Report No. DODIG-2021-004

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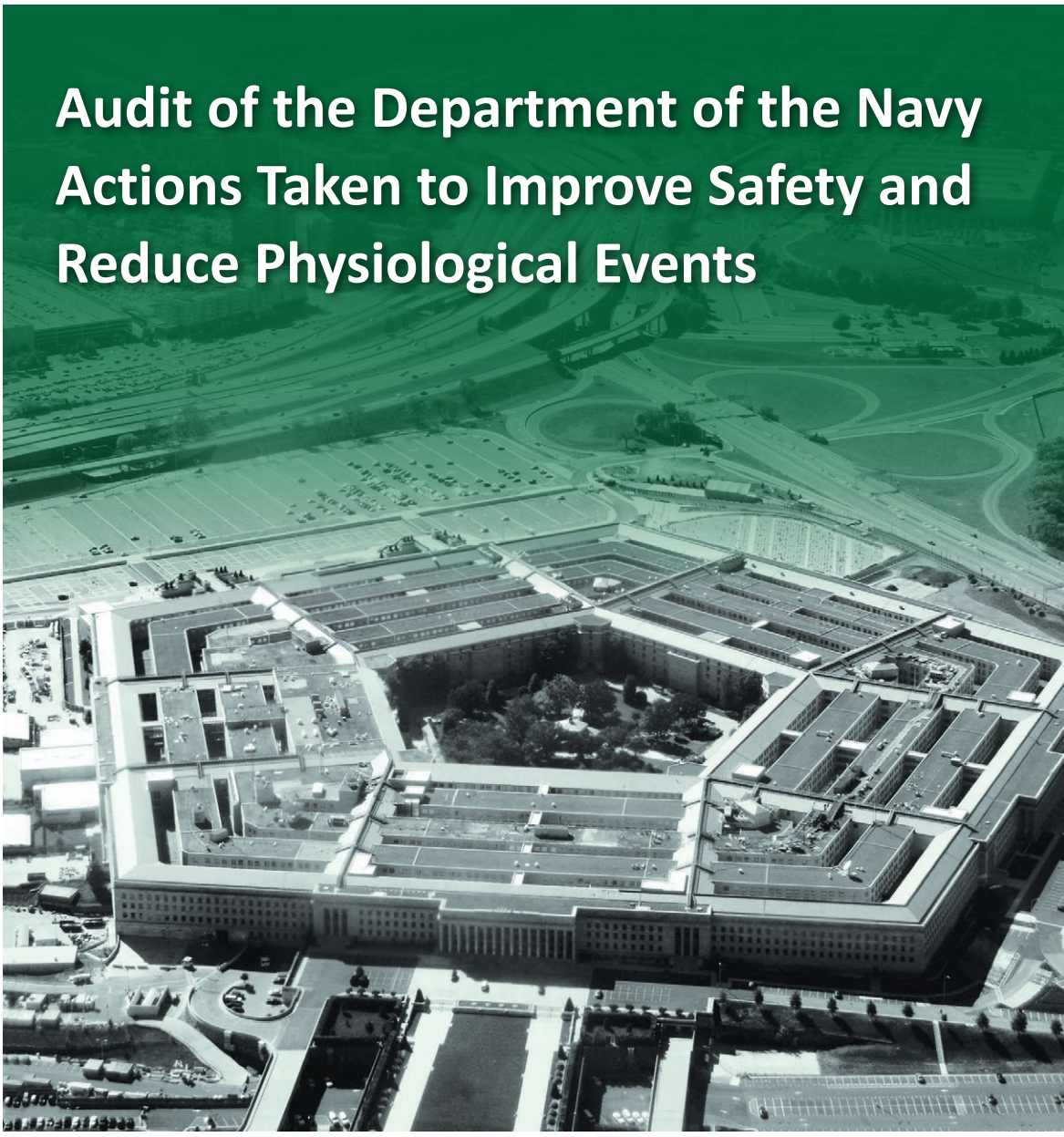
U.S. Department of Defense

NOVEMBER 4, 2020

Audit of the Department of the Navy Actions Taken to Improve Safety and Reduce Physiological Events



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DEPARTMENT OF DEFENSE

Results in Brief

Audit of the Department of the Navy Actions Taken to Improve Safety and Reduce Physiological Events

November 4, 2020

Objective

The objective of this audit was to determine to what extent the Department of the Navy (DON) performed research, training, maintenance, upgrades, and testing on fixed-wing aircraft to improve safety and reduce physiological events (PEs).

Background

A PE occurs when an aircrew member experiences physiological symptoms, and the symptoms are directly attributable to a known or suspected aircraft or aircrew systems malfunction. The DON experienced an increase from 13 PEs in FY 2010 to 165 PEs in FY 2017. As a result, Congress has expressed an increased interest in the DON's efforts to reduce PEs.

During this audit we reviewed the DON's actions taken to reduce PEs in the T-45 (Goshawk), F/A-18 A-D (Legacy Hornets), F/A-18 E/F (Super Hornets), and EA-18G (Growler). We chose these aircraft because they are the trainer and fighter aircraft that reported the highest average number of PEs per 100,000 flight hours from FYs 2010 to 2019.

Finding

The DON has taken actions to improve overall safety and reduce PEs for the eight aircraft we reviewed.

Finding (cont'd)

The DON performed research, training, maintenance, upgrades, and testing with the goal of improving safety and reducing PEs. Specifically, the DON:

- performed research on aircrew breathing equipment (such as masks), on air quality, and on in-flight physiological monitors;
- trained aircrew members on PE causes, symptoms, prevention, and emergency procedures;
- performed maintenance and upgraded aircraft components to ensure system maintenance and functionality on Goshawks;
- established system component life limits, inspected and replaced system components, and planned to upgrade an aircraft component on Legacy Hornets, Super Hornets, and Growlers; and
- tested in-flight physiological monitors and conducted test flights with aircrew members wearing monitors that collected data on potential causes of PEs.

Through this research, training, maintenance, upgrading, and testing, the DON has taken actions to reduce, mitigate, and identify causes for PEs related to the Goshawks, Legacy Hornets, Super Hornets, and Growlers. The DON has implemented 189 recommendations from the Goshawk, Legacy Hornet, Super Hornet, and Growler Root Cause Corrective Action teams and has ongoing plans to implement an additional 250 recommendations. By implementing the recommendations and other DON initiatives, the DON has achieved consistent year-to-year reductions from FYs 2017 through 2020 in the PE rate per 100,000 flight hours for two of the aircraft in our review.[1] For five aircraft the DON achieved a reduction in the PE rate in FY 2020 when compared to FY 2017. For the remaining aircraft, the DON had no PEs from FYs 2017 through 2020.

[1] The FY 2020 data are from October 1, 2019, through August 31, 2020.

Results in Brief

Audit of the Department of the Navy Actions Taken to Improve Safety and Reduce Physiological Events

Finding (cont'd)

In addition, the DON's completed and ongoing research, testing, and development of solutions to gather data in real time on both the physiology of the aircrew members and the environmental conditions within the aircraft will improve the DON's ability to identify PEs and determine potential root causes.

Finally, the DON will never completely eliminate PEs because they can be caused by malfunctioning aircraft components and human factors such as dehydration. However, the actions taken thus far have eliminated potential causes of PEs related to aircraft systems, air contamination, and flight gear fit. Furthermore, ongoing and planned actions are comprehensive and address potential areas for the DON to identify the root causes of PEs and improve safety for the aircrew members.

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

November 4, 2020

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION AND SUSTAINMENT
AUDITOR GENERAL, DEPARTMENT OF THE NAVY

SUBJECT: Audit of the Department of the Navy Actions Taken to Improve Safety and Reduce Physiological Events (Report No. DODIG-2021-004)

This final report provides the results of the DoD Office of Inspector General's audit. We considered management comments on a discussion draft of this report when preparing this final report. We did not make any recommendations; therefore, no management comments are required.

If you have any questions or would like to meet to discuss the audit, please contact me at [redacted] We appreciate the cooperation and assistance received during the audit.

Richard B. Vasquez
Assistant Inspector General for Audit
Readiness and Global Operations

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Introduction

Objective

The objective of this audit was to determine to what extent the Department of the Navy (DON) performed research, training, maintenance, upgrades, and testing on fixed-wing aircraft to improve safety and reduce physiological events (PEs).[2] See Appendix A for a discussion of the scope and methodology.

Background

The DON defines a PE as a type of physiological episode that occurs when an aircrew member experiences physiological symptoms, and the symptoms are directly attributable to a known or suspected aircraft or aircrew systems malfunction.[3] Examples of physiological symptoms include cognitive impairment, difficulty breathing, headaches, dizziness, chest tightness, joint pain, or other medical symptoms that manifest during or after flight.

Congressional Interest in Physiological Events

Since 2010 the DON has experienced an increased number of PEs. Specifically, from FYs 2010 through 2017 the number of PEs increased from 13 to 165. As a result, Congress expressed an increased interest in DON efforts to reduce PEs. Public Law 114-328, "National Defense Authorization Act for Fiscal Year 2017," required the Secretary of the Navy to conduct an independent review of the Navy's plans, programs, and research related to the PEs affecting aircrew members of the F/A-18 A-D (Legacy Hornets) and F/A-18 E/F (Super Hornets). According to Public Law 114-328, the review needed to include the efforts of both the Navy and the Marine Corps to prevent and mitigate the effects of PEs.[4]

Public Law 115-91, "National Defense Authorization Act for Fiscal Year 2018," required the Secretary of the Navy to provide information to the congressional defense committees every 90 days until January 1, 2020, on efforts by the Navy Physiological Episodes Action Team (PEAT) to combat the occurrence of PEs in T-45C (Goshawks), Legacy Hornets, Super Hornets, and EA-18G (Growlers).[5]

[2] The Department of the Navy refers to both the Navy and the Marine Corps.

[3] Naval Safety Center, "PE Investigation and Reporting Guide," March 29, 2019. A physiological episode occurs when the aircrew member is physically impaired, experiencing decreased performance due to a variety of adverse physiological symptoms.

[4] Section 237(a) of the National Defense Authorization Act for FY 2017.

[5] Section 1063(a) of the National Defense Authorization Act for FY 2018.

Public Law 115-232, "John S. McCain National Defense Authorization Act for Fiscal Year 2019," required the Secretary of the Navy to modify the Legacy Hornets, Super Hornets, and Growlers to reduce the occurrence of and mitigate the risk posed by PEs affecting aircrew members. Public Law 115-232 also required the Secretary of the Navy to submit a written update on the status of all modifications to Legacy Hornets, Super Hornets, and Growlers to the congressional defense committees no later than February 1, 2019, and annually thereafter through February 1, 2021.[6]

Nonstatistical Sample of DON Aircraft

We selected a nonstatistical sample of DON aircraft and reviewed the DON's actions taken to improve safety and reduce PEs in these aircraft. We selected Goshawks, Legacy Hornets, Super Hornets, and Growlers to review. We chose these aircraft based on the aircrafts' average rate of PEs per 100,000 flight hours between FYs 2010 and 2019. These are also the aircraft identified in the legislation discussed in the previous section of this report.

The Naval Safety Center provided a universe of all PEs reported between FYs 2010 and 2019 and the total annual flight hours for each of the 19 aircraft that had experienced PEs. The Naval Safety Center used these data to calculate for each fiscal year an annual rate of PEs per 100,000 flight hours for each of the 19 aircraft included in the universe of PEs, and then provided these rates to the audit team.[7] We used the annual rates provided by the Naval Safety Center to calculate an average rate of PEs per 100,000 flight hours for each type of aircraft between FYs 2010 and 2019. We identified the type of fighter or attack aircraft and trainer aircraft with the highest average rates of PEs per 100,000 flight hours from FYs 2010 through 2019. See Table 1 for the average rate of PEs per 100,000 flight hours that we calculated.

[6] Section 127 (a) and (b) of the John S. McCain National Defense Authorization Act for FY 2019.

[7] The Naval Safety Center calculated the rate of PEs per 100,000 flight hours by dividing the number of PEs reported by the annual flight hours multiplied by 100,000 for each aircraft.

Table 1. Average Rate of Physiological Events per 100,000 Flight Hours for DON Aircraft in Our Sample for FYs 2010 Through 2019

Aircraft	Total Number of PEs	Total Number of Flight Hours	Average Rate of PEs per 100,000 Flight Hours
F/A-18C, Legacy Hornet	189	564,241	45.70
EA-18G, Growler	113	286,962	30.19
F/A-18D, Legacy Hornet	48	195,871	26.41
F/A-18E, Super Hornet	193	706,703	25.82
F/A-18F, Super Hornet	150	662,882	23.16
F/A-18A, Legacy Hornet	14	125,611	14.25
T-45C, Goshawk	127	637,747	21.08
F/A-18B, Legacy Hornet	1	19,201	4.10

Note: To calculate the average rate of PEs per 100,000 flight hours from FYs 2010 through 2019, we averaged the PE rate per 100,000 flight hours for those 10 years. Therefore, the total number of PEs divided by the total number of flight hours will not produce the average rate of PEs per 100,000 flight hours shown in this table.

Source: The DoD OIG.

As shown in Table 1, the F/A-18C had the highest average rate of PEs per 100,000 flight hours between FYs 2010 and 2019 of the fighter (or attack) aircraft at 45.70. Also shown in Table 1, the T-45C had the highest rate of PEs per 100,000 flight hours between FYs 2010 and 2019 of the trainer aircraft at 21.08. The F/A-18C is one of seven models of the Hornet series aircraft. The Hornet series aircraft include Legacy Hornets (F/A-18 Models A-D), Super Hornets (F/A-18 Models E and F), and Growlers (EA-18G). We included all of the Hornet series aircraft in our audit scope because DON efforts to improve safety and reduce PEs, such as the F/A-18 PE Root Cause Corrective Action (RCCA), included all of the Hornet series. Therefore, the audit scope included the Goshawk, Legacy Hornet, Super Hornet, and Growler. See Appendix A for a complete description of the audit universe and our sample selection, including the data used in our calculations.

Background on Aircraft Selected for Review

We selected Goshawks, Legacy Hornets, Super Hornets, and Growlers to review. The DON trainer aircraft with the highest average rate of PEs was the Goshawk and the fighter aircraft with the highest average rate of PEs was the Legacy Hornet.

The Goshawk is a two-seat, carrier-capable, jet trainer whose mission is to provide intermediate and advanced training to Navy and Marine Corps pilots. Figure 1 shows the Goshawk.

Figure 1. T-45C Goshawk
Source: Defense Visual Information Distribution Service.

The Legacy Hornet is an all-weather fighter and attack aircraft that is used for fighter escort, fleet air defense, force protection, and close and deep air support. The Legacy Hornet has single-seat (F/A-18 A and C) and two-seat (F/A-18 B and D) models. Figure 2 shows a Legacy Hornet C model.

Figure 2. F/A-18 Legacy Hornet C Model
Source: Defense Visual Information Distribution Service.

The Super Hornet is a fighter and attack aircraft that provides escort and fleet air defense as well as offensive capabilities. The aircraft can target enemy fighter aircraft and attack ground and surface targets. The Super Hornet has increased maneuverability, range, and payloads compared to the Legacy Hornet. The Super Hornet has single-seat (F/A-18 E) and two-seat (F/A-18 F) models. Figure 3 shows a Super Hornet E model and F model.

Figure 3. F/A-18 Super Hornet E Model (bottom) and F Model (top)
Source: Defense Visual Information Distribution Service.

The Growler is a variant of the Super Hornet with a sophisticated electronic warfare suite. The two-seat, electronic attack aircraft integrates electronic attack technology, including jamming pods, communication countermeasures, radar, and satellite communications. Figure 4 shows a Growler.

Figure 4. EA-18G Growler
Source: Defense Visual Information Distribution Service.

Organizations That Support Physiological Event Reduction Efforts

In April 2017, the Vice Chief of Naval Operations ordered the Commander of the U.S. Pacific Fleet to lead a comprehensive review of PEs involving aircrew members of the Goshawk, Legacy Hornet, Super Hornet, and Growler.[8] The U.S. Pacific Fleet team reviewed organizational factors, PE data, aircrew member and aircraft systems, physiological factors, maintenance procedures, medical training, and PE lessons from other Government agencies and allied nations. In September 2017, to address the requirements of Public Law 114-328, the Navy commissioned the National Aeronautics and Space Administration Engineering and Safety Center to conduct an independent review of ongoing PE efforts for Legacy Hornets, Super Hornets, and Growlers. The National Aeronautics and Space Administration Engineering and Safety Center team reviewed the Navy's PE resolution efforts, factors that may reduce the PE rate, and the performance of subsystems in Legacy Hornets, Super Hornets, and Growlers. See Appendix B for a detailed summary of the Commander of the U.S. Pacific Fleet review and Appendix C for a detailed summary of the National Aeronautics and Space Administration Engineering and Safety Center review. Several DON organizations are involved in identifying, studying, and reducing PEs in Goshawks, Legacy Hornets, Super Hornets, and Growlers. Table 2 summarizes these organizations.

Table 2. DON Organizations Involved in Reducing Physiological Events

Organization	Role
Navy Physiological Episodes Action Team	**Single point of contact for coordination between all organizations that support PE reduction efforts.**
Naval Air Systems Command	**Provides life-cycle support of naval aviation aircraft, weapons, and systems operated by the Navy and Marine Corps.**
PEO for Tactical Aircraft Programs	Oversees multiple DON aircraft and weapon systems.
Naval Undergraduate Flight Training Program Office (PMA-273)	Acquires, develops, and sustains the Goshawk.
F/A-18 and EA-18G Program Office (PMA-265)	Acquires, delivers, and sustains the Legacy Hornet, Super Hornet, and Growler.
PEO for Aviation Common Systems and Commercial Services	Delivers DON aviation common systems, services, and support to the warfighter.
Aircrew Systems Program Office (PMA-202)	Oversees all systems that directly support the aircrew member in the performance of missions.

[8] Memorandum for Commander, U.S. Pacific Fleet Commander, "Comprehensive Review of the T-45 and F-18 Physiological Episodes," April 21, 2017.

Table 2. DON Organizations Involved in Reducing Physiological Events (cont'd)

Organization	Role
Naval Test Wing Atlantic	Tests and evaluates the Navy aviation systems.
Air Test and Evaluation Squadron Two Three (VX-23)	Oversees aircraft maintenance, test planning and conduct, and safety of the squadron's Goshawks, Legacy Hornets, Super Hornets, and Growlers.
Naval Medical Research Unit-Dayton	**Conducts aerospace medical and environmental health research within the DON.**
Naval Aerospace Medical Research Laboratory	Conducts research to mitigate and prevent factors associated with aviation mishaps, and to protect and enhance the health, readiness, and performance of aircrew members.
Environmental Health Effects Laboratory	Studies the potential health effects associated with exposure to environmental stressors in all occupational environments.
Naval Safety Center	**Supports and oversees the naval safety program.**
Root Cause Corrective Action Teams	**Conducts analysis and make recommendations to identify and address potential causes of PEs within specific aircraft.**
PE Rapid Response Teams	**Investigates, documents, and reports PEs to the Naval Safety Center.**

Legend
PEO Program Executive Office
PMA Program Manager Air

Source: The DoD OIG.

Navy Physiological Episodes Action Team

Based on recommendations from both the U.S. Pacific Fleet and the National Aeronautics and Space Administration reviews, the DON formed the Navy PEAT to take the lead in unifying multiple DoD agencies, industry partners, and foreign nations to facilitate collaboration and reduce redundant efforts. The Navy PEAT is a single point for coordination between all organizations that support PE reduction efforts, including the DoD, non-DoD entities, and foreign partners. Within the DON, the Navy PEAT is responsible for coordinating PE-related efforts between the Office of the Chief of Naval Operations; the Commander, Naval Air Forces; Naval Air Systems Command (NAVAIR); the Bureau of Medicine and Surgery; and the Naval Safety Center.[9] External to the DON, the Navy PEAT provides a single leader to discuss DON PE efforts with Congress and other Military Departments and DoD organizations.

[9] The Bureau of Medicine and Surgery is the headquarters of the Navy Medicine enterprise. The Navy Medicine enterprise includes the Naval Medical Research Center. Naval Medical Research Unit-Dayton is a subordinate command to the Naval Medical Research Center.

Naval Air Systems Command

NAVAIR provides life-cycle support of naval aviation aircraft, weapons, and systems operated by the Navy and Marine Corps. Life-cycle support includes designing, developing, acquiring, testing, and supporting the system throughout the life of the system. The Naval Aviation Program Executive Officers and their assigned program managers are responsible for meeting the cost, schedule, and performance requirements of their assigned weapon systems.

As a component of NAVAIR, the Program Executive Office for Tactical Aircraft Programs oversees multiple aircraft and weapon systems, including the Goshawk, Legacy Hornet, Super Hornet, and Growler. Two program offices under the Office for Tactical Aircraft Programs oversee the aircraft in our review:

- The Naval Undergraduate Flight Training Systems Program Office (Program Manager Air [PMA]-273) (Training [PMA-273]) acquires, develops, and sustains the Goshawk.
- The F/A-18 and EA-18G Program Office (PMA-265) (Hornets and Growlers [PMA-265]) acquires, delivers, and sustains the Legacy Hornet, Super Hornet, and Growler.

As a component of NAVAIR, the Program Executive Office for Aviation Common Systems and Commercial Services delivers aviation common systems, services, and support to the warfighter. As part of the Program Executive Office for Aviation Common Systems and Commercial Services, the Aircrew Systems Program Office (PMA-202) (Aircrew Systems [PMA-202]) is responsible for all systems that directly support the aircrew member in the performance of missions. Aircrew Systems (PMA-202) manages systems, such as aircrew members' masks, hoses, liquid oxygen converters, and concentrators. Aircrew Systems (PMA-202) personnel analyze, develop, and execute innovative solutions to optimize human performance, protection, and sustainment in aviation.

Within NAVAIR, Naval Test Wing Atlantic has four test and evaluation squadrons, including Air Test and Evaluation Squadron Two Three (VX-23) (Test and Evaluation Squadron [VX-23]). Test and Evaluation Squadron (VX-23) is NAVAIR's largest flight test organization, based at Naval Air Station (NAS), Patuxent River, Maryland. Test and Evaluation Squadron (VX-23) supports the aircraft maintenance, test planning and conduct, safety oversight, and support of the squadron's Goshawks, Legacy Hornets, Super Hornets, and Growlers.

Naval Medical Research Unit–Dayton

The mission of Naval Medical Research Unit-Dayton (NAMRU-D), located at Wright-Patterson Air Force Base, Ohio, is to maximize warfighter performance and survivability through aerospace medical and environmental health research. NAMRU-D is a major DoD medical research command and the home of the Naval Aerospace Medical Research Laboratory and the Environmental Health Effects Laboratory. The Naval Aerospace Medical Research Laboratory conducts research to mitigate and prevent factors associated with aviation mishaps. The medical laboratory also conducts research to protect and enhance the health, readiness, and performance of aircrew members. The Environmental Health Effects Laboratory studies the potential health effects associated with exposure to various environmental stressors in all occupational environments.

Naval Safety Center

The mission of the Naval Safety Center, located in Norfolk, Virginia, is to provide safety advice and assistance to the Secretary of the Navy and to manage the DON's safety and occupational health program on behalf of the Chief of Naval Operations. The Naval Safety Center provides support and oversight to the naval safety program through safety and risk management policy and guidance, safety data services, safety communications, and safety education and training. The Naval Safety Center provides safety information to all levels of the Navy, Marine Corps, and other Federal agencies, contractors, and foreign governments.

In October 2017, a message from the Commander, Naval Air Forces; the Naval Safety Center; and the Navy PEAT directed the Naval Safety Center to manage the PE investigation, validation, and verification process.[10] Additionally in October 2017, the Naval Safety Center assumed the oversight responsibility across the Navy Aviation Enterprise for PE investigation policy, PE safety management system reporting, and PE investigative evidence data consolidation and archiving.

Root Cause Corrective Action Teams

The Navy's RCCA process determines the reason for a failure in a complex engineered system. This process is a "top-down" model wherein a series of hypotheses for potential causes are proposed and then evaluated using empirical data and other relevant information until only the most probable root cause remains. The DON has two RCCA teams, one for Goshawks, and another for Legacy Hornets, Super Hornets, and Growlers. As of December 2019, both RCCA teams had completed their analysis and made recommendations to identify and

[10] Commander, Naval Safety Center Message, "Revised Aviation Physiological Episode (PHYSEP) and Physiological Event (PE) reporting for all USN [U.S. Navy] and USMC [U.S. Marine Corps] Aircraft," October 17, 2017.

address potential causes of PEs within specific aircraft. The Navy PEAT maintains the consolidated list of the RCCA teams' 466 recommendations and is in charge of tracking the closure of the recommendations.

Physiological Event Rapid Response Teams

In the October 2017 message, the Commander, Naval Air Forces; the Naval Safety Center; and the Navy PEAT mandated that each NAS and Marine Corps Air Station with aircraft equipped with liquid oxygen or Onboard Oxygen Generation System (OBOGS) establish a PE Rapid Response Team. The Navy Wing or Marine Corps Aircraft Group aeromedical safety officer will lead the PE Rapid Response Team and will have the authority to operate in support of an Aviation Mishap Board. The PE Rapid Response Teams are responsible for investigating, documenting, and reporting PEs to the Naval Safety Center. Each PE Rapid Response Team must include the Navy Wing or Marine Corps Aircraft Group aeromedical safety officer, affected squadron aviation safety officer, affected squadron flight surgeon or duty flight surgeon, and a technical representative.

Physiological Event Reporting Process

The March 2019 Naval Safety Center PE Investigations and Reporting Operating Guide (PE Guide) details the multi-step process that the PE Rapid Response Team is required to complete when a suspected PE occurs.[11] The PE Guide provides the following reporting timelines after a suspected PE occurs.

- **Initial Notification** – 24 hours or 4 hours for special circumstances (aircrew member treated in hyperbaric chamber, when there is an impaired landing, or when a foreign national aircrew member is involved)
- **PE Part A** (narrative from aircrew member that experienced the PE) – 48 hours
- **PE Part B** (narrative from maintenance personnel) – 7 calendar days
- **PE Part C** (narrative from flight surgeon or aerospace medicine physician assistant) – 7 calendar days
- **PE Part D** (narrative from aeromedical safety officer and parachute rigger or flight equipment technician) – 7 calendar days[12]
- **Hazard Report or Safety Investigation Report** (as required) – 30 calendar days
- **PE Rapid Response Team Final Summary Report** – 30 calendar days

[11] Naval Safety Center Code 10 Aviation Safety Programs, "PE Investigations and Reporting Operating Guide," March 29, 2019.

[12] Parachute Riggers, also known as Aircrew Survival Equipmentmen, are responsible for keeping parachutes, life rafts, personal flight gear, and other aviation survival gear in proper working order.

Once the PE Rapid Response Team completes the final summary report, the team provides the report to the Naval Safety Center. The Naval Safety Center distributes the endorsed results of the PE Rapid Response Team's report to the fleet using the Web Enabled Safety System.[13] In addition, the Naval Safety Center meets with fleet officials weekly, monthly, and annually to share PE data and educational opportunities with the DON officials involved in mitigating PEs.

Review of Internal Controls

DoD Instruction 5010.40 requires DoD organizations to implement a comprehensive system of internal controls that provides reasonable assurance that programs are operating as intended and to evaluate the effectiveness of the controls.[14] We did not identify internal control weakness related to the DON's actions taken to reduce PEs in the aircraft we reviewed.

[13] The Naval Safety Center's Web Enabled Safety System Risk Management Framework contains all reported PE hazard and mishap events, and its purpose is to document, archive, and provide information for current and future safety analyses.

[14] DoD Instruction 5010.40, "Managers' Internal Control Program Procedures," May 30, 2013.

Finding

The DON Has Taken Actions to Improve Safety and Reduce Physiological Events

The DON has taken actions to improve safety and reduce PEs for the eight aircraft we reviewed—the Goshawk, Legacy Hornets (F/A-18 Models A-D), Super Hornets (F/A-18 Models E and F), and Growler. Specifically, the DON performed research, training, maintenance, upgrades, and testing with the goal of improving safety and reducing PEs, including implementing 189 recommendations from the RCCA teams, and continues to implement an additional 250 recommendations. Through research, training, maintenance, upgrades, and testing, the DON has taken actions to reduce, mitigate, and identify causes for PEs related to Goshawks, Legacy Hornets, Super Hornets, and Growlers.

Although the DON has not achieved a complete or consistent reduction in PEs for all eight aircraft we reviewed, the DON has achieved consistent year-to-year reductions from FYs 2017 through 2020 in the PE rate per 100,000 flight hours for two of the aircraft in our review.[15] For five aircraft the DON achieved a reduction in the PE rate in FY 2020 when compared to FY 2017. For the remaining aircraft, the DON had no PEs from FYs 2017 through 2020.

In addition, the DON's completed and ongoing research, testing, and development of solutions to gather data in real time on both the physiology of the aircrew members and the environmental conditions within the aircraft will improve the DON's ability to identify PEs and determine potential root causes.

Finally, the DON will never completely eliminate PEs because they can be caused by malfunctioning aircraft components and by human factors such as dehydration. However, the actions taken thus far have eliminated some potential causes of PEs related to aircraft systems, air contamination, and flight gear fit. Furthermore, ongoing and planned actions are comprehensive and address potential areas for the DON to identify the root causes of PEs and improve safety for the aircrew members.

The DON Improved Safety and Reduced Physiological Events

The DON has taken actions to improve safety and reduce PEs for the eight aircraft we reviewed—the Goshawk, Legacy Hornets (F/A-18 Models A-D), Super Hornets (F/A-18 Models E and F), and Growler. Specifically, the DON has performed research, training, maintenance, upgrades, and testing to

[15] The FY 2020 data are from October 1, 2019, through August 31, 2020.

improve safety and reduce PEs for the eight aircraft. The Goshawk RCCA team developed 195 recommendations, and the Legacy Hornet, Super Hornet, and Growler RCCA team developed 369 recommendations to address PEs for a total of 564 recommendations. The RCCA teams recommended that the DON take actions to research aircraft components and physiological monitors for aircrew members; maintain, upgrade, and test aircraft components; as well as train aircrew members on gear fit and potential PE symptoms to reduce PEs.

The Navy PEAT reviewed the recommendations and consolidated the lists to remove duplicates. The Navy PEAT maintains the list of the 466 consolidated recommendations for the RCCA teams and is in charge of tracking the closure of the recommendations and briefing the progress to DON senior leaders monthly. Specifically, the Navy PEAT is tracking all 466 RCCA recommendations, which were assigned to 10 DON organizations to address. We discuss examples of recommendations from the RCCA teams related to research, training, maintenance, upgrades, and testing, and the actions taken or planned to address those recommendations in this report. Table 3 summarizes the status of all 466 RCCA recommendations as of August 21, 2020.

Table 3. Status of RCCA Recommendations for Goshawks, Legacy Hornets, Super Hornets, and Growlers as of August 21, 2020

Responsible Office	Total Number of Recommendations	Number of Implemented Recommendations	Number of Recommendations With Ongoing Responses	Number of Recommendations With Planned Responses
PMA-265	244	94	134	16
PMA-273	10	5	5	0
PMA-202	85	41	40	4
PMA-205	8	4	4	0
BUMED	53	27	23	3
CNAF	48	5	39	4
NSC	5	5	0	0
PEAT	9	6	3	0
CNATRA	2	2	0	0
NAWCAD	2	0	2	0
Total	**466**	**189**	**250**	**27**

Legend

BUMED	Bureau of Medicine and Surgery	NAWCAD	Naval Air Warfare Center Aircraft Division
CNAF	Commander, Naval Air Forces	NSC	Naval Safety Center
CNATRA	Chief of Naval Air Training	PMA-205	Naval Aviation Training Systems and Ranges Program Office

Note: Of the 27 planned recommendations, 10 recommendations have no implementation dates.
Source: The Navy.

As Table 3 demonstrates, as of August 21, 2020, the DON had implemented 189 of the 466 recommendations. By implementing these 189 recommendations, the DON has identified, eliminated, or mitigated potential root causes of PEs in Goshawks, Legacy Hornets, Super Hornets, and Growlers. Specifically, the implemented recommendations included inspections and testing related to aircraft components such as aircrew member oxygen systems and the environmental control system (ECS). The implemented recommendations also included training parachute riggers on properly fitted flight gear and training aircrew members to recognize potential PE symptoms.

Table 3 also shows that the DON had 250 recommendations with ongoing responses. Those 250 responses have estimated completion dates from fourth quarter FY 2020 to first quarter FY 2024 and included research related to the effects of cabin pressure fluctuations on aircrew members and maintenance and upgrades to OBOGS and ECS components. For the additional 27 planned recommendations, the Navy has implementation dates for 17 recommendations ranging from first quarter FY 2021 to first quarter FY 2024. These 17 recommendations related to testing aircraft components such as the ECS and conducting additional research on aircrew member equipment. As of August 21, 2020, the remaining 10 planned recommendations did not have implementation dates. We reviewed the DON's implementation of actions related to RCCA recommendations in the areas of research, training, maintenance, upgrades, and testing. We developed the research, training, maintenance, upgrades, and testing categories ourselves, so the 466 recommendations do not tie to these categories individually and could cross multiple categories.

In addition, we identified and analyzed other efforts taken by the DON (efforts the DON took in addition to the RCCA teams' recommendations) to determine potential causes of PEs. In the next section we discuss examples of the work that the DON performed or had ongoing at the time of our audit in the areas of research of aircrew member equipment, aircrew member physiological monitors, and aircraft components; aircrew member training; maintenance and upgrades of aircraft components; and testing of aircraft components and aircrew member physiological monitors.

Aircrew Member Equipment, In-flight Physiological Monitors, and Aircraft Component Research

The DON has conducted research to identify causes of PEs, improve safety, and reduce PEs. The Legacy Hornet, Super Hornet, and Growler RCCA team made recommendations for the DON to conduct research on aircrew member equipment

and on in-flight physiological monitors that gather data on aircrew members to determine potential causes of PEs. In addition, NAMRU-D conducted research on aircraft components to determine whether contamination was a potential cause of PEs.

Aircrew Member Equipment Research

In response to the Legacy Hornet, Super Hornet, and Growler RCCA team recommendations to conduct research on aircrew member equipment, the DON performed research on breathing units in Legacy Hornets, Super Hornets, and Growlers and performed research on air quality during flight in Goshawks, Legacy Hornets, Super Hornets, and Growlers. The purpose of the research was to identify and eliminate potential causes for PEs related to breathing units and air contaminants. Specifically, the Legacy Hornet, Super Hornet, and Growler RCCA team recommended that Aircrew Systems (PMA-202) study two mask breathing units, which are prone to failures causing alterations in breathing for the aircrew members. The Human Systems department within Aircrew Systems (PMA-202) was replicating tests from the original equipment manufacturer and expected to close the recommendation in first quarter FY 2022.

In-Flight Physiological Monitor Research

The RCCA team for Legacy Hornets, Super Hornets, and Growlers recommended that the DON continue researching in-flight physiological monitors. According to an Aircrew Systems (PMA-202) official, Aircrew Systems (PMA-202) was collaborating with the U.S. Air Force School of Aerospace Medicine, the National Aeronautics and Space Administration, NAVAIR, NAMRU-D, and the Royal Australian Air Force to evaluate commercial off-the-shelf body-mounted systems for measuring and monitoring the pilot's in-flight supply of air in Legacy Hornets and Super Hornets. The goal of the research is to identify body-mounted monitors that can provide the DON with real-time information and record the aircrew members' air supply while in flight, which can then help the DON identify the root causes for PEs related to air supply. We also discuss physiological monitors in the section of this report titled Physiological Monitor Testing.

Aircraft Component Research and Ongoing Research

NAMRU-D conducted research on aircraft components to determine whether air contamination was a potential cause of PEs. NAMRU-D collaborated with NAVAIR to research contamination of the air from the ECS and OBOGS during ground and flight operations as a potential root cause of PEs in the Goshawk, Legacy Hornet,

Super Hornet, and Growler. NAMRU-D tested the chemicals present in Goshawk, Legacy Hornet, Super Hornet, and Growler air samples in a lab and determined that no contaminants were present in the samples at concentrations sufficient to induce PE symptoms.

According to a NAMRU-D official, 35 to 40 percent of the lab's research relates to PEs. One example of a NAMRU-D research effort that was ongoing as of first quarter FY 2019 was a study to assess the effects of low-level nitrogen oxide exposure on pilot cognition and performance. NAMRU-D stated that low levels of nitrogen oxide were detected in the breathing supply of the Goshawk and Growler. Another example of ongoing NAMRU-D research as of first quarter FY 2019 was related to reducing PEs in Legacy Hornets, Super Hornets, and Growlers and was an examination of the physiological and cognitive effects of cabin pressure fluctuations on aircrew members. A third example of NAMRU-D ongoing research as of third quarter FY 2019 was related to Legacy Hornets, Super Hornets, and Growlers and was a comprehensive evaluation of the mechanical, ventilatory, physiological, and cognitive impacts of the life support system on aircrew members.

DON Research to Identify PE Causes and Reduce PEs Was Ongoing

The DON performed research with the goal of improving safety, reducing PEs, and determining whether each research topic contributed to PEs. Specifically, the DON has taken actions to close the RCCA teams' recommendations by performing research on masks and air quality to determine whether they contributed to PEs. Through the NAMRU-D research, the DON has eliminated contaminated air as a cause of PEs and was still assessing the effects of low-level nitrogen oxide exposure on aircrew members, how cabin pressure fluctuations effect aircrew members, and researching in-flight physiological monitors to monitor the aircrew members' air supply to determine potential causes of PEs. Because the DON has ongoing research to identify PE causes, we did not make any recommendations related to research into PEs.

Training Designed to Mitigate Physiological Events

The DON conducted training to improve safety and reduce PEs, which aligned with the recommendations from the April 2017 U.S. Pacific Fleet comprehensive review and the RCCA teams. The recommendations related to training included increasing or improving training on potential PE causes, symptoms, prevention, and emergency procedures. We determined which PE-related training the DON provided to aircrew members, maintenance personnel, and parachute riggers in alignment with the findings and recommendations from the April 2017

U.S. Pacific Fleet comprehensive review and RCCAs. Examples of PE-related training provided to Goshawk, Legacy Hornet, Super Hornet, and Growler aircrew members, maintenance personnel, and parachute riggers are discussed in the next section, including PE roadshows, gear fit, hypoxia recognition, and other training.

PE Roadshows

The April 2017 U.S. Pacific Fleet comprehensive review identified that the DON lacked a comprehensive, integrated communication approach related to PEs. The April 2017 U.S. Pacific Fleet comprehensive review concluded that the lack of communication resulted in a lack of understanding of the technical solutions being worked to resolve PEs and reduced aircrew member confidence in PE mitigation efforts. As a result, the DON established the Navy PEAT and the PEAT's requirement to develop a comprehensive PE communication plan.

According to the Navy PEAT lead's appointment letter, the Navy PEAT was required, since August 2017, to develop a method of communicating PE information with the fleet. To communicate PE information to the fleet, the Navy PEAT, NAVAIR, and the Naval Safety Center began traveling to squadrons for "PE Roadshows" to share information regarding PEs with the fleet. As of March 2020, the Navy PEAT continued to conduct PE Roadshows.

PE Roadshows include executive engagement sessions, individual squadron briefs and interactions, progress updates, training on properly managing cabin pressure data, and training to ensure that flight gear is worn correctly. Of the 20 squadrons we interviewed, personnel from 12 squadrons stated that people in their squadron attended PE Roadshows. According to aircrew members, PE Roadshows were successful in educating aircrew members on PEs and the Roadshows allowed for open communication. A safety officer stated that the PE Roadshow provided a better understanding of the symptoms and causes of PEs. A maintenance official stated that he gained awareness of the PE issue and learned about reducing the risk of aircrew members flying with improper flight gear from the PE Roadshow.

However, aircrew members also told us that they felt PE Roadshows were used to blame aircrew members for PEs. The Goshawk RCCA team recommended that NAVAIR and the Commanding Officer approve the content of PE Roadshows prior to presenting the information to aircrew members to ensure the message was well thought out. The Navy PEAT has implemented this recommendation. The Navy PEAT had scheduled PE Roadshows to occur after March 2020, but canceled them because of the coronavirus pandemic. Navy PEAT officials stated that they were developing a virtual Roadshow so the training could continue.

Aircrew Member Flight Gear Training

The RCCA teams identified improperly fitted flight gear as a possible cause of PEs. As a result, both RCCA teams recommended that Aircrew Systems (PMA-202) provide training to aeromedical safety officers and parachute riggers that covers how improperly fitted gear affects aircrew members' breathing. In July 2018, the Commander, Naval Air Forces, mandated that an Aircrew Systems (PMA-202) Fleet Air Introduction Liaison of Survival Aircrew Flight Equipment team visit each tactical air command and conduct hands-on training for sailors and marines to increase awareness and reduce the risk of aircrew members flying with improperly fitted gear.[16] The training is required to cover proper fitting and use of the torso harness, G-suit, helmet, oxygen mask, flight vest, and life preserver unit.[17] Of the 20 squadrons we interviewed, personnel in 12 squadrons stated that they attended Fleet Air Introduction Liaison of Survival Aircrew Flight Equipment training with Aircrew Systems (PMA-202). According to parachute riggers, the training was beneficial and useful in ensuring aircrew member gear fit properly.

Dynamic Hypoxia Training

Commander, Naval Air Forces Instruction 3710.2 requires aircrew members to complete dynamic hypoxia training with a reduced oxygen breathing device biannually.[18] Hypoxia occurs when an individual has insufficient oxygen supply to the body significant enough to cause an impairment of function. The reduced oxygen breathing device uses reduced oxygen mixtures to provide training in hypoxia recognition and emergency procedures.

According to a Commander Electronic Attack Wing Pacific official, dynamic hypoxia training conducted in operational simulators is an example of a successful effort to reduce PEs. During interviews with the audit team, aircrew members stated that they were able to identify hypoxia-like symptoms during recent PEs because of the reduced oxygen breathing device training. However, aircrew members also stated that the training was not as realistic as they would experience during an actual flight. Additionally, aircrew members stated that the training was limited to hypoxia-like symptoms, and did not prepare aircrew members for other PE symptoms. Both RCCA teams recommended that improvements be made to dynamic hypoxia training with a reduced oxygen breathing device. Specifically, the RCCA teams recommended that the DON make the training conditions more

[16] Commander, Naval Air Forces Message, "FAILSAFE [Fleet Air Introduction Liaison of Survival Aircrew Flight Equipment] Training on the Refit Process of ALSS [Aviation Life Support Systems] for TACAIR [Tactical Air] Platforms," July 26, 2018.

[17] A G-suit is a flight suit worn by aircrew members subject to high levels of acceleration force due to aircraft maneuvering. It is designed to prevent a loss of consciousness caused by the blood pooling in the lower part of the body when under acceleration, thus depriving the brain of blood, which in turns leads to temporary hypoxia.

[18] Commander, Naval Air Forces Instruction 3710.2, "Dynamic Hypoxia Training," October 26, 2015.

realistic. As a result, in FY 2020, the DON began acquiring a new hypoxia training device to replace the reduced oxygen breathing device. Additionally, the RCCA teams recommended expanding the training to help aircrew members recognize and correct other issues beyond hypoxia. The RCCA teams also recommended that the DON stop referring to the training as hypoxia awareness training because aircrew members may experience physiological symptoms during the training other than hypoxia. Lastly, the RCCA teams recommended that the DON require aircrew members to observe their peers complete the training to teach aircrew members how to spot physiological effects in others. The DON is in the process of implementing these recommendations.

Implementation of Additional PE-Related Training

As of August 2020, the DON was in the process of implementing additional PE-related training as a result of RCCA recommendations. For example, the Legacy Hornet, Super Hornet, and Growler RCCA team recommended that the Commander, Naval Air Forces ensure that aircrew members and other personnel be briefed on changes made to the Naval Air Training and Operating Procedures. According to aircrew members we interviewed, they had received briefs on Naval Air Training and Operating Procedures Standardization updates related to PEs.

Another example of PE-related training that resulted from an RCCA recommendation is breathing technique training. The Goshawk RCCA team recommended that breathing techniques be included in annually required training for aircrew members. To implement the Goshawk RCCA team recommendation, a Navy PEAT member stated that the Navy PEAT created a Dynamic Breathing brief that the DON planned to incorporate into the annual and pre-deployment training required for all aircrew members starting in October 2020. Training Wing One, a Goshawk Wing that the audit team visited, had already implemented this recommendation and included breathing dynamics in its annual training.

DON Training to Identify PE Causes and Reduce PEs Was Ongoing

The DON has developed a method for communicating PE information with the fleet, offered flight gear fit training for aircrew members and parachute riggers, and updated annual training requirements. Specifically, the DON has taken actions to address the RCCA teams' recommendations by requiring Aircrew Systems (PMA-202) to visit each tactical air command to conduct flight gear fit training and by training aircrew members on Naval Air Training and Operating Procedures Standardization updates. Additionally, the DON is in the process of addressing the RCCA teams' recommendations by acquiring a new hypoxia training

device and by updating the annual and pre-deployment training requirements for aircrew members. Because the DON has ongoing training efforts to improve safety and reduce PEs, we did not make any recommendations about training.

Maintenance and Upgrades of Aircraft Components

The DON has performed maintenance and upgrades of aircraft components to improve safety and reduce PEs. The RCCA teams determined that there was not a single root cause for PEs, and made recommendations for the DON to perform maintenance and upgrades to the OBOGS and ECS in Goshawks, Legacy Hornets, Super Hornets, and Growlers. In addition, the DON performed other maintenance and upgrades to the OBOGS and ECS by issuing airframe bulletins, and airframe changes, which we refer to collectively as technical changes.

Inspection, Maintenance, and Upgrades to OBOGS and ECS

The following are examples of four technical changes recommended by the RCCA teams and three additional DON initiatives to inspect, maintain, and upgrade OBOGS and ECS and their components in Goshawks, Legacy Hornets, Super Hornets, and Growlers. The Goshawk RCCA team recommended Training (PMA-273) to continue efforts to improve air quality for aircrew members with two technical changes that required one-time inspections of the OBOGS and ECS in Goshawks. One of the technical changes was to perform a maintenance check of the OBOGS and ECS, and the other technical change was a maintenance check on a specific OBOGS component for conditions that may lead to PEs.[19] The DON completed these two technical changes in all Goshawks that were not down for long-term maintenance or being removed from inventory. According to a Training (PMA-273) official, as of May 28, 2020, the DON performed the one-time inspection of the OBOGS and ECS on 192 of 194 Goshawks, and as of June 11, 2020, the DON performed the OBOGS component inspection on 191 of 194 Goshawks. A Training (PMA-273) official stated that the DON would perform the one-time inspection of the OBOGS and ECS on the two remaining Goshawks and the OBOGS component inspection on the three remaining Goshawks in long-term maintenance before those aircraft rejoined the fleet.

In addition to implementing the technical changes related to OBOGS and ECS components, to stabilize the cabin pressure environment in Legacy Hornets, the Legacy Hornet, Super Hornet, and Growler RCCA team recommended Hornets and Growlers (PMA-265) implement a technical change to disable an ECS subsystem. The technical change required maintenance personnel to disable the Cabin Exit

[19] Airframe Bulletin 262, "Onboard Oxygen Generating System (OBOGS) and Environmental Control System (ECS) Hygiene/Integrity Inspection," April 25, 2017. Airframe Bulletin 264, "Onboard Oxygen Generating System (OBOGS) Heat Exchange Inspection," June 22, 2017.

Air Pressure Regulator System to prevent deficiency in aircraft cabin pressure.[20] According to the Legacy Hornet, Super Hornet, and Growler RCCA team, the ECS subsystem and its components led to pressure-related and oxygen-related PEs. A Hornets and Growlers (PMA-265) official stated that as of September 16, 2020, the DON disabled the required ECS subsystem in 279 of 343 Legacy Hornets. The DON stated that the remaining 64 aircraft were either down for long-term maintenance or were scheduled to be removed from the inventory.

Furthermore, to mitigate the risk of pressure-related and oxygen-related PEs in Super Hornets and Growlers, the Legacy Hornet, Super Hornet, and Growler RCCA team recommended Hornets and Growlers (PMA-265) implement a technical change to reroute an element of an ECS subsystem. The technical change required maintenance personnel to modify an element within the ECS Bleed Air subsystem.[21] According to the Legacy Hornet, Super Hornet, and Growler RCCA team, the Bleed Air Subsystem and its components led to pressure-related and oxygen-related PEs. As of June 1, 2020, the DON modified the required Bleed Air element in 476 of 507 Super Hornets, and as of July 1, 2020, the DON modified 129 of 135 Growlers. The DON planned to complete the remaining 31 Super Hornets and 6 Growlers by December 31, 2025.

Another example of a technical change the DON implemented is a technical change to perform a maintenance check of the OBOGS in Goshawks to ensure that the aircraft engine idled at a specific revolutions per minute, which resulted in sufficient airflow into the OBOGS.[22] According to a training (PMA-273) official, as of May 28, 2020, the DON completed this technical change to perform a one-time inspection of the engine idle speed in 190 of 194 Goshawks that were not down for long-term maintenance or being removed from inventory. A Training (PMA-273) official stated that one Goshawk was being removed from inventory, and the DON was planning to perform the inspection on the remaining three Goshawks in long-term maintenance before those aircraft rejoined the fleet.

Finally, two technical changes required DON officials to inspect ECS components on Legacy Hornets, Super Hornets, and Growlers to establish life limits and overhaul (perform maintenance and rebuild) intervals for certain components.[23] The technical changes also required DON officials to replace any failed ECS components found during the inspection. The DON had established life limits

[20] Interim Airframe Change 676, "Disabling of Cabin Exit Air Pressure Regulator System, Revision A," April 4, 2017.

[21] Airframe Change 665, "Secondary Bleed Air Regulator Bay Bleed Air Leak Detection Element Rerouting," May 3, 2017.

[22] Airframe Bulletin 265, "Engine Idle Speed Inspection," April 11, 2018.

[23] Airframe Bulletin 814, "Inspection of Environmental Control System (ECS) Components Serial Numbers and Establishment of Scheduled Removal Component (SRC) Cards," February 17, 2017, for Legacy Hornets. Airframe Bulletin 815, "Inspection of Environmental Control System (ECS) Components Serial Numbers and Establishment of Scheduled Removal Component (SRC) Cards," February 2, 2017, for Super Hornets and Growlers.

and overhaul intervals for certain ECS components on the Legacy Hornets, Super Hornets, and Growlers. As of September 24, 2020, the DON implemented those life limits and overhaul intervals on 270 of 351 Legacy Hornets. Of the 81 remaining Legacy Hornets, 63 were at the depot for maintenance, and the DON plans to complete the remaining 18 before the next maintenance phase. As of June 1, 2020, the DON implemented the life limits and overhaul intervals on 485 of 536 Super Hornets. As of July 1, 2020, the DON implemented the life limits and overhaul intervals on 139 of 153 Growlers. The DON plans to complete the remaining 51 Super Hornets and 14 Growlers by June 30, 2021.

Future Upgrade to Real-Time Cabin Pressure Monitoring

In addition to the technical changes, the DON plans to upgrade a Goshawk OBOGS component and install a Cabin Pressure and OBOGS Monitoring System on Legacy Hornets, Super Hornets, and Growlers. Aircrew Systems (PMA-202) plans to perform system validation and verification testing of the new Goshawk OBOGS component in second quarter FY 2021, which will enable control over OBOGS oxygen levels. The DON plans to upgrade the current analog cabin pressure gauge in Legacy Hornets, Super Hornets, and Growlers to a Cabin Pressure and OBOGS Monitoring System. The new Cabin Pressure and OBOGS Monitoring System will record and display aircraft cabin pressure and record OBOGS information. The data from the new system will be available for download after a flight. According to a Hornets and Growlers (PMA-265) official, once the DON completes the validation process to approve the new system, the aircraft maintenance personnel will install the new system in the Hornets and Growlers. As of August 2020, Hornets and Growlers (PMA-265) was planning to award a contract to install the Cabin Pressure and OBOGS monitoring System by December 31, 2020, and start installation in second quarter FY 2021. Figure 5 shows a Cabin Pressure and OBOGS Monitoring System display.

Figure 5. Cabin Pressure and OBOGS Monitoring System Display
Source: The Navy.

Because the analog cabin pressure gauge in Legacy Hornets, Super Hornets, and Growlers did not record data on the changes in cabin pressure throughout a flight, in October 2017 the DON began having pilots carry a portable device to record cabin pressure data.[24] The portable device was called a slam stick and was about the size of a universal serial bus (USB) drive (see Figure 6). At the conclusion of the flight, the pilot downloaded the data from the slam stick, which the DON used to determine the health and performance of the aircraft. According to a Hornets

[24] Commander, Naval Safety Center Message, "Revised Aviation Physiological Episode (PHYSEP) and Physiological Event (PE) Reporting for all USN [U.S. Navy] and USMC [U.S. Marine Corps] Aircraft," October 17, 2017.

and Growlers (PMA-265) official, it will take several years for the DON to install the new Cabin Pressure and OBOGS Monitoring System on all Legacy Hornets, Super Hornets, and Growlers because the aircraft cabin has to be modified for the installation. Therefore, the DON will continue to require aircrew members to carry slam sticks during flight.

Figure 6. Slam Sticks
Source: The Marine Corps.

The DON Performed Maintenance and Upgraded Aircraft Components

The DON performed maintenance and upgraded aircraft with the goal of improving safety, reducing PEs, and identifying the causes of PEs. Specifically, the DON has taken actions to close RCCA teams' recommendations and implement technical changes designed to reduce PEs by:

- performing one-time inspections of the OBOGS and ECS and their components in Goshawks;
- disabling a system to stabilize the cabin pressure environment in Legacy Hornets;
- modifying an ECS subsystem to reduce the risk of pressure-related and oxygen-related PEs in Super Hornets and Growlers;
- establishing and implementing life limits and overhaul intervals for ECS components in Legacy Hornets, Super Hornets, and Growlers;

- planning to upgrade an OBOGS component to control oxygen levels in Goshawks;
- using slam sticks to collect data on cabin pressure in Legacy Hornets, Super Hornets, and Growlers; and
- upgrading the cabin pressure system to have real-time information about cabin pressure in Legacy Hornets, Super Hornets, and Growlers.

Because the DON has completed and also has ongoing maintenance and upgrades to identify PE causes and reduce PEs, we did not make any recommendations related to maintenance and upgrades of systems and components of the Goshawks, Legacy Hornets, Super Hornets, and Growlers.

Aircrew Member Monitors and Aircraft Component Testing

The DON conducted several tests on potential aircrew member physiological monitors that gather data on aircrew members' physiology and conducted tests on aircraft components to determine potential causes and contributing factors of PEs in Goshawks, Legacy Hornets, Super Hornets, and Growlers. The RCCA recommendations for testing included conducting tests on aircrew members' monitors that will gather data on physiology of aircrew members. The DON conducted additional testing including tests of OBOGS and cabin pressure and air flow.

Physiological Monitor Testing

To assist with gathering data on aircrew members' physiology during flights, Aircrew Systems (PMA-202) conducted tests on aircrew member physiological monitors. As of January 2020, Aircrew Systems (PMA-202) was testing several aircrew member physiological monitors in response to the Goshawk, Legacy Hornet, Super Hornet, and Growler RCCA teams' recommendations to conduct studies on human factors that could cause PEs. Specifically, Aircrew Systems (PMA-202) was testing monitors that gather information about cabin air pressure. The monitors also gather information about each aircrew members' physiology, such as breathing rate, oxygen saturation rate, heart rate, or core temperature. The Aircrew Systems (PMA-202) personnel conducted the tests to determine whether the monitors function in a dynamic flight environment, could be integrated into aircrew members' equipment, or could be worn by the aircrew members during flight. The DON is developing and testing aircrew member physiological monitors with an estimated completion date of fourth quarter FY 2022 because the DON lacks data on aircrew member physiology and these data could help the DON identify solutions to reduce PEs.

Aircraft Component Testing

The DON performed tests of OBOGS and air flow both within and exterior to the aircraft to improve safety and identify potential root causes for PEs. As of December 2019, Aircrew Systems (PMA-202) has completed 3 of 5 years of OBOGS testing (known as PUNISHER testing) on the nitrogen-removing material (concentrator sieve bed material) for the Goshawk, Legacy Hornet, Super Hornet, and Growler.[25] Aircrew Systems (PMA-202) performed this OBOGS testing to ensure that the material (sieve material) in the OBOGS concentrators for Goshawks, Legacy Hornets, Super Hornets, and Growlers removed carbon monoxide from the air in accordance with standards. By performing OBOGS testing on Goshawks, Legacy Hornets, Super Hornets, and Growlers, the DON took action to determine whether PEs were caused by contaminants in the air from the OBOGS, and the RCCA teams used the results from the tests to eliminate contamination as a cause of PEs.

In addition, the Legacy Hornet, Super Hornet, and Growler fleet support team at NAS North Island, California, conducted testing on Legacy Hornets and Super Hornets to determine potential causes of PEs. Specifically, the fleet support team completed nine reports that explained the results of its testing for pressure-related issues that could cause PEs in Legacy Hornets and Super Hornets. For example, the August 2018 test report stated that the fleet support team testing involved observing and analyzing the air flow dynamic in Legacy and Super Hornets. The testing revealed that disabling a valve in the air flow path improved the cabin pressurization system for Legacy Hornet C configurations, and the report stated that converting all cabin exit air systems in the Legacy Hornet C configuration would improve the cabin pressure regulation capability.[26]

As a result of the fleet support team tests, the DON is working on a technical change to remove the cabin exit air system from Legacy Hornets and replace it with the Super Hornet configuration to potentially reduce PEs.[27] The Navy configuration control board stakeholders, such as engineering, logistics, and the integrated project team, are reviewing the technical change to reconfigure the cabin exit air system in the Legacy Hornet with the goal of formal approval by

[25] The sieve bed is part of the OBOGS and holds a material that uses adsorption (process when a solid holds molecules of gas as a thin film) to remove nitrogen from air for breathing.

[26] F/A-18 and EA-18G Fleet Support Team – North Island, "Cabin Exit Air System Deconfiguration Modification Test Report," August 8, 2018.

[27] Engineering Change Proposal 1233, "Cabin Exit Air System Removal."

the end of October 2020. Figure 7 shows the air flow path of the Legacy Hornet A model and Super Hornet E model (on the left) and the Legacy Hornet C model (on the right). The air flow path on the left shows what the Legacy Hornet C model will look like after the Navy implements the technical change, and the air flow path on the right is the Legacy Hornet C model air flow configuration before any changes.

In addition, Training (PMA-273), Hornets and Growlers (PMA-265), Aircrew Systems (PMA-202), and the Navy PEAT tasked Test and Evaluation Squadron (VX-23) to conduct tests on Goshawks, Legacy Hornets, Super Hornets, and Growlers to help determine potential causes of PEs. From April 2017 through December 2019, Test and Evaluation Squadron (VX-23) conducted 143 flights and 66 ground tests for Goshawks. In addition, from August 2016 through December 2019, Test and Evaluation Squadron (VX-23) conducted 97 flights and 70 ground tests for Legacy Hornets, Super Hornets, and Growlers. Specifically, Test and Evaluation Squadron (VX-23) collected data to evaluate OBOGS pressure from engine to aircrew member using a VigilOX instrumented mask, hydrocarbon detector, and sorbent tube adapter.[28] The RCCA teams used the physiological monitoring data that Test and Evaluation Squadron (VX-23) collected to rule out potential causes of PEs. See Figure 8 for the aircrew member physiological monitoring testing equipment that Test and Evaluation Squadron (VX-23) used to perform tests on Goshawk, Legacy Hornet, Super Hornet, and Growler aircrew members.

[28] The VigilOX is an instrumented mask that records several air parameters, such as air flow, air pressure, and temperature of the air flow and cabin. The sorbent tube adapter is a man-mounted air sensor that is on the aircrew members' vest, and the hydrocarbon detector is a self-contained volatile organic compound detector for air.

Figure 8. VigilOX Testing Equipment with Hydrocarbon Detector and Sorbent Tube Adapter

Source: The Navy.

The DON Performed Testing of Physiological Monitors and Aircraft Systems

The DON performed tests on aircraft components, conducted tests on the function of aircrew member monitors during flight, and used aircrew member monitors to gather data during test flights to determine potential causes and contributing factors of PEs and eliminate causes of PEs. Specifically, the DON implemented RCCA team recommendations to test aircrew member physiological monitors

and conducted test flights with aircrew members wearing monitors that collected data on potential causes of PEs. As a result, the RCCA teams eliminated potential causes of PEs, such as contamination of breathing air. Furthermore, the DON initiated a technical change to improve aircraft components by removing the cabin exit air system in the Legacy Hornet C model and replacing it with the configuration of the Super Hornet E model and Legacy Hornet A model. In addition, the DON was testing physiological monitors to gather data on human factors that could contribute to PEs. Therefore, we did not make any recommendations about testing.

The DON Has Implemented and Plans to Implement Recommendations to Determine the Potential Causes of Physiological Events

The DON implemented 189 of the 466 recommendations from the RCCA teams, had ongoing efforts to implement 250 of the 466 recommendations, and planned to implement an additional 27 of the 466 recommendations in the areas of aircrew member training; research and testing of aircrew member physiology, aircrew member equipment, aircraft components, and aircraft environment; and maintenance and upgrades of aircraft components. Since approximately 94 percent of the 466 recommendations from the RCCA teams have been implemented or are in the process of being implemented and address the areas we reviewed, we did not make additional recommendations in this report.

The DON's actions resulted in reduced PEs per 100,000 flight hours from FYs 2017 to 2020 for seven of the eight aircraft we reviewed, but the reductions were not consistent each year across all the aircraft.[29] The remaining aircraft did not have PEs in FYs 2017 through 2020. See Table 4 for the rate of PEs per 100,000 flight hours from FYs 2017 through 2020 for Goshawks, Legacy Hornets, Super Hornets, and Growlers.

[29] The FY 2020 data are from October 1, 2019, through August 31, 2020.

Table 4. Rate of PEs per 100,000 Flight Hours for FYs 2017 Through 2020 for Each Aircraft Reviewed

Fiscal Year	Goshawk C Model	Legacy Hornet A Model	Legacy Hornet C Model	Legacy Hornet D Model	Super Hornet E Model	Super Hornet F Model	Growler
2017	63.05	46.02	133.83	43.37	33.34	25.81	66.08
2018	8.55	0.00	79.64	48.37	38.36	34.72	36.89
2019	4.04	30.72	28.62	24.23	33.03	29.61	35.67
2020*	5.84	33.70	4.47	18.17	12.61	14.50	18.53
Difference in rate from FYs 2017 to 2020	**(57.21)**	**(12.32)**	**(129.36)**	**(25.20)**	**(20.73)**	**(11.31)**	**(47.55)**

Note: We excluded Legacy Hornet- B Model because there were no PEs. See Table 1 for total number of PEs and total number of flight hours for FYs 2010 through 2019.

* The data for FY 2020 are from October 1, 2019, through August 31, 2020.

Source: The Navy.

As Table 4 shows, the PEs per 100,000 flight hours did not consistently decrease for all eight aircraft. Of the eight aircraft we reviewed:

- two aircraft—the Legacy Hornet C Model and Growler—experienced declines in the rate of PEs per 100,000 flight hours each fiscal year;
- five aircraft—the Goshawk, Legacy Hornet A Model, Legacy Hornet D Model, Super Hornet E Model, and Super Hornet F Model—had fewer PEs per 100,000 flight hours in FY 2020 compared to FY 2017, but did not experience a consistent decline in the PE rate each year; and
- one aircraft, the Legacy Hornet B Model, had no PEs.

Although the DON has not achieved a complete or consistent reduction in PEs across all eight aircraft platforms, the DON plans to continue researching, training, maintaining, upgrading, and testing to identify root causes for PEs and improve safety. The DON also plans to continue to develop solutions to gather real-time data on aircrew members' physiology and the environmental conditions within the aircraft during flight. For example, the DON plans to integrate the life support systems (including the OBOGS and the Cabin Pressure and OBOGS Monitoring System) in Legacy Hornets, Super Hornets, and Growlers so the data from the Cabin Pressure and OBOGS Monitoring System will automatically save to the memory unit instead of maintenance personnel having to download the data after every flight. As of October 30, 2020, a Hornets and Growlers (PMA-265)

official stated that the office received and is evaluating Boeing's proposal for the life support systems integration effort. With an increase in data collection through real-time monitoring, the DON will improve its ability to identify PEs and determine potential root causes. In addition, having this real-time data may enable aircrew members to recognize factors that could lead to a PE and take action to prevent the PE from occurring.

Finally, the DON will never completely eliminate PEs because they can be caused by malfunctioning aircraft components and by human factors such as dehydration. However, the actions taken thus far have eliminated some potential causes of PEs related to aircraft systems, air contamination, and flight gear fit. Furthermore, ongoing and planned actions are comprehensive and address potential areas for the DON to identify the root causes of PEs and improve safety for the aircrew members.

Appendix A

Scope and Methodology

We conducted this performance audit from September 2019 through November 2020 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Audit Universe and Sample Selection

We nonstatistically selected the sample for this audit. We obtained an annual rate of PEs per 100,000 flight hours for the 19 aircraft type that had reported PEs from FYs 2010 through 2019. The Naval Safety Center calculated this rate by dividing the number of PEs that Navy and Marine Corps aircrew members reported by the flight hours for each aircraft type and multiplying by 100,000. The purpose of calculating the rate per 100,000 flight hours was to standardize the data and allow a comparison to be made between different aircraft types with varying total flight hours. We used these data to calculate an average rate of PEs per 100,000 flight hours for each of the 19 aircraft from FYs 2010 through 2019.

We selected the fighter (or attack) aircraft and trainer aircraft with the highest average rate of PEs per 100,000 flight hours. For fighter (or attack) aircraft, the highest rate of PEs per 100,000 flight hours was for the F/A-18C. For the trainer aircraft, the highest rate of PEs per 100,000 flight hours was for the T-45C. The F/A-18C is one of seven models of the 18-series aircraft. The 18-series aircraft include Legacy Hornets (F/A-18 Models A-D), Super Hornets (F/A-18 Models E and F), and Growlers (EA-18G). We decided to include all of the 18-series aircraft in our audit scope. Therefore, the audit scope included the Goshawk, Legacy Hornet, Super Hornet, and Growler.

The data that were used to complete these calculations can be found in the following tables. See Table 5 for the number of PEs that Navy and Marine Corps aircrew members reported. See Table 6 for the total annual flight hours for each type of aircraft that had reported PEs. See Table 7 for the annual rate of PEs per 100,000 flight hours for the 19 aircraft types that had reported PEs. See Table 8 for the average rates of PEs per 100,000 flight hours for DON fighter (or attack) aircraft from FYs 2010 through 2019 and Table 9 for the average rates of PEs per 100,000 flight hours for DON trainer aircraft for FYs 2010 through 2019.

Table 5. Number of Physiological Events Reported by Aircrew Members in DON Aircraft for FYs 2010 Through 2019

Aircraft	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total per Aircraft
F/A-18E, Super Hornet	4	4	10	13	24	20	34	28	29	27	193
F/A-18C, Legacy Hornet	5	10	18	13	16	19	32	45	24	7	189
F/A-18F, Super Hornet	2	8	21	18	14	16	17	16	21	17	150
T-45C, Goshawk	0	0	2	15	12	23	35	31	6	3	127
EA-18G, Growler	0	1	1	1	4	13	36	27	15	15	113
F/A-18D, Legacy Hornet	2	4	2	4	9	5	4	8	7	3	48
F/A-18A, Legacy Hornet	0	1	1	2	1	2	1	4	0	2	14
AV-8B, Harrier	0	0	0	0	0	0	0	3	3	5	11
T-6B, Texan	0	0	1	0	0	0	0	1	5	4	11
T-6A, Texan	0	0	0	0	0	1	1	0	2	0	4
F-35B, Lightning[1]	–	–	0	0	0	0	0	1	1	1	3
F-5N, Adversary Aircraft	0	0	1	0	0	0	0	0	0	1	2
F-16, Fighting Falcon	0	0	0	0	0	0	0	0	2	0	2
EA-6B, Prowler	0	0	0	0	0	0	0	0	2	0	2
F-5F, Adversary Aircraft	0	0	0	0	0	0	0	1	0	0	1
E-2D, Hawkeye	0	0	0	0	0	0	0	0	0	1	1
F/A-18B, Legacy Hornet	0	0	0	0	1	0	0	0	0	0	1
F-35C, Lightning[2]	–	–	–	–	0	0	0	0	0	1	1
T-34C, Turbomentor	0	0	1	0	0	0	0	0	0	0	1

Note: The aircraft are listed in descending order of total PEs.

[1] The DON did not fly the F-35B in FYs 2010 through 2011.

[2] The DON did not fly the F-35C in FYs 2010 through 2013.

Source: The Navy.

Table 6. Total Annual Flight Hours for DON Aircraft for FYs 2010 Through 2019

Aircraft	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total per Aircraft
T-6B, Texan	6,401	22,229	44,905	58,665	76,236	99,396	104,425	98,849	98,914	102,692	712,712
F/A-18E, Super Hornet	53,574	61,292	60,898	61,520	68,964	75,593	83,550	83,978	75,595	81,739	706,703
F/A-18F, Super Hornet	71,821	75,452	81,661	68,408	60,254	65,535	59,871	61,991	60,485	57,404	662,882
T-45C, Goshawk	62,686	63,121	64,882	64,855	58,794	59,552	70,165	49,166	70,211	74,315	637,747
F/A-18C, Legacy Hornet	93,418	91,105	80,716	67,619	59,662	48,316	35,189	33,625	30,134	24,457	564,241
T-34C, Turbomentor	87,946	86,752	54,268	31,912	27,189	9,310	2,654	2,455	3,680	3,524	309,690
EA-18G, Growler	8,309	17,709	18,373	19,939	26,110	34,863	38,087	40,860	40,656	42,056	286,962
AV-8B, Harrier	30,571	32,547	33,626	28,926	23,599	24,478	23,357	21,762	19,439	21,892	260,197
F/A-18D, Legacy Hornet	26,635	24,702	23,871	18,413	19,819	17,485	19,648	18,444	14,473	12,381	195,871
T-6A, Texan	18,111	16,050	17,105	16,119	17,127	16,972	14,919	15,033	13,463	14,628	159,527
F/A-18A, Legacy Hornet	18,611	18,347	17,518	12,648	11,918	10,685	8,574	8,691	12,109	6,510	125,611
EA-6B, Prowler	28,996	27,467	22,391	13,328	9,657	7,004	5,761	5,976	3,247	531	124,358
F-5N, Adversary Aircraft	11,772	11,105	10,513	10,707	10,664	10,635	11,007	9,957	9,637	8,513	104,510
E-2D, Hawkeye	658	1,378	2,390	2,289	4,013	6,625	5,465	8,839	9,973	11,612	53,242
F-35B, Lightning[1]	–	–	223	317	2,930	5,146	6,047	6,478	8,008	11,644	40,793
F-35C, Lightning[2]	–	–	–	–	693	1,986	2,907	3,901	5,042	6,673	21,202
F-16, Fighting Falcon	2,669	2,631	2,741	399	1,742	2,334	1,770	1,876	1,549	1,646	19,357
F/A-18B, Legacy Hornet	2,662	2,312	2,310	2,413	2,437	1,869	1,581	1,626	1,277	714	19,201
F-5F, Adversary Aircraft	618	703	736	519	691	465	451	442	326	370	5,321

Note: The aircraft are listed in descending order of total flight hours.

[1] The DON did not fly the F-35B in FYs 2010 through 2011.

[2] The DON did not fly the F-35C in FYs 2010 through 2013.

Source: The Navy.

Table 7. Annual Rate of Physiological Events per 100,000 Flight Hours for DON Aircraft, FYs 2010 Through 2019

Aircraft	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
F-5F, Adversary Aircraft	0.00	0.00	0.00	0.00	0.00	0.00	0.00	226.24	0.00	0.00
F-5N, Adversary Aircraft	0.00	0.00	9.51	0.00	0.00	0.00	0.00	0.00	0.00	11.75
F-16, Fighting Falcon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	129.12	0.00
T-45C, Goshawk	0.00	0.00	3.08	23.13	20.41	38.62	49.88	63.05	8.55	4.04
EA-18G, Growler	0.00	5.65	5.44	5.02	15.32	37.29	94.52	66.08	36.89	35.67
AV-8B, Harrier	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.79	15.43	22.84
E-2D, Hawkeye	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.61
F/A-18A, Legacy Hornet	0.00	5.45	5.71	15.81	8.39	18.72	11.66	46.02	0.00	30.72
F/A-18B, Legacy Hornet	0.00	0.00	0.00	0.00	41.03	0.00	0.00	0.00	0.00	0.00
F/A-18C, Legacy Hornet	5.35	10.98	22.30	19.23	26.82	39.32	90.94	133.83	79.64	28.62
F/A-18D, Legacy Hornet	7.51	16.19	8.38	21.72	45.41	28.60	20.36	43.37	48.37	24.23
F-35B, Lightning[1]	–	–	0.00	0.00	0.00	0.00	0.00	15.44	12.49	8.59
F-35C, Lightning[2]	–	–	–	–	0.00	0.00	0.00	0.00	0.00	14.99
EA-6B, Prowler	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.60	0.00
F/A-18E, Super Hornet	7.47	6.53	16.42	21.13	34.80	26.46	40.69	33.34	38.36	33.03
F/A-18F, Super Hornet	2.78	10.60	25.72	26.31	23.23	24.41	28.39	25.81	34.72	29.61
T-6A, Texan	0.00	0.00	0.00	0.00	0.00	5.89	6.70	0.00	14.86	0.00
T-6B, Texan	0.00	0.00	2.23	0.00	0.00	0.00	0.00	1.01	5.05	3.90
T-34C, Turbomentor	0.00	0.00	1.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: The aircraft are listed alphabetically.

[1] The DON did not fly the F-35B in FYs 2010 through 2011.

[2] The DON did not fly the F-35C in FYs 2010 through 2013.

Source: The Navy.

Table 8. Average Rate of Physiological Events per 100,000 Flight Hours for DON Fighter or Attack Aircraft, FYs 2010 Through 2019

Aircraft	Average Rate of PEs per 100,000 Flight Hours
F/A-18C, Legacy Hornet	45.70
EA-18G, Growler	30.19
F/A-18D, Legacy Hornet	26.41
F/A-18E, Super Hornet	25.82
F/A-18F, Super Hornet	23.16
F-5F, Adversary Aircraft	22.62
F/A-18A, Legacy Hornet	14.25
F-16, Fighting Falcon	12.91
EA-6B, Prowler	6.16
AV-8B, Harrier	5.21
F-35B, Lightning[1]	4.56
F/A-18B, Legacy Hornet	4.10
F-35C, Lightning[2]	2.14
F-5N, Adversary Aircraft	2.13
E-2D, Hawkeye	0.86

Note: The aircraft are listed in descending order of the average rate of PEs per 100,000 flight hours.

[1] The DON did not fly the F-35B in FYs 2010-2011. Therefore, this is the average rate from FYs 2012 through 2019.

[2] The DON did not fly the F-35C in FYs 2010-2013. Therefore, this is the average rate from FYs 2014 through 2019.

Source: The DoD OIG.

Table 9. Average Rate of Physiological Events per 100,000 Flight Hours for DON Trainer Aircraft, FYs 2010 Through 2019

Aircraft	Average Rate of PEs per 100,000 Flight Hours
T-45C, Goshawk	21.08
T-6A, Texan	2.75
T-6B, Texan	1.22
T-34C, Turbomentor	0.18

Note: The aircraft are listed in descending order of the average rate of PEs per 100,000 flight hours.

Source: The DoD OIG.

Site Visit Selection

We nonstatistically selected site visit locations by identifying the NASs that had reported the largest number of PEs in Goshawks, Legacy Hornets, and Growlers from FYs 2010 through 2019. For Super Hornets, we identified that NAS Lemoore had reported the largest number of PEs, and NAS Oceana had reported the second largest number of PEs. We determined it would be more efficient, based on the proximity to the DoD OIG headquarters and audit team's location, to visit NAS Oceana. As a result, we selected NAS Oceana. To ensure that the Marine Corps was included in the scope of the audit, we also identified the Marine Corps Air Stations that had reported the largest number of PEs in Legacy Hornets from FYs 2010 through 2019. Both Marine Corps Air Station Beaufort and Marine Corps Air Station Miramar had reported the same number of PEs. We visited Marine Corps Air Station Miramar because its proximity to NAS North Island and NAS Whidbey Island would allow for a more efficient visit. See Tables 10 through 13 for the Goshawk, Legacy Hornet, Super Hornet, and Growler total number of reported PEs in the continental United States for FYs 2010 through 2019.

Table 10. Goshawk Total Number of Physiological Events Reported in the Continental United States for FYs 2010 Through 2019

Aircraft	Location	Total Number of PEs Reported
T-45	NAS Meridian, Mississippi	105
T-45	NAS Kingsville, Texas	78
T-45	NAS Pensacola, Florida	20

Source: The Navy.

Table 11. Legacy Hornet Total Number of Physiological Events Reported in the Continental United States for FYs 2010 Through 2019

Aircraft	Location	Total Number of PEs Reported
F/A-18A	NAS Oceana, Virginia	6
F/A-18A	Marine Corps Air Station Beaufort, South Carolina	6
F/A-18A	Marine Corps Air Station Miramar, California	4
F/A-18B	NAS Patuxent River, Maryland	1
F/A-18C	NAS Oceana	291
F/A-18C	NAS Lemoore, California	37
F/A-18C	Marine Corps Air Station Beaufort	34
F/A-18C	Marine Corps Air Station Miramar	24
F/A-18C	NAS Patuxent River	10
F/A-18C	NAS Fallon, Nevada	8
F/A-18C	NAS North Island, California	6
F/A-18C	NAS Joint Reserve Base New Orleans, Louisiana	4
F/A-18C	Marine Corps Air Station Yuma, Arizona	4
F/A-18C	NAS Pensacola	1
F/A-18C	Naval Air Weapons Station China Lake, California	1
F/A-18D	Marine Corps Air Station Miramar	32
F/A-18D	Marine Corps Air Station Beaufort	20
F/A-18D	NAS Patuxent River	9
F/A-18D	NAS Oceana	4
F/A-18D	Naval Air Weapons Station China Lake	2

Source: The Navy.

Table 12. Super Hornet Total Number of Physiological Events Reported in the Continental United States for FYs 2010 Through 2019

Aircraft	Location	Total Number of PEs Reported
F/A-18E	NAS Lemoore	185
F/A-18E	NAS Oceana	104
F/A-18E	NAS Patuxent River	4
F/A-18E	Naval Air Weapons Station China Lake	3
F/A-18E	NAS Fallon	2
F/A-18F	NAS Oceana	120
F/A-18F	NAS Lemoore	71
F/A-18F	Naval Air Weapons Station China Lake	22
F/A-18F	NAS Patuxent River	1

Source: The Navy.

Table 13. Growler Total Number of Physiological Events Reported in the Continental United States for FYs 2010 Through 2019

Aircraft	Location	Total Number of PEs Reported
EA-18G	NAS Whidbey Island, Washington	247
EA-18G	Naval Air Weapons Station China Lake	1

Source: The Navy.

Site Visits and Interviews

We conducted site visits to the following locations to perform our audit.

- Navy PEAT in Arlington, Virginia
- NAVAIR at NAS Patuxent River, Maryland
- Naval Safety Center at NAS Norfolk, Virginia
- NAMRU-D at Wright-Patterson Air Force Base, Ohio
- Commander, Strike Fighter Wing Atlantic at NAS Oceana, Virginia
- 3rd Marine Aircraft Wing at Marine Corps Air Station Miramar, California
- Fleet Readiness Center Southwest at NAS North Island, California
- Commander Electronic Attack Wing Pacific, NAS Whidbey Island, Washington
- Training Air Wing One, NAS Meridian, Mississippi

We also visited 20 squadrons to determine the process for reporting PEs, the status of implementing technical changes, and the effectiveness of training provided for PEs. Table 14 shows the 20 squadrons we visited to perform this audit.

Table 14. Squadrons Visited During the Audit

Squadron	Location
VX-23	NAS Patuxent River
VX-20	NAS Patuxent River
Training Squadron-7	NAS Meridian
Training Squadron-9	NAS Meridian
Fighter Squadron Composite-12	NAS Oceana
Marine Fighter Attack Training Squadron-101	Marine Corps Air Station Miramar
Marine Fighter Attack Squadron-232	Marine Corps Air Station Miramar
Marine Aviation Logistics Squadron-11	Marine Corps Air Station Miramar
Strike Fighter Squadron (VFA)-34	NAS Oceana
VFA-37	NAS Oceana
VFA-103	NAS Oceana
VFA-106	NAS Oceana
VFA-143	NAS Oceana
VFA-213	NAS Oceana
Electronic Attack Squadron (VAQ)-140	NAS Whidbey Island
VAQ-129	NAS Whidbey Island
VAQ-133	NAS Whidbey Island
VAQ-136	NAS Whidbey Island
VAQ-135	NAS Whidbey Island
VAQ-131	NAS Whidbey Island

Source: The DoD OIG.

During our site visits, we interviewed personnel and obtained documentation to support the testimonial evidence. Specifically, we interviewed:

- officials from the Navy PEAT, NAMRU-D, the Naval Safety Center, Training (PMA-273), Hornets and Growlers (PMA-265), Aircrew Systems (PMA-202), test squadrons, PE integrated project teams, and Fleet Readiness Center Southwest on the actions they have taken to reduce PEs;

- leadership, aircrew members, maintenance personnel, and parachute riggers from Commander, Strike Fighter Wing Atlantic and Commander Electronic Attack Wing Pacific on DON efforts to reduce PEs in Legacy Hornets, Super Hornets, and Growlers;
- leadership, aircrew members, maintenance personnel, and flight equipment technicians from the 3rd Marine Aircraft Wing about the DON's efforts to reduce PEs in Legacy Hornets; and
- aircrew members and maintenance personnel from Training Air Wing One and officials from the Office of the Chief of Naval Air Training on DON efforts to reduce PEs in Goshawks.

To determine the extent to which the DON has completed research to reduce PEs and improve safety, we reviewed PE-related research reports completed by NAMRU-D, Commander of the U.S. Pacific Fleet, and National Aeronautics and Space Administration. Additionally, we reviewed briefing charts on NAMRU-D PE lines of effort. To determine the extent to which the DON has completed training to reduce PEs and improve safety, we reviewed training requirements and examples of training schedules, agendas, and briefing slides. To determine the extent to which the DON has completed maintenance and upgrades to reduce PEs and improve safety, we reviewed technical changes, engineering change proposals, maintenance logs, and Naval Aviation Logistics Command Management Information System reports. Additionally, we reviewed briefing slides on the Hornet Health Assessment and Readiness Tool. To determine the extent to which the DON has completed testing to reduce PEs and improve safety, we reviewed briefing charts on Test and Evaluation Squadron (VX-23's) PE related efforts and reports on testing completed by the Fleet Readiness Center Southwest and the PE RCCA Teams.

Use of Computer-Processed Data

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

Prior Coverage

No prior coverage has been conducted on the DON's efforts to improve safety and reduce PEs in the Goshawk, Legacy Hornet, Super Hornet, or Growler during the last 5 years.

Appendix B

Commander of the U.S. Pacific Fleet Review Findings

On April 21, 2017, the Vice Chief of Naval Operations directed the Commander of the U.S. Pacific Fleet to lead a comprehensive review of the facts, circumstances, and processes surrounding recent PEs, including how these issues have been addressed. The U.S. Pacific Fleet team assessed the following areas related to the Goshawk, Legacy Hornet, Super Hornet, and Growler.

- Organizational factors including command, control, and communications
- PE analysis and trends
- PE corrective actions and processes
- Aircrew member breathing air systems
- Cabin pressurization systems
- Cockpit environmental monitoring and alerting systems
- Physiological factors including aircrew monitoring
- Aircrew member procedures, training, and proficiency
- Maintenance infrastructure and procedures
- Medical training, emergency response and research
- PE lessons including those from other government agencies and countries

The U.S. Pacific Fleet team made the following conclusions about the Goshawk.

- The root cause of PEs is unidentified.
- There was no single event that caused the operational risk management-based flight cancellations on March 31, 2017.
- Flight cancellations were caused by declining confidence in OBOGS because of increased number and perceived severity of PEs, declining confidence in the Naval Aviation Enterprise ability and urgency to fix the issue, and perception by some instructor pilots that the Chief of Naval Air Training leadership placed higher priority on aircrew member production rather than on risk to aircrew members.
- The bleed air piping into the OBOGS was designed without a moisture separator or in-line mechanical filter, which potentially allows contaminates to enter the system.
- There was a lack of communication in the Goshawk community between the class desk, NAVAIR, and the operators.

The U.S. Pacific Fleet team made the following conclusions about the Legacy Hornet, Super Hornet, and Growler.

- The root cause of PEs is unidentified.
- Aircrew members expressed confidence in the safety of the aircraft and in the efforts being pursued to prevent future PEs.
- Contributing factors to ECS performance issues are age of the system, failure of maintenance procedures to keep up with complex ECS failures, and the effect of making incremental improvements to the ECS without a holistic evaluation of the system.
- The cockpit altimeter gauge does not adequately display cabin pressure, does not record during flight, does not alert aircrew members of pressurization deviations, and does not provide playback capability during post-flight debrief to determine exactly when and what variations occurred.

The U.S. Pacific Fleet team made the following Goshawk recommendations.

- Leverage commercial industry expertise to augment NAVAIR engineers on a full-time basis until a permanent solution is determined and implemented.
- The Commander, Naval Air Forces in conjunction with the Chief of Naval Personnel should conduct a comprehensive review of all aspects of aircrew member production.
- Review the requirements for and source a full-time position for the Goshawk Class Desk.
- Embed a rotating Goshawk instructor pilot at NAVAIR to function as a liaison officer.

The U.S. Pacific Fleet team made the following Legacy Hornet, Super Hornet, and Growler recommendations.

- Execute a depot-level deep dive inspection of the entire F/A-18 ECS and OBOGS, to include all sub-components and piping.
- Replace the cockpit altimeter with a digital display that is more precise and easier for the aircrew member to monitor during flight.

The U.S. Pacific Fleet team made the following common issue recommendations.

- Establish a single, dedicated organization to lead the Naval efforts to resolve PEs.
- Continue ongoing RCCA efforts until root cause fault trees are fully adjudicated.

- Re-design aircraft life support systems as required to meet OBOGS input specifications.
- Develop a comprehensive Naval Aviation Enterprise communications strategy.
- Consider PE mitigation technologies for instances where aircrew members are cognitively impaired.
- Standardize PE adjudication.
- Develop comprehensive PE-resolution instrumented data plans including multi-media in-flight audio and video recording.
- Establish an integrated life support system program at NAVAIR.
- Review adequacy of test and evaluation infrastructure.
- Conduct a comprehensive Naval Safety Center review of PEs.
- The Commander, Naval Air Forces should conduct a well-publicized industry day, openly soliciting PE resolution ideas and recommendations.
- NAVAIR should institute periodic exchanges with other organizations managing life support systems required for highly demanding environments, such as the National Aeronautics and Space Administration, Air Force, and Naval Sea Systems Command.
- Establish or retain formal connectivity with manufacturer expertise after aircraft production ends.
- Review life support system specifications and maintenance practices.
- Optimize aircrew member PE alerting and protection for each aircraft.
- Streamline post-flight reporting and database management.
- The Commander, Naval Air Forces should develop multi-media training products for significant PEs.
- The Commander, Naval Air Forces should develop a standardized operational risk management process pre-flight briefing sheet for each type, model, and series of aircraft.
- Standardize the risk assessment review process.
- Naval Aviation Enterprise leadership should reinforce an unconstrained resource approach.

Appendix C

National Aeronautics and Space Administration Report Findings

In the National Defense Authorization Act for 2017, Congress requested the Secretary of the Navy to conduct an independent review of PEs, and the Navy requested assistance from the National Aeronautics and Space Administration for the review. The National Aeronautics and Space Administration Engineering and Safety Center conducted the review of Legacy Hornets, Super Hornets, and Growlers and determined the following.

- PEs happen to people and not aircraft; however, the Navy is addressing the PE problem as an aircraft problem and not a human problem.
- Hypoxia is the condition of insufficient delivery of oxygen to the body and not a condition of insufficient levels of oxygen in the aircrew members' breathing gas; however, without a precise definition of hypoxia, it is easy to misinterpret the meaning of an OBOGS Degrade status light, which indicates that the level of breathing gas dropped below a specified level.
- Uniform operating conditions are the key to reliable, repeatable, and predictable OBOGS performance; however, the F/A-18 operating environment is dynamic and non-uniform, and evaluations of the breathing gas supply should be made with a consideration to the dynamic operating environment.
- Creating a stable environment is the key to maintaining human health performance; however the F/A-18 cabin environment is dynamic and non-uniform and changes in flight environment cause changes in the work load and corresponding breathing rates.
- The memory unit data was developed to assess the state of hardware systems and not to diagnose PEs; therefore, in assessing PEs, the key evidence relates to the health and performance of the aircrew member, but it is hard to measure health and performance in an F/A-18 environment.
- The F/A-18 systems that support human health are complex, dynamic, and interactive and should start with clearly defined human systems requirements and include extensive human systems integration testing.
- PEs will persist in the F/A-18 and all high performance aircraft if there is a piecemeal approach to human systems integration; therefore, human systems integration needs to be addressed at the requirement level and managed at every stage of development and operations.

In addition, the National Aeronautics and Space Administration Engineering and Safety Center found the following.

- The conditions for carbon monoxide poisoning did not exist.
- No evidence supports contamination or toxicological poisoning.
- No dedicated human system requirements document was followed or adhered to in the design or maintenance of the F/A-18.
- Early PE safety reports contained inconsistent findings and the methods for acquiring physiologic data were inconsistent and accompanied with substandard medical documentation.
- Organizational and cultural differences exist throughout the F/A-18 community that affect mask use by aircrew members that contradict the Naval Air Training and Operating Procedures Standardization requirements.
- Fly to fail policy for several ECS components changed to replacement at 400 flight hour intervals and will take several years for effectiveness to be known.
- Prior to 2017, the Navy had not been using data to perform comprehensive fleet-level analysis of PEs.
- Data from sensors that would be useful in analyzing and understanding the root causes of PEs are not recorded in memory unit data or are only intermittently recorded when triggered by a caution and warning.
- Slam stick data were insufficient for PE reconstruction because of missing sortie, aircraft bureau number, and memory unit file name.

The National Aeronautics and Space Administration Engineering and Safety Center recommended that NAVAIR take the following actions.

- Measure parameters that directly assess human health and performance and make measurements in the cabin environment whenever possible.
- Adopt the oxygen versus altitude schedule in Military Standard 3050.
- Determine the capability and optimal organizational relationships to support fleet-level data analysis throughout the operational life of all F/A-18 models.
- Establish volatile organic compound testing at OBOGS outlet on all F/A-18 model aircraft to evaluate the association between volatile organic compound level and PE rate found in Growler samples.
- Take steps to validate and apply the National Aeronautics and Space Administration cabin pressure model.

The National Aeronautics and Space Administration Engineering and Safety Center recommended that the Commander, Naval Air Forces, take the following actions.

- Launch a structured data-driven analysis effort that includes the organizational level upon recognition of the existence of severe and widespread safety hazards.
- Require oxygen mask usage in accordance with Commander, Naval Air Forces Manual 3710.7.
- Protect oxygen masks from environmental contaminates, such as dirt or oils, when transitioning to and from the aircraft and clean the masks consistently after each use.

The National Aeronautics and Space Administration Engineering and Safety Center recommended that the Commander, Naval Air Forces; the Bureau of Medicine and Surgery, and NAVAIR form a multi-disciplinary working group to conduct a dedicated physiological investigation. The primary focus should be the human physiological basis and root cause, which could drive engineering changes and modifications.

The National Aeronautics and Space Administration Engineering and Safety Center recommended that the Commander, Naval Air Forces and the Bureau of Medicine and Surgery develop and implement a dedicated clinical practice guideline for PEs.

The National Aeronautics and Space Administration Engineering and Safety Center recommended that the Naval Aviation Enterprise review:

- the most recent Military Standard 3050 and determine how those specifications can be incorporated into the current F/A-18, and
- workforce capability and billets regarding human systems integration to determine if they meet the requirements and intent of the applicable sections of DoD Instruction 5000.02.

The National Aeronautics and Space Administration Engineering and Safety Center recommended that the DON establish a task force to address the PEs being experienced by the F/A-18 and Goshawk communities.

Acronyms and Abbreviations

DON	Department of the Navy
ECS	Environmental Control System
NAMRU-D	Navy Medical Research Unit-Dayton
NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
OBOGS	On-board Oxygen Generation System
PE	Physiological Event
PEAT	Physiological Episodes Action Team
PMA	Program Manager Air
RCCA	Root Cause Corrective Action


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