failure, according to the Director, Operational Test and Evaluation Report, "Combined Operational Test and Evaluation and Live Fire Test and Evaluation Report on the V-22 Osprey," November 17, 2000. However, the V-22 Program Office indicated that the V-22 has limited ability to autorotate.

Qualitative Considerations. (Pages 32 and 33) The Navy did not plan to rigorously test the V-22 EMD test aircraft as part of the V-22 flight test program. The system safety risk assessment stated that:

- EMD testing will be conservative,
- EMD aircraft will have limited exposure compared to fleet aircraft, and
- EMD aircraft will not be transitioned to fleet use.

Because EMD testing is used to demonstrate system capabilities, and V-22 EMD test aircraft will be used throughout EMD testing, low-risk testing may be incompatible with making an adequate determination of the aerodynamic characteristics and operational limitations of the V-22. Further, in December 2000, the Defense Science Board criticized the V-22 Program for severely reducing the scope of developmental testing.

Data Independence and Variability. The independence and variability of probability factors used in the system safety risk assessment are questionable.

- **Probability That a Crash Is Survivable and Probability That the Crash Occurs Over Land.** (Page 33) Factors in the hazardous probability calculations may not be independent. For example, the “probability that a crash is survivable” and “probability that the crash occurs over land” may be dependent. The Navy should have considered dependencies among factors in making the safety risk level determination.
- **Probability That the Fuel Tank Is Compromised During a Crash Condition.** (Pages 33 and 34) Calculations in the Navy’s system safety risk assessment addressed the variability in the number of crashes. However, the variability of other factors, such as the “probability that the fuel tank is compromised during a crash condition,” was not addressed in the risk assessment.

Conclusion. If the crash frequency probability was based on the past performance of either the V-22 or fixed-wing EMD aircraft, which the Navy did provide, and the system safety risk assessment model was adjusted to account for the nonindependence between the “probability that the crash occurs over land” and the “probability that a crash is survivable,” the safety risk assessment code would increase from undesirable or a medium safety risk to unacceptable or high safety risk. Accordingly, we have concerns with the methodology, reasonableness, and support of the probability factors used in the system safety risk assessment for the noncompliant sponson fuel cells on the V-22 EMD aircraft.

Appendix L. Office of the Inspector General of the Department of Defense Memorandum Concerning Safety of V-22 Aircraft



INSPECTOR GENERAL
DEPARTMENT OF DEFENSE
400 ARMY NAVY DRIVE
ARLINGTON, VIRGINIA 22202-4704

JUN 7 2002

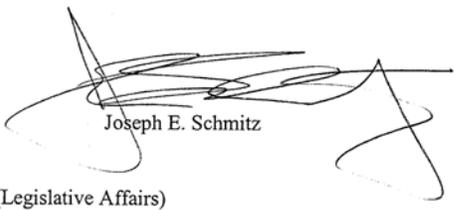
MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION,
TECHNOLOGY, AND LOGISTICS

SUBJECT: Safety of the V-22 Osprey Joint Advanced Vertical Aircraft (Project
No. D2002AE-0065)

This memorandum is in response to your May 28, 2002, memorandum that endorsed the Navy's May 24, 2002, System Safety Formal Risk Assessment on the engineering and manufacturing development (EMD) V-22 noncompliant sponson fuel cells as a response to a draft audit recommendation. Because of a new issue that the Navy's Risk Assessment has raised, we are unable to audit and validate the reasonableness of the Risk Assessment.

The Navy's System Safety Formal Risk Assessment purported to determine that the risk of flying V-22 EMD aircraft with noncompliant fuel cells should be categorized as "1D Catastrophic, unlikely but possible (Medium Risk)." The Risk Assessment does not appear to have taken into consideration the unique nature of the EMD testing and the EMD test aircraft, which raises fundamental questions concerning the evaluation methodology used. At least one key factor appears to be based on data from operational aircraft, which appears to be a significant methodological error.

We plan to issue another draft report that details concerns associated with the safety risk assessment of the fuel cells installed in the V-22 EMD test aircraft and that requests comments on new recommendations. Also, we intend to include the May 24, 2002, safety risk assessment in the draft report and will ask the Navy to correct an error in the introductory "scrivener notes" to the assessment.


Joseph E. Schmitz

cc: Secretary of the Navy
Assistant Secretary of Defense (Legislative Affairs)
Assistant Secretary of Defense (Public Affairs)
Director of Operational Test and Evaluation

Appendix M. Navy Response to Questions on the System Safety Risk Assessment for V-22 Fuel Cells

Questions Concerning the Safety Assessment for the V-22 Engineering and Manufacturing Development Fuel Cells

USD(AT&L) Flight Decision Documents.

1. Provide a copy of the sponson fuel cell SAR report to include all entries made as of May 6, 2002 (SAR report cut off date), and all entries as of date this Email was received.

This document is proprietary to Bell-Boeing. It will be forwarded by separate correspondence when it has been approved for release by Bell-Boeing.

2. Provide Flight Readiness Review, March 21, 2002, briefings, results and any other documentation available used to support the review or to record the review results. Provide a list of review attendees. Also include any documentation or assessments to support the contention that the safety of the EMD aircraft sponson fuel cells was addressed.

The discussion at the FRR concerning the safety of the EMD aircraft with respect to non-compliant fuel cells was not documented. RDML Heely personally briefed VADM Dyer and LTGEN Reynolds concerning the risks associated with the fuel cells. VADM Dyer and LTGEN Reynolds concurred with the assessment as briefed and no further discussion was required.

Safety Assessment Data and Methodology.

3. Was actual V-22 crash history and/or developmental aircraft accident history factored into the "probability of a crash" factor? If yes, how was it done? If no, please explain why not?

No, this risk assessment attempts to take into account a "reasonable" worst case (10 per 100K flight hours for mishap rate - 1 every 10,000 flight hours - probable). The EMD aircraft have flown nearly 2000 hours without a mishap. It must be noted, the FRR concurred that the expected level of risk for the V-22 return to flight for EMD to be medium. This was based on all the efforts conducted over the 14 month down period to assess and improve overall safety.

Below find an explanation of the crash history and rationale:

V-22 has experienced 4 Class A mishaps:

FSD DT testing - 1184 flight hours. 2 mishaps. A/C 5 and A/C 4

EMD DT testing - 1894 flight hours. 0 mishaps

LRIP - 1869 flight hours. 2 mishaps. A/C 14 and A/C 18

A/C 5 mishap occurred in 1991. Aircrew/occupants aboard aircraft #5 survived with minimal injuries. The crash occurred on the A/C's maiden flight and was the result of flawed assembly processes (*The impact forces were survivable*).

A/C 4 mishap was the result of a design deficiency that allowed fluid to pool in a nacelle inlet and be ingested by an engine following conversion. An engine surge resulted and the back pressure failed the inlet. A fire propagation path to the upper nacelle resulted in fire impingement on the pylon driveshaft. The shaft subsequently failed resulting in asymmetric thrust (*The impact forces were not survivable*).

A/C 14 mishap occurred when the pilot exceeded the flight clearance. As a result, the a/c entered into vortex ring state and an asymmetric thrust condition (*The impact forces were not survivable*).

A/C 18 mishap chain of events are as follows. Hydraulic leak followed by multiple PFCS resets. The rotor governor re-initialization logic resulted in large pitch changes at the blades. All three actuators in one nacelle were rate limited due to the initial hydraulic leak. Multiple PFCS resets eventually put the a/c in an unrecoverable yaw/wing stall state (*The impact forces were not survivable*).

Each development aircraft is different....varying requirements, varying levels of accepted risks, and different configurations. Developmental aircraft, in general, have very few flight hours compared to the number of flight hours the aircraft accumulates during deployment. As such, "Mishap Rates" are generally higher than compared to aircraft which are flying in the fleet (i.e. rates for DT/OT testing phases: F-14A - 79/100,000; F-16A - 50/100,000; F-18A/B - 61/100,000). Due to the various differences between development aircraft (as mentioned earlier) usage of this mishap rate would not be reflective of one specific airframe in development/flight test phase. Using mishap rates incurred on like aircraft in the fleet that have accumulated significant flight hours combined with the use of conservative factors provides a more "realistic" assessment. Risk assessments are a tool to evaluate risk using relevant data when available (readily within reason). Qualitative factors (judgement call sometimes based on common sense and lessons learned) are sometime the only way to induce realism in the risk projection. Mil-Std-882 provides the following guidance in terms of mishap probability: *"Assigning a quantitative mishap probability to a potential design or procedural hazard is generally not possible early in the design process. At that stage, qualitative mishap probability may be derived from research, analysis, and evaluation of historical safety data from similar systems.*

4. Because the V-22 configuration and capabilities are unique, please explain why you used historical helicopter survivability experience when establishing the "probability that a [V-22] crash is survivable" rather than historical airplane survivability experience?

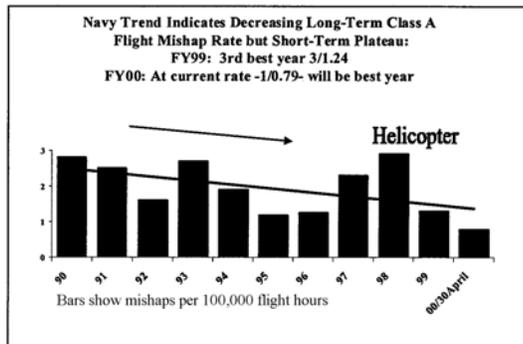
The V-22, as a tilt-rotor aircraft incorporates crashworthy features in critical subsystems; Landing Gear, Structure (includes soft soil impact, wing failure modes and blade strike assessments), Crew Seats, Troop and auxiliary seats, Cargo restraint, Crew injurious environment, Emergency egress, Water ditching and post-ditching flotation, fuel system. Transport fixed wing aircraft are not designed to the same stringent (Mil-Std-1290 - light fixed and rotary wing aircraft crashworthiness) requirements that have been imposed on the V-22 and are imposed on all new light fixed and rotary wing military aircraft platforms. High-performance, fixed wing aircraft are equipped with ejection seats and do not share the same crashworthiness features nor do they operate in the same environment. Similarly, large multi-engine transport aircraft, do not employ the same crashworthiness features (such as energy attenuating landing gear and seating) and rely more heavily on large fuselage deformation for energy attenuation. It is therefore deemed appropriate to make this comparison.

5. What was the source of the helicopter data used for the safety assessment, what was the population and population size the data was developed from, and what timeframe does the data represent? Did the data include helicopters without the capability to make an autorotation landing in the event of engine failure? Please provide a copy of the data used. (NOTE: We

attempted to view the website source referenced in the risk assessment, but were unable to determine the exact link you used.)

* Autorotations are performed in response to either total power loss (requires dual engine failures in all Navy/Marine Corp helicopters, including V-22) or due to tail rotor failures (for conventional helicopters). The vast majority of autorotations are due to tail rotor failures. Lack of tail-rotor will reduce the need for V-22 autorotation capability (compared to single rotor helicopters). The probability of having to conduct an autorotation is considered improbable. The data source for mishap rate is provided below:

Naval Safety Center Data



The following additional data sources support this assessment:

Source 1: V-22 Crashworthiness Presentation Summary , Boeing Vertol Company 6 May 1986.

Source 2: The Naval Aircraft Accident Environment, Phase I, Helicopter Aircrew Survivability and Structural Response, Prepared by, Joseph W. Coltman, Simula Inc. 1984.

Source 3: Interim Reports 1-2. 1 - Analysis of Navy/Marine Corps Helicopter mishaps, 2- Terrain Characteristics in Navy/Marine Corps Helicopter mishaps, prepared by KETRON Division of the Bionetics Corporation for the Naval Air Warfare Center Aircraft Division Code 4.6.2.1, September 1998.

Source 4 : Data from Naval Safety Center.

6. What was the source for the data used to develop the “probability that a crash is survivable” factor, what was the population and population size the data was developed from, and what timeframe does the data represent. Why was only class A mishaps represented by this factor? Please provide a copy of the data used.

Source 2 data - Helicopter Flight Mishap Analysis (CY 1972 -1981). Sample size was 184 mishaps. 53 events considered low severity impacts. - No injury to occupant (Note: A Class A Mishap is one in which damage costs exceeded 1 million dollars (or fatalities/permanent disability). Class B and C mishaps include those involving a smaller dollar amount. Class B and C mishaps are not typically classified as crashes), 101 events considered significantly survivable

mishaps. - Flight mishap resulting in at least substantial structural damage and one or more major injuries to the occupants, 30 events considered non-survivable mishaps. - The impact acceleration environment exceeded the limits of human tolerance, and/or the occupied volume was compromised. Eliminating the 54, low severity impact events (hard landing events) results in a non-survivability rate of 30 non-survivable /131 total events = 23%

Source 3 data - used class A mishap data from 1980 to 1997. This data indicates that out of 284 mishaps, 208 were categorized as Survivable or Partially Survivable (Some portion of the airframe maintained enough occupiable volume to allow for occupant survival - usually involves some occupant deaths and some occupant injuries). 76 of the mishaps were considered Non-Survivable (27% non-survivable).

The assessment assumed that the survivability rate was 50%.

If the assessment were adjusted to reflect a survivability rate of 75%, the risk level for the hazardous condition would be:

before: $2 \times .5 \times .5 \times .5 \times 1 \times .5 = .125$ events per hundred thousand flight hrs. = D (Remote)
 $10 \times .5 \times .5 \times .5 \times 1 \times .5 = .625$ events per hundred thousand flight hrs. = D (Remote)

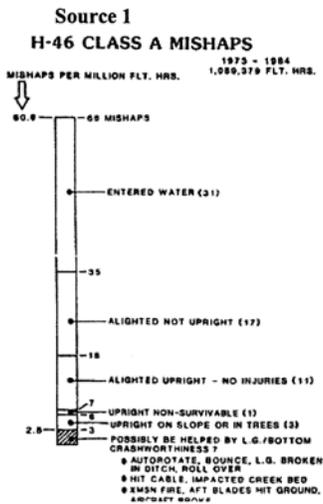
after: $2 \times .75 \times .5 \times .5 \times 1 \times .5 = .1875$ events per hundred thousand flight hrs. = D (Remote)
 $10 \times .75 \times .5 \times .5 \times 1 \times .5 = .94$ events per hundred thousand flight hrs. = D (Remote)

7. What was the source for the data that was used to develop the "probability that a crash occurs over land" factor, what was the population and population size the data was developed from, and what timeframe does the data represent? Please provide a copy of the data used.

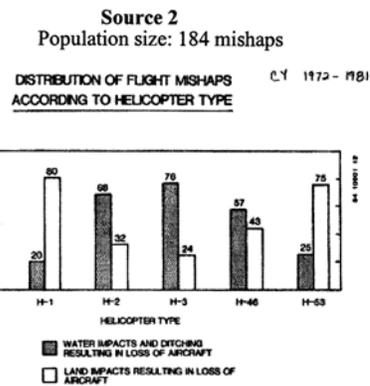
The V-22 is a replacement for the H-46. The data below fully supports the 50% over land statement.

H-46 Data: Source 1 data source shows 31/66 = 47% water crashes, Source 2 data 57% water crashes, Source 4 data shows 32/52 or 62% water crashes.

Source 3 data indicates that for all Navy/Marine Corps Helicopters, 157/284 or 55% of all crashes occurred into the water



4



Source 4 data:

NAVAL SAFETY CENTER
AIRCRAFT MISHAP LOCATION SUMMARY
(01 OCT 1985 - 10 JUN 2002)

INCIDENT TYPE	AIRCRAFT TYPE										SUMMARY	
	H-1	H-2	H-3	H-46	H-53	H-57	H-58	H-60	V-22	TOTAL		
B1 GROUND; UNCONTROLLED	18	6	3	10	8	2	1	3	0	51	Total Ground: 124	
B2 GROUND; CONTROLLED	5	0	2	0	2	2	0	1	0	12		
B6 GROUND; UNDETERMINED	1	0	0	0	2	1	0	0	1	5		
B8 GROUND; CONTROLLED, UNINTENTIONAL	16	0	1	7	6	2	0	3	0	35		
B9 GROUND; CONTROLLED, INTENTIONAL	4	1	0	1	2	0	0	2	1	11		
XU AIRCRAFT GROUND HANDLING	1	1	2	1	1	0	0	3	0	9		
Q9 GROUND RESONANCE; HELOS	0	0	0	1	0	0	0	0	0	1		
B5 GROUND OR WATER; UNDETERMINED	1	0	0	0	0	0	0	0	0	1		Undetermined: 1
B0 WATER; CONTROLLED, UNINTENTIONAL	6	3	3	10	4	0	0	7	0	33		Total Water 115
B3 WATER; UNCONTROLLED	5	4	5	4	4	0	0	2	1	25		
B4 WATER; CONTROLLED	0	3	2	0	0	0	0	0	0	5		
B7 WATER; UNDETERMINED	1	0	0	3	0	0	1	5	0	10		
BA WATER; CONTROLLED, INTENTIONAL	1	9	8	14	1	0	0	8	0	41		
J4 WATER	0	0	0	1	0	0	0	0	0	1	Trees: 12	
CN TREES	3	1	0	5	3	0	0	0	0	12		
ACFT TOTALS:	58	25	25	52	31	7	2	33	3	236		

* NOTE: INCIDENT TYPE MAY BE MULTIPLY CODED

Source 3 data indicates that 157 of 284 (55%) mishaps occurred over water for all helos.

8. Please provide evidence that the factors "probability that a crash is survivable" and "probability that a crash occurs over land" are actually mathematically independent factors.

Data is not currently available to state that the probabilities are totally independent. There may be some degree of statistical dependence but that degree is unknown. In the V-22 mishaps, there were 3 land crashes and 1 was survivable. Fuel cell crashworthiness would not have been a factor in 3 out of the 4 mishaps (75%) - impact loads far exceeded survivable mishap threshold (human thresholds).

Source 4 data indicates that:

32 of the 157 water mishaps (or 20% of water mishaps were considered non-survivable).
44 out of 127 land mishaps (or 35% of land mishaps were considered non-survivable).

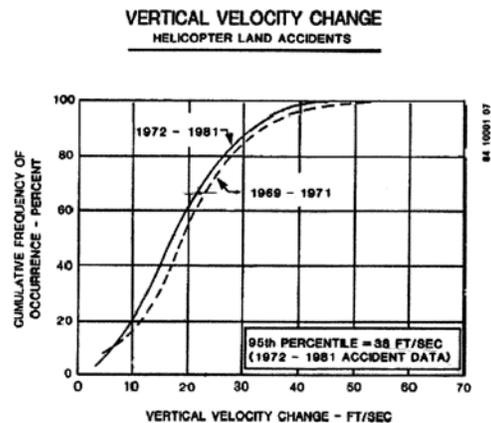
9. What was the source for the data that was used to develop the "probability that the fuel tank is compromised during a crash condition" factor and what was the population and population size the data was developed from, and what timeframe does the data represent? Please provide a copy of the data used. You use a "probability that the fuel tank is compromised during a crash condition" factor of 50 percent, what would be the factor for sponson fuel cells that met the

EMD aircraft specification, and how did you adjust that factor to address noncompliant fuel cells?

A fully compliant tank may be compromised on the order of 10-20% based on the data presented and discussed below. The 50 percent factor addresses the fact that the tank is not fully compliant tank. The probability that an extensible tank is compromised will be a function of the magnitude of the crash. The V-22 landing gear is capable of attenuating impact velocities up to 24 ft/sec. The function of the landing gear system in a crash situation is to provide controlled loading and energy attenuation. Deceleration loads experienced by the extensible tanks during a 24 ft/sec crash are not anticipated to compromise the integrity of the tank. Impacts beyond 24 ft/sec could impart significant loading to the extensible fuel cells. It is therefore conservatively assumed that fuel leakage will occur for impact velocities above 24 ft/sec. It is also assumed (and historically supported) that approximately 50% of the survivable mishaps will have an impact velocity of greater than 24 ft/sec.

The data provided below refers to "survivable crashes" and suggests that only about 30% (vs. the 50% used in the calculations) of the survivable mishaps occur with vertical velocities of above 24 ft/sec. Below 24 ft/sec, the deceleration is controlled by the landing gear. Beyond 24 ft/sec, the deceleration is controlled by fuselage deformation and is somewhat unpredictable. This does not mean that the tank will fail. The assumption that the tank will fail is conservative and the percentage of survivable mishaps with vertical impact velocities greater than 24 ft/sec is also conservative. A/C 5 mishap was a survivable crash. All onboard fuel at the time of the mishap was recovered from the sponson tanks.

Source 2 Data : The Naval Aircraft Accident Environment, Phase I, Helicopter Aircrew Survivability and Structural Response, Prepared by, Joseph W. Coltman, Simula Inc. 1984.



10. Is there any data available to be used as a basis to support the assumption used for the "probability that an ignition source is present following a post crash fuel spill" factor? If there is no data available to be used as a basis for this assumption, please explain the basis you used for the assumption.

The 100% assumption is ultra conservative. When lacking data, System Safety tends to side towards being conservative. Again, below 24ft/sec, the crash sequence is controlled. At fuselage separation/deformation points, self-sealing breakaway valves are provided. It is safe to

say that some crashes beyond 24 ft/sec will not produce an ignition source of sufficient energy to ignite a fuel source (the engines which are considered the primary hot surface ignition source are at the wing tips and are not located near the fuselage & sponson tanks).

11. Is there any data available to be used as a basis to support the assumption used for the "probability that occupants are not able to egress the aircraft during a post crash fire" factor? If there is no data available to be used as a basis for this assumption, please explain the basis you used for the assumption.

Assumption is viewed as reasonable given the number of aircraft egress points (7) and the fact that flight test operations will be limited to minimum essential crew. This should extend time allowed for egress in the event that the engines are the ignition source. A/C 5 experienced a post-crash fire and the crew had adequate time to egress the a/c. The Naval Safety Center supported this figure.

Source 4 data request was made subsequent to initial submittal of the Safety Assessment report to verify the assumption regarding post-crash fire egress. A data query was set up to look at class A and B helicopter mishaps from the 1985 to 2002. The data looked mishaps involving a post-crash fire, occupant injury type (not cause) and egress method.

37 events were identified involving 236 occupants

109 occupants were killed - Cause of death is not provided (crash impact vs. post crash fire)
127 occupants survived both the impact and the post-crash fire.

If we assume that all 109 occupant fatalities were the result of post-crash fire related factors (this is a conservative assumption), the data indicates that 127 out of 236 or 53% of occupants were able to egress the a/c and were not killed by the post-crash fire.

An example of an a/c that experienced a post-crash fire in which the occupants had adequate time to egress the a/c is provided below:

Acft crashed into ground during takeoff.

Acft impacted ground during takeoff & was destroyed by post-crash fire. Aircrew safely egressed. Following landing for 3rd hot refuel in desert environment helicopter aircraft commander again placed nr 1 & nr 3 eng speed control levers in ground idle position to prevent nose gearbox overtemp. After refueling, copilot, following section leader, began downwind running takeoff on short end of runway concentrating on lineup. Aircraft lifted 10-15 ft in ground effect but approaching end of runway began to settle back towards ground. Helicopter Aircraft Commander took control of aircraft. Copilot placed hand on speed control levers & realized only 1 engine lever was advanced & moved all 3 levers to Full power. Helicopter Aircraft Commander initiated flair at low altitude. Tail skid struck ground & Copilot pulled all engines back to idle. Mishap Aircraft hit ground on nose landing 410 ft from departure end of runway, lifted up & flipped right, landing upside down on rotor Head. Fire damage resulted when left sponson fuel tank ruptured pouring fuel on Nr 1 eng.

12. Have you performed and documented other system safety risk assessments for the V-22 program? If you have performed and documented other system safety risk assessments, please provide a few examples.

Yes, System Safety has performed approximately 50 formal risk assessments over the past 5 years. Two examples are:

Cross Channel Data Link Failures, FRA-2002-01, Jan 02
Rudder Actuator Binding, FRA-2002-03, Dec 01

13. Why doesn't the model consider a range (sensitivity) of factor probabilities for the "probability that occupants are not able to egress the aircraft during a post crash fire" factor, "probability that an ignition source is present following a post crash fuel spill" factor, "probability that the fuel tank is compromised during a crash condition" factor, "probability that a crash occurs over land" factor, and the "probability that a crash is survivable" factor?

The approach used in this risk assessment is typical of any analysis conducted by System Safety. The qualitative assessment is used in conjunction with the quantitative assessment (if sufficient applicable data is available to support such analysis) to develop a Risk Assessment. It is the combination of qualitative and quantitative analyses that determines Risk (we do not look strictly at historical data and/or reliability numbers when assessing Risk). If the assumptions are conservative then there should not be a need for a sensitivity analysis. Again, quantitative analysis is never the end all when it comes to determining risk.

V-22 Test Program.

14. Provide the planned V-22 developmental test and operational test program and schedule to include number of planned flight hours.

Estimated planned (developmental test) flight hrs.

A/C 8 - 548
A/C 10 - 560
A/C 7&9 combined - 1429 hrs

Total - 2537 flight hours

15. Will the EMD aircraft be used for the operational test and evaluation?

No - A/C 34 will be the first OT&E A/C and it will have the Block A fuel cells, non-extensible tanks, that have fully passed qualification testing. OT pilots will participate in the EMD program, but dedicated OT&E will not be conducted with EMD aircraft.

16. How long would the V-22 developmental test and operational test program schedule be delayed if compliant fuel cells were installed in the EMD aircraft?

A six to eight week delay per aircraft is expected once all material has been received.

17. Provide a copy of the waiver for the acceptance of the EMD aircraft installation of noncompliant sponson fuel cells.

There is no waiver related to fuel cells for the EMD aircraft. These aircraft were never officially bought by the government (DD250). The configuration control is maintained by Bell-Boeing, with DCMA and NAVAIR oversight for Flight Clearances and Airworthiness Certification.

18. Has the sponson fuel cell qualification test report (for the EFC manufactured cells) been reviewed and approved by the Fuel IPT? If not, why not, and when will the test report be reviewed and approved?

Yes, it has been reviewed and approved

19. How do you reconcile the system safety risk assessment contention that the EMD aircraft testing will be conservative, and the EMD aircraft will have limited exposure compared to fleet aircraft resulting in low risk EMD aircraft flights, with a testing program that requires testers to adequately validate the aircraft design improvements and determine the aerodynamic characteristics and operational limitations of the V-22 aircraft?

EMD flight testing is conducted in a controlled environment with substantial build-up/prerequisite testing and planning. Flight test plans are routed across a broad expanse of engineering competencies and must move past several layers of approval authority before flight test crews can even man up developmental aircraft for flight testing. Before flight test plans get to the final review stage, they can be subject to the equivalent of hundreds of years of flight test and risk management experience. Risks are carefully considered and mitigated to the greatest degree possible.

Instrumentation provides data in the form of real time telemetry to the flight test team for the a/c that are conducting envelope expansion testing. Aircraft response and airworthiness is very often observed real-time by flight test engineers, who then communicate with test crews to provide them a magnitude of situational awareness and wealth of professional knowledge that is not available to the fleet pilot. It is rather routine, to have a flight test engineer immediately abort a flight when an aircraft limit exceedence is experienced – limiting exposure of a flight test crew to an unsafe condition. In contrast, the fleet operational pilots do not operate in this relatively pristine environment and are not subject to the oversight mandated by the Integrated Test Team. There is much more room for human/operator error in the fleet.

Within flight test organizations, maintenance intervals are much more frequent than would be seen for a fleet aircraft. The amount of oversight and scrutiny placed upon daily aircraft operations is an order of magnitude beyond what would be typical of fleet operations.

Points of Contact in PMA-275, Col. Paul Croisetiere, Weapons System Integrator (301) 757-5576, or Cdr. Tim Dunigan, V-22 Class Desk (301) 757-5541.

Appendix N. Analysis of the Navy Response to Issues With the System Safety Risk Assessment for V-22 Fuel Cells

The V-22 Program Office provided comments in response to issues we had with the System Safety Risk Assessment for the V-22 fuel cells (Appendix M). The issues include the USD(AT&L) flight decision documents, safety assessment data and methodology, and the V-22 test program. The following discusses those issues by number; the Navy's response; and the audit response, as applicable.

USD(AT&L) Flight Decision Documents

1. Provide a copy of the sponson fuel cell SAR [safety action record] report to include all entries made as of May 6, 2002 (SAR report cut off date), and all entries as of date this Email was received.

Navy Response. The V-22 Program Office stated that the safety action record for the V-22 sponson fuel cell is proprietary to Bell-Boeing and will be forwarded by separate correspondence when Bell-Boeing has approved it for release.

Audit Response. On July 22, 2002, we received the safety action record. The safety action record did not document and support the basis for assessing the safety risk as "1D (medium) risk" (undesirable risk) rather than "high risk" (unacceptable risk), the next higher level of safety risk.

2. Provide Flight Readiness Review, March 21, 2002, briefings, results and any other documentation available used to support the review or to record the review results. Provide a list of review attendees. Also include any documentation or assessments to support the contention that the safety of the EMD [engineering and manufacturing development] aircraft sponson fuel cells was addressed.

Navy Response. The V-22 Program Office stated that nobody documented the discussion at the March 21, 2002, Flight Readiness Review concerning the safety of the EMD aircraft with respect to the noncompliant fuel cells. However, the V-22 Program Office stated that Rear Admiral Heely, Assistant Commander, Naval Air Systems Command for Research and Engineering, personally briefed Vice Admiral Dyer, Commander, Naval Air Systems Command; and Lieutenant General Reynolds, Commander, Aeronautical Systems Center, Air Force Materiel Command, concerning the risks associated with the fuel cells. Vice Admiral Dyer and Lieutenant General Reynolds concurred with the assessment, as briefed, and no further discussion was required.

Audit Response. In his May 28, 2002, memorandum, the USD(AT&L) stated that the Navy specifically addressed the fuel cell issue at a Flight Readiness Review on March 21, 2002. However, without documentation from the Flight Readiness Review, we cannot verify from an audit perspective that the safety of the EMD aircraft sponson fuel cells was specifically addressed at the review.

Safety Assessment Data and Methodology

3. Was actual V-22 crash history and/or developmental aircraft accident history factored into the “probability of a crash” factor? If yes, how was it done? If no, please explain why not?

Navy Response. The V-22 Program Office response addressed the probability of a crash and aircraft mishap rates.

Probability of a Crash. The V-22 Program Office stated that actual V-22 crash history and developmental aircraft accident history were not factored into the “probability of a crash” factor because the risk assessment attempts to take into account a “reasonable” worst case of 10 mishaps per 100,000 flight hours or 1 mishap every 10,000 flight hours. Further, the Program Office stated that the EMD aircraft have flown nearly 2,000 hours without a mishap and noted that the Flight Readiness Review concurred that the expected level of risk for the V-22 EMD test aircraft returning to flight was medium. The Program Office also stated that the medium level of risk was based on the efforts conducted over the 14-month down period to assess and improve overall safety.

Aircraft Mishap Rates. The V-22 Program Office stated that the V-22 aircraft have flown a total of 4,947 hours during full-scale development, EMD, and low-rate initial production developmental aircraft testing and have experienced four Class A mishaps as follows:

- for 1,184 flight hours of full-scale development aircraft testing, the V-22 experienced two mishaps involving Aircraft Build Nos. 4 and 5;
- for 1,894 flight hours of EMD aircraft testing, the V-22 experienced no mishaps; and
- for 1,869 flight hours of low-rate initial production aircraft testing, the V-22 experienced two mishaps involving Aircraft Build Nos. 14 and 18.

The V-22 Program Office provided details concerning the four Class A mishaps and noted that the impact forces were not survivable for all of the mishaps except Aircraft Build No. 5. Further, the Program Office stated that developmental aircraft generally have very few flight hours compared to the number of flight hours the aircraft accumulates during deployment; therefore, mishap rates are generally higher for developmental aircraft. During

developmental and operational testing, the F-14A, the F-16A, and the F-18A/B experienced 79, 50, 61 mishaps per 100,000 flight hours, respectively. The Program Office believes that using mishap rates incurred on like aircraft in the fleet that have accumulated significant flight hours, combined with the use of conservative factors, provide a more realistic assessment.

The V-22 Program Office also stated that risk assessments are a tool to evaluate risk using relevant data when available; however, qualitative factors or judgment calls are sometimes the only way to induce realism in the risk projection. The Program Office also stated that DoD Military Standard 882D, "Standard Practice for System Safety," February 10, 2000, provides that assigning a quantitative mishap probability to a potential design or procedural hazard is generally not possible early in the design process. At that stage, qualitative mishap probability may be derived from research, analysis, and evaluation of historical safety data from similar systems.

Audit Response. The Navy did not provide a reasonable analysis to support how it extrapolated from the "efforts conducted" that the expected level of risk for the V-22 EMD test aircraft returning to flight was medium. However, the Navy did provide mishap rate data for airplanes, but not for EMD helicopters to correlate with the V-22's unique operational characteristics. Further, the lowest mishap rate the Navy reported for fixed-wing aircraft was 50 mishaps per 100,000 flight hours for the F-16A, which does not support the "worst case" assumption of 2 to 10 mishaps per 100,000 flight hours for the V-22. In addition, whether the impact forces were not survivable for all of the mishaps except Aircraft Build No. 5 is not relevant to the "probability of crash" assumption in the system safety risk assessment (Appendix J, page 32). Instead, the survivability of the mishaps should be included with the "probability that crash is survivable" assumption.

Although the Navy cited DoD Military Standard 882D guidance on assigning mishap probability, it did not use crash history in deriving its "probability of a crash" risk factor. Using a V-22 mishap rate of one mishap about every 1,200 flight hours (4 mishaps in 4,947 flight hours), equates to a mishap rate of about 83 mishaps per 100,000 flight hours. Therefore, the projection of 10 mishaps per 100,000 flight hours for the V-22 EMD test aircraft was not supportable in the Navy's response as evidenced by the V-22's actual mishap history and the mishap history for the F-14A, the F-16A, and the F-18A/B.

4. Because the V-22 configuration and capabilities are unique, please explain why you used historical helicopter survivability experience when establishing the "probability that a [V-22] crash is survivable" rather than historical airplane survivability experience?

Navy Response. The V-22 Program Office stated that historical helicopter survivability experience was used rather than historical airplane survivability experience because the V-22, as a tilt-rotor aircraft, incorporates crashworthy features in critical subsystems. Further, the Program Office stated that transport fixed-wing aircraft are not designed to the same stringent requirements as those imposed on the V-22 and on all new light-fixed and rotary-wing military

aircraft. The Program Office also stated that high-performance, fixed-wing aircraft are equipped with ejection seats and do not share the same crashworthiness features or operate in the same environment. Similarly, large multi-engine transport aircraft do not employ the same crashworthiness features. Instead, those aircraft rely more on large fuselage deformation for energy reduction.

Audit Response. The Navy’s explanation for using historical helicopter survivability experience when establishing the “probability that a crash is survivable” rather than historical airplane survivability experience seems reasonable.

5. What was the source of the helicopter data used for the safety assessment, what was the population and population size the data was developed from, and what timeframe does the data represent? Did the data include helicopters without the capability to make an autorotation landing in the event of engine failure? Please provide a copy of the data used.

Navy Response. The V-22 Program Office stated that autorotations are performed in response to total power loss, resulting from dual engine failures in Navy and Marine Corp helicopters, including the V-22; or in response to tail-rotor failures in conventional helicopters for which the vast majority of autorotations occur. Because the V-22 does not have a tail rotor, the need for autorotation capability is reduced. For its mishap rate, the V-22 Program Office provided a graph, “Naval Safety Center Data,” as the data source. In addition, the Program Office listed four data sources to support the “Naval Safety Center Data” assessment.

Audit Response. The Navy did not provide the population and population size for the “Naval Safety Center Data” and copies of support data. Further, the times given in the data sources were unclear about whether they were timeframes of data or publication dates of studies.

6. What was the source for the data used to develop the “probability that a crash is survivable” factor, what was the population and population size the data was developed from, and what timeframe does the data represent. Why was only Class A mishaps represented by this factor? Please provide a copy of the data used.

Navy Response. The V-22 Program Office provided data sources from the Helicopter Flight Mishap Analysis (CY 1972-1981) and Class A mishap data from 1980 to 1997 to support nonsurvivability rates of 23 and 27 percent, respectively, for its “probability that a crash is survivable” factor. The V-22 Program Office stated that the Navy risk assessment assumed that the survivability rate was 50 percent; however, if the assessment were adjusted to show a survivability rate of 75 percent, the risk level for the hazardous condition would remain a “D” or remote chance of occurrence.

Audit Response. The data that the Navy provided supported 75 percent rather than 50 percent as the value for the “probability that a crash is survivable” factor.

7. What was the source for the data that was used to develop the “probability that a crash occurs over land” factor, what was the population and population size the data was developed from, and what timeframe does the data represent? Please provide a copy of the data used.

Navy Response. The V-22 Program Office stated that the V-22 is a replacement for the H-46 helicopter and provided 4 sources for data to support the “probability that a crash occurs over land” factor of 50 percent. The 4 sources showed the probabilities of water crashes as 47 percent, 57 percent, 55 percent, and 62 percent, respectively.

Audit Response. The source 1 and 2 data were old, 1973 through 1984 and 1972 through 1981, respectively; and the source 3 data were unclear as to whether 55 percent of the helicopter mishaps occurred over water. Further, the source 4 data were not for EMD aircraft and generally supported the “probability of crash over land” factor equating to 50 percent.

8. Please provide evidence that the factors “probability that a crash is survivable” and “probability that a crash occurs over land” are actually mathematically independent factors.

Navy Response. The V-22 Program office stated that data is not currently available to show that the “probability that a crash is survivable” and the “probability that a crash occurs over land” are totally independent. Further, the Program Office stated that some degree of statistical dependence may exist; however, that degree is unknown. In the V-22 mishaps, three were land crashes and one was survivable. The V-22 Program Office also stated that fuel cell crashworthiness would not have been a factor in 75 percent (3 out of 4) of the mishaps because impact loads far exceeded the survivable mishap threshold for humans. Further, the Program Office stated that source data indicates that 20 percent (32 divided by 157) of water mishaps and 35 percent (44 divided by 127) of land mishaps were considered nonsurvivable.

Audit Response. The Navy admitted that probabilities for crashing over land and survivability of crash were not totally independent. Instead of using 2 separate factors in the current safety risk assessment model and the admitted relationship between crashing over land and survivability of crash, the Navy should have used one combined factor “probability that crash is over land and survivable,” equaling approximately 29 percent $[(127 - 44) \div (127 + 157) = .292]$. By presenting two dependent factors as independent factors, the Navy understated the numeric value of the safety risk assessment.

9. What was the source for the data that was used to develop the “probability that the fuel tank is compromised during a crash condition” factor and what was the population and population size the data was developed from, and what timeframe does the data represent? Please

provide a copy of the data used. You use a “probability that the fuel tank is compromised during a crash condition” factor of 50 percent, what would be the factor for sponson fuel cells that met the EMD aircraft specification, and how did you adjust that factor to address noncompliant fuel cells?

Navy Response. The V-22 Program Office provided data that indicated that a fully compliant tank may be compromised during a crash condition from 10 to 20 percent. The Program Office stated that the 50 percent factor presented in the equation used for the V-22 safety risk assessment addresses the fact that the tank is not a fully compliant tank. The probability that an extensible tank is compromised would be a function of the magnitude of the crash. The V-22 Program Office conservatively assumed that the extensible fuel cells would encounter fuel leakage as a result of impact velocities above 24 feet per second. Further, the Program Office assumed, in conjunction with historically support, that approximately 50 percent of the survivable mishaps will have an impact velocity of greater than 24 feet per second.

The V-22 Program Office provided a graph, “Vertical Velocity Change,” with data from 1969 through 1981 that referred to survivable crashes and stated that the graph suggests that only about 30 percent of the survivable mishaps, instead of 50 percent used in the risk assessment calculations, occur with vertical velocities of about 24 feet per second. Further, the Program Office stated that, at less than 24 feet per second, the landing gear controls the deceleration. However, at greater than 24 feet per second, the fuselage deformation controls deceleration, which is somewhat unpredictable, but that does not mean that the fuel tank would fail. The Program Office also stated that the assumption that the fuel tank will fail is conservative and that the percentage of survivable mishaps with vertical impact velocities greater than 24 feet per second is also conservative. Further, the Program Office stated that the Aircraft Build No. 5 mishap was a survivable crash and that all onboard fuel at the time of the mishap was recovered from the sponson fuel tanks.

Audit Response. The Navy did not present any direct data to support its assumptions concerning fuel tank compromise during a crash condition. Further, the Navy’s vertical velocity change data is more than 20 years old. However, the Navy’s response that supported its “probability that the fuel tank is compromised during a crash condition” factor of 50 percent seems reasonable.

10. Is there any data available to be used as a basis to support the assumption used for the “probability that an ignition source is present following a post crash fuel spill” factor? If there is no data available to be used as a basis for this assumption, please explain the basis you used for the assumption.

Navy Response. The V-22 Program Office stated that the assumption of a 100 percent “probability that an ignition source is present following a post crash fuel spill” is ultra conservative. Further, the Program Office stated that, when lacking data, system safety tends to side towards being conservative, and reiterated that, below 24 feet per second, the crash sequence is controlled. The

Program Office also stated that, at fuselage separation or deformation points, self-sealing breakaway valves are provided and that some crashes beyond 24 feet per second will not produce an ignition source of sufficient energy to ignite a fuel source. The Program Office noted that the engines, which are considered the primary hot surface ignition source, are at the wing tips and are not located near the fuselage and sponson tanks.

Audit Response. We agree that the assumption of a 100 percent “probability that an ignition source is present following a post crash fuel spill” is conservative.

11. Is there any data available to be used as a basis to support the assumption used for the “probability that occupants are not able to egress the aircraft during a post crash fire” factor? If there is no data available to be used as a basis for this assumption, please explain the basis you used for the assumption.

Navy Response. The V-22 Program Office stated that the assumption used for the “probability that occupants are not able to egress the aircraft during a post crash fire” is reasonable because the V-22 has seven egress points and the flight test operations will be limited to minimum essential crew. Further, the Program Office stated that those egress points and the test operation limitation should extend the time required for egress in the event that the engines are the ignition source. The Program Office noted that, during the Aircraft Build No. 5 mishap, the aircraft experienced a post-crash fire and the crew had adequate time to egress the aircraft.

The V-22 Program Office stated that a data request was made after the initial submittal of the Safety Assessment Report to verify the assumption regarding post-crash fire egress. The Program Office requested data concerning Class A and B helicopter mishaps that occurred from 1985 to 2002. The Navy summarized the data it obtained as follows:

- 37 events were identified involving 236 occupants;
- 109 occupants were killed; however, the cause of death, namely crash impact or post crash fire, was not provided; and
- 127 occupants survived both the impact and the post-crash fire.

The Program Office assumed that, if all 109 occupant fatalities were the result of post-crash fire related factors, which is a conservative assumption, the data indicates that about 53 percent (127 divided by 236) of the occupants were able to egress the aircraft and were not killed by the post-crash fire. To illustrate its point, the Program Office provided an example of an aircraft that experienced a post-crash fire in which the occupants had adequate time to egress the aircraft.

Audit Response. The Navy provided summarized information and not documented data as requested to support the assumption used for the “probability that occupants are not able to egress the aircraft during a post crash fire” factor.

12. Have you performed and documented other system safety risk assessments for the V-22 Program? If you have performed and documented other system safety risk assessments, please provide a few examples.

Navy Response. The V-22 Program Office stated that System Safety performed approximately 50 formal risk assessments over the past 5 years and cited two examples:

- Cross Channel Data Link Failures, FRA-2002-01, Jan 02
- Rudder Actuator Binding, FRA-2002-03, Dec 01

13. Why doesn't the model consider a range (sensitivity) of factor probabilities for the “probability that occupants are not able to egress the aircraft during a post crash fire” factor, “probability that an ignition source is present following a post crash fuel spill” factor, “probability that the fuel tank is compromised during a crash condition” factor, “probability that a crash occurs over land” factor, and the “probability that a crash is survivable” factor?

Navy Response. The V-22 Program Office stated that the approach used in the system safety risk assessment is typical of any analysis conducted by System Safety. Further, the Program Office stated that the qualitative assessment is used in conjunction with the quantitative assessment to develop a risk assessment if sufficient applicable data is available to support such an analysis. The Program Office also stated that it does not look strictly at either historical data or reliability numbers, or both, when assessing risk. Instead, the combination of qualitative and quantitative analyses determines risk. Further, the Program Office stated that a sensitivity analysis should not be necessary if the assumptions used are conservative. Therefore, the Program Office concluded that quantitative analysis is not the only method to use when determining risk.

Audit Response. The Navy is not correct when it stated that a sensitivity analysis should not be necessary if the assumptions used are conservative. A sensitivity analysis provides the user of model results with information on the uncertainty inherent in the results, regardless of whether or not the assumptions are conservative. Further, the Navy is inconsistent when it implies that quantitative analysis need not be rigorous because quantitative analysis only augments qualitative analysis, and then cites quantitative analysis as independent support for its position. Only two defensible choices exist with respect to quantitative analysis: either perform it with sufficient rigor to stand alone or do not perform it.

V-22 Test Program

14. Provide the planned V-22 developmental test and operational test program and schedule to include number of planned flight hours.

Navy Response. The V-22 Program Office stated that they planned to perform approximately 2,537 flight hours of V-22 developmental testing for four aircraft:

- Aircraft Build Nos. 7 and 9, a combined total of 1,429 flight hours;
- Aircraft Build No. 8, a total of 548 flight hours; and
- Aircraft Build No. 10, a total of 560 flight hours.

Audit Response. The Navy's response identified the estimated number of planned developmental flight hours; however, the Navy did not provide the planned V-22 developmental test and operational test program and schedule, as requested, so that we could evaluate the technical risks the aircraft would be subjected to during the remaining testing.

The "V-22 Long-Term Schedule" in the "V-22 Program Status Report to Congress," April 2002, shows that EMD aircraft will be used in flight testing through 2007. Further, the "V-22 Developmental Flight Test Schedule" in the report shows that the flight testing will include tests of formation flying and handling qualities. However, if those tests are conducted in a low-risk environment, as discussed in the system safety risk assessment, the Navy will not be able to fully meet developmental test requirements to verify:

- the status of technical progress,
- whether design risks have been minimized, and
- the achievement of contract technical performance.

15. Will the EMD aircraft be used for the operation test and evaluation?

Navy Response. The V-22 Program Office stated that it would not conduct operational test and evaluation with EMD aircraft; however, operational test pilots will participate in the EMD program. Further, the Program Office stated that a Lot 4, LRIP aircraft, will be the first operational test and evaluation aircraft, and it will have nonextensible fuel cells that passed qualification testing.

Audit Response. Although the EMD aircraft may not be used in operational testing, the Navy still must rigorously test the EMD aircraft to ensure that the V-22 aircraft is ready for operational testing.

16. How long would the V-22 developmental test and operational test program schedule be delayed if compliant fuel cells were installed in the EMD aircraft?

Navy Response. The V-22 Program Office stated that, if compliant fuel cells were installed in the EMD aircraft, the V-22 developmental test and operational test program schedule would be delayed 6 to 8 weeks per aircraft once all material is received.

17. Provide a copy of the waiver for the acceptance of the EMD aircraft installation of noncompliant sponson fuel cells.

Navy Response. The V-22 Program Office stated that a waiver related to fuel cells for the EMD aircraft does not exist and that the Government never officially bought those aircraft. Further, the Program Office stated that Bell-Boeing maintains configuration control with Defense Contract Management Agency and Naval Air Systems Command oversight for flight clearances and airworthiness certification.

18. Has the sponson fuel cell qualification test report (for the EFC [Engineered Fabrics Corporation] manufactured cells) been reviewed and approved by the Fuel IPT [integrated product team]? If not, why not, and when will the test report be reviewed and approved?

Navy Response. The V-22 Program Office stated that the sponson fuel cell qualification test report for the fuel cells manufactured by Engineered Fabric Corporation has been reviewed and approved.

Audit Response. The Navy did not indicate who reviewed and approved the sponson fuel cell qualification test report.

19. How do you reconcile the system safety risk assessment contention that the EMD aircraft testing will be conservative, and the EMD aircraft will have limited exposure compared to fleet aircraft resulting in low risk EMD aircraft flights, with a testing program that requires testers to adequately validate the aircraft design improvements and determine the aerodynamic characteristics and operational limitations of the V-22 aircraft?

Navy Response. The V-22 Program Office discussed EMD flight testing, instrumentation, and maintenance intervals in its response.

EMD Flight Testing. The V-22 Program Office stated that EMD flight testing will be conducted in a controlled environment with substantial build-up or prerequisite testing and planning. Further, the Program Office stated that flight test plans include a broad range of engineering competencies and must be approved before beginning flight testing of developmental aircraft. The Program Office also stated that flight test plans can be subject to the equivalent of hundreds of years of flight test and risk management experience before they get to the final review stage. Further, risks are carefully considered and mitigated to the greatest degree possible.

Instrumentation. The V-22 Program Office stated that instrumentation provides data in the form of real time telemetry to the flight test team for the test aircraft. Further, the Program Office stated that aircraft response and airworthiness is often observed real-time by flight test engineers, who communicate with test crews to provide them with situational awareness and professional knowledge that is not available to the fleet pilot. The Program Office also stated that flight test engineers routinely abort a flight when an aircraft limit is exceeded, thereby limiting exposure of a flight test crew to an unsafe condition. In contrast, the fleet operational pilots do not operate in this relatively pristine environment and are not subject to the oversight mandated by the integrated test team.

Maintenance Intervals. The V-22 Program Office stated that, within flight test organizations, maintenance intervals are much more frequent than would be seen for a fleet aircraft. Further, the Program Office stated that the amount of oversight and scrutiny placed upon daily aircraft operations is greater than what would be typical of fleet operations.

Audit Response. Although the measures described by the Navy are risk abating, EMD aircraft tests to identify undetermined technical characteristics and the extent to which the V-22 can meet mission needs would need to test the limits of the aircraft. To adequately test such characteristics and limitations would not seem to be “conservative” or low risk.

Further, the Navy substantiated the higher risks expected during developmental testing in their response to Issue 3 when the Program Office stated that developmental aircraft generally have very few flight hours compared to the number of flight hours the aircraft accumulates during deployment; therefore, mishap rates are generally higher for developmental aircraft. Accordingly, the Navy’s position that the developmental aircraft testing will be conservative and have limited exposure compared to fleet aircraft resulting in low risk EMD aircraft flights is not defensible. Developmental testing facilitates design maturation, determines unknown technical boundaries, establishes the extent to which the aircraft meets the mission needs, and determines operational limitations so that that operational aircraft and crew members’ exposure to risks will be minimized. Developmental aircraft need to test and define performance bounds and operational aircraft need to have operational limitations stemming from the results of the developmental testing.

Conclusion

Based on the data that the Navy submitted on July 12, 2002, to support the May 24, 2002, System Safety Risk Assessment, we again concluded that the methodology used to make the assessment was flawed. Specifically, the Navy made assumptions concerning the “probability of crash,” the “probability that crash is survivable,” and the “probability that the crash occurs over land” that were not adequately supported in the documentation provided. Consequently, the System Safety Risk Assessment that the Navy prepared did not support the basis for assessing the safety risk as “1D (medium) risk” (undesirable risk)

rather than “high risk” (unacceptable risk), the next higher level of safety risk. Using the crash frequency probability data that the Navy did provide and adjusting for the revised methodology, the safety risk assessment code would increase from undesirable or a medium safety risk to unacceptable or high safety risk.

Appendix O. Report Distribution

Office of the Secretary of Defense

Under Secretary of Defense for Acquisition, Technology, and Logistics
Under Secretary of Defense (Comptroller)/Chief Financial Officer
 Deputy Chief Financial Officer
 Deputy Comptroller (Program/Budget)
General Counsel of the Department of Defense
Director, Operational Test and Evaluation

Department of the Army

Auditor General, Department of the Army

Department of the Navy

Secretary of the Navy
Commandant of the Marine Corps
 Aviation Department
Assistant Secretary of the Navy (Manpower and Reserve Affairs)
Assistant Secretary of the Navy (Research, Development, and Acquisition)
 Commander, Naval Air Systems Command
 Program Executive Officer, Air Anti-Submarine Warfare, Assault, and Special
 Mission Programs
 V-22 Program Manager
Naval Inspector General
Auditor General, Department of the Navy
Inspector General of the Marine Corps
Commander, Operational Test and Evaluation Force
 Operational Test Squadron HMX-1

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Assistant Secretary of the Air Force (Financial Management and Comptroller)
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Senate Subcommittee on Defense, Committee on Appropriations
Senate Committee on Armed Services
Senate Committee on Governmental Affairs
House Committee on Appropriations
House Subcommittee on Defense, Committee on Appropriations
House Committee on Armed Services
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House Subcommittee on National Security, Veterans Affairs, and International Relations, Committee on Government Reform
House Subcommittee on Technology and Procurement Policy, Committee on Government Reform

Under Secretary of Defense for Acquisition, Technology, and Logistics Comments



THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

07 OCT 2002

MEMORANDUM FOR DEPUTY INSPECTOR GENERAL

SUBJECT: Report on Fuel Cells of the V-22 Osprey Joint Advanced Vertical Aircraft (Project No. D2002AE-0065.001)

This responds to your August 23, 2002, draft report on fuel cells for the V-22.

You recommended that I: 1) reconsider my decision to fly EMD test aircraft without sponson fuel cells that comply with crashworthy standards, and 2) establish procedures to ensure that system safety risk assessments use a relevant methodology and are fully supported and documented. I have reconsidered both recommendations.

After careful consideration, I have again concluded that the benefits of continuing to fly to address my other technical concerns outweigh the limited risk reduction attained by stopping the flight test program and retrofitting fuel cells with greater crashworthiness on the four EMD-only aircraft.

I agree that the procedures used by the Services to assess risk, including calculations of risk probability, should use relevant methodology and be fully supported and documented. We will ensure that the Service safety organizations review their procedures, and update them, as appropriate.

A handwritten signature in black ink, appearing to read "E. C. Aldridge, Jr." with a stylized flourish at the end.

E. C. Aldridge, Jr.

cc:
Deputy Director,
Acquisition Management Directorate
DUSD (I&E)

Team Members

The Acquisition Management Directorate, Office of the Assistant Inspector General for Auditing of the Department of Defense prepared this report. Personnel of the Office of the Inspector General of the Department of Defense who contributed to the report are listed below.

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