EXECUTIVE SUMMARY

This Comprehensive Review (CR) examined the facts, circumstances and processes surrounding the recent Physiological Episodes (PEs) involving T-45 and FA-18 aircrew, including how these issues have been addressed. While conducting this examination the CR review included:

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

As of this writing, efforts are ongoing across the Naval Aviation Enterprise (NAE) to address the PE issue. Therefore, it is likely some of this report's recommendations are already being implemented to some degree. Fundamental issues remain. These include:

- Unity of PE correction and mitigation is lacking, as there is no single, dedicated entity leading PE resolution efforts or leveraging DoD, academia, medical and industry resources.
- The integration of the on-board oxygen generation system (OBOGS) in the T-45 and FA-18 is inadequate to consistently provide high quality breathing air. To varying degrees, neither aircraft is equipped to continuously provide clean, dry air to OBOGS – a design specification for the device. The net result is contaminants can enter aircrew breathing air provided by OBOGS and potentially induce hypoxia.
- The environmental control system (ECS) aboard T-45 and FA-18 providing cockpit pressurization is a complex aggregate of sub-components, all of which must function for the system to work as a whole. Aging parts, inadequate testing methodologies and numerous other factors are impacting Fleet ECS reliability, inducing several instances of Decompression Sickness (DCS).

EXECUTIVE SUMMARY

- Disciplined PE root cause identification and correction requires improvement. The NAE has implemented an engineering-centric PE mitigation effort in which potential causes can be dismissed without full adjudication
- Naval Air Systems Command (NAVAIR) organizational alignment does not reflect the complex, integrated human-machine nature of the PE problem. The continued management of systems and components critical to aircrew health as separate and distinct entities likely compounded the PE problem and remains an impediment to its solution.
- Existing PE reporting processes are fundamentally flawed, as the vast majority of PE data originates with self-diagnosis and self-reporting by aircrew with potential cognitive impairment. Aircrew physiological and performance monitoring before, during and after flight could mitigate this shortfall, but rarely occurs.

The CR concluded an apparent 2010 increase in PEs was likely more reflective of a change in aircrew awareness and reporting mechanisms than a sudden rise in PEs. Thus, comparison of pre- and post-2010 PE is essentially impossible and could lead to inappropriate conclusions. The CR also surmised recent PE reporting numbers are probably more reflective of the actual number of PEs, although elements of over- and under-reporting are evident.

Despite the absence of statistically accurate PE reporting, the number and severity of Naval Aviation PEs is unacceptable. As a result, NAE views PEs as its number one safety priority and announced an "unconstrained resource" approach to finding a solution. Given the "unconstrained resource" approach, the CR concluded several steps can be taken to substantially reduce PE numbers and risk. These include:

- Establish a single, dedicated organization to lead Naval PE resolution efforts. This temporary organization should be headed by a Naval Aviator Flag/General Officer, embrace the "unconstrained resource" approach and fully incorporate all stakeholders.
- Re-design aircraft systems to meet oxygen generation system technical requirements.
- Execute a multi-faceted approach to improve ECS reliability, particularly on the FA-18. This effort must address component reliability, system inspections and testing.

EXECUTIVE SUMMARY

- Embrace and resource a methodical PE root cause corrective action process for each aircraft under the single, dedicated organization tasked to lead PE efforts. Additionally, standardize and improve the PE investigation and adjudication process.
- Establish an integrated life support system program at NAVAIR that, at a minimum, manages Naval Aviation oxygen generation and connecting systems; cabin environment and pressurization systems; and physiological monitoring. This program must regularly leverage the lessons of other organizations managing similar technologies.
- Address PE reporting shortfalls, including physiological monitoring; aircrew alerting; and cockpit audio, video and habitability recording.

To date, finding a solution to the U.S. Navy and U.S. Marine Corps' high performance jet aircraft PE challenge has proved elusive. The complexity of aircraft human-machine interfaces and the unforgiving environment in which aircrew operate will continue to generate PEs whenever systems do not operate as intended or human physiology is a factor. The number and severity of PEs can and must be dramatically reduced with a unified, systematic approach.

While the conclusions and recommendations of this CR were developed specifically for the U.S. Navy and U.S. Marine Corps T-45 and FA-18, PEs are a known problem in other aircraft. Elements of this report may be of value to those attempting to address PEs throughout the U.S. military.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. FA-18 OVERVIEW 4

a. FA-18 CONCLUSIONS. 16

3. T-45 OVERVIEW 18

a. T-45 CONCLUSIONS. 30

4. MEDICAL OVERVIEW. 33

a. MEDICAL CONCLUSIONS 38

5. COMMON ISSUES. 40

a. COMMON ISSUE CONCLUSIONS 50

6. RECOMMENDATIONS 56

INTRODUCTION

Physiological Episodes (PEs) occur when aircrew are physically impaired, experiencing decreased performance due to a variety of factors. The two broad PE categories currently being addressed by the Naval Aviation Enterprise (NAE)[1] relate to aircraft system malfunctions: where the aircraft cabin pressurization system is not operating as designed, leading to decompression sickness (DCS); and where the breathing air supply system does not provide adequate air volume, oxygen concentration or purity, leading to varying forms of hypoxia. Complicating the understanding of the PEs caused by aircraft system malfunctions are PEs contributing human factors, such as fatigue, dehydration, diet, nutrition, anxiety, panic and hyperventilation.[2]

In 2010 the number of FA-18[3] hazard reports (HAZREP) related to hypoxia began increasing.[4] Various organizations within the NAE began to gather additional data and investigate causes of the increased PEs, an effort that expanded as PE reports continue to increase within the FA-18 model aircraft and more recently within the T-45 model aircraft. Amongst the efforts, Naval Air Systems Command (NAVAIR) established a Physiological Episode Team (PET) and an Integrated Project Team (IPT) that included an Aeromedical Crisis Action Team (ACAT). In December 2016, as part of the Fiscal Year 2017 Defense Authorization Act, Congress mandated an Independent Review Team (IRT) sourced from NASA to assist the Navy; the IRT report is due to Congress December 2017. Despite these actions the Navy has not yet been able to pinpoint a specific root cause of the PEs in the T-45 and the FA-18 aircraft.

The Naval Safety Center (NAVSAFECEN) has promulgated guidance for reporting a PE via the Web-Enabled Safety System (WESS) as a HAZREP or Naval mishap and also reaffirmed Commander, Naval Air Forces' (CNAF) guidance to submit the NAVAIR PE Report (Parts A, B and C) that collects data from the aircrew experiencing a PE; the aircrew's maintenance department; and the local flight surgeon, respectively. Accurate reporting begins with self-recognition that a PE has occurred. The local flight surgeon makes an initial determination of the cause in the PE report based on aircrew input. The PET adjudicates the PE event which includes characterizing PEs into categories, determining plausible causal factors and subsequent corrective actions and/or mitigations.

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[1] NAE mission is to sustain required current readiness and advance future warfighting capabilities.
[2] Refer to Annex D (1) for a description of the types of PEs.
[3] For the remainder of this report, FA-18A-D, FA-18E/F and EA-18G will be referred to as the FA-18.
[4] PEs are one of the hazards inherent in Naval Aviation. For perspective, in 2016, the worst year for FA-18 PEs of any severity or type, there were 125 PEs, equating to 1 PE per 1,990 FA-18 sorties. By comparison, the number of bird strike events, another inherent risk of varying severity, was 517 or about 1 every 481 sorties in 2016.

INTRODUCTION

On 31 March 2017, instructor pilots (IPs) raised operational risk management (ORM) concerns, causing cancelation of roughly 40 percent of T-45 flights at naval aviation training commands in Meridian, Mississippi; Pensacola, Florida; and Kingsville, Texas. CNAF VADM Mike Shoemaker directed a three-day operational pause on 5 April 2017, for T-45 training commands to allow time for Naval Aviation leadership to engage aircrew, hear their concerns, discuss risk mitigations and ongoing efforts to correct the issues. During that operational pause, NAVAIR engineering experts met with aircrew at the Training Wings, followed by VADM Shoemaker. After meeting with the aircrew in those three training-command locations from 6 – 9 April 2017, VADM Shoemaker extended the operational pause indefinitely to "allow Naval Aviation Leadership time to review the engineering data and develop a path forward for the Fleet that will ensure the safety of its aircrew." On 21 April 2017, Vice Chief of Naval Operations (VCNO) ADM William F. Moran directed Commander, U.S. Pacific Fleet (PACFLT) ADM Scott H. Swift to "lead a comprehensive review of the facts, circumstances and processes surrounding recent PEs . . . to include how these issues have been addressed."[5]

To complete the review, ADM Swift appointed a team from "across the entire Naval Enterprise constituency." The team was chosen from a variety of communities (surface warfare, submarine warfare, aviation, medical and legal) and organizations (Naval Sea Systems Command and NAVAIR). The intent was to bring a fresh perspective to attack this complex, perplexing issue from a different approach. The group consisted of a core team with two specialized sub-teams – medical and engineering.[6]

The FA-18 and T-45 systems and issues are sufficiently different that they will be addressed separately. Following these sections are sections covering medical-related issues and broad common issues; these sections address issues applicable to both the FA-18 and the T-45.

The information in the 'overview' sections are based on interviews, briefings and reports; all of which are included in the annexes in part or whole. The 'conclusions' are the review team's assessment based on the 'overview' data presented; the recommendations flow from the conclusions.

[5] Refer to Annex A for ADM Moran's letter.
[6] Refer to Annex B for a list of team members and locations visited.

INTRODUCTION

It should be noted that while this review was being conducted, efforts were in place across the NAE such that it is likely some of the recommendations included in this report are already being implemented to some degree.

FA-18 OVERVIEW

FA-18 Background

The FA-18 Hornet is a twin-engine, multi-role fighter/attack aircraft built by McDonnell Douglas and then Boeing after the companies merged in 1997. Introduced in 1978, the Hornet replaced the F-4 Phantom and A-7 Corsair II. The FA-18 Hornet has four variants designated A-D, where the A and C variants are single-seat; and B and D variants are dual-seat. The B variant is configured as a trainer.

The FA-18E/F variants, called Super Hornet, are multi-role fighter/attack aircraft built by Boeing based on the original FA-18 airframe. Introduced in 2001, the FA-18E/F replaced the F-14 Tomcat. The FA-18E is a single-seat variant, while the FA-18F is a dual-seat variant. The EA-18G Growler is a variant of the FA-18F Super Hornet Block II designed to perform the airborne electronic attack (AEA) mission as a replacement for the EA-6B Prowler. The EA-18G was first introduced to the Fleet in 2008.

For purposes of this report, FA-18A-D will be referred to as "Legacy Hornet" and are further divided by Lot number, roughly one new Lot per year, from Lot 1 through 21; FA-18E/F will be referred to as "Super Hornet"; and the EA-18G will be referred to as "Growler". FA-18E/F and EA-18G are also further subdivided into annual Lots from 22 through 37. FA-18 Program Manager (PMA-265) is the Naval Air Systems Command (NAVAIR) program office responsible for acquiring, delivering and sustaining the FA-18.

FA-18 Environmental Control System (ECS) Description

The FA-18 environmental control system (ECS) is a complex system of inter-related

components which must function in unison for proper operation. FA-18 ECS utilizes engine bleed air, two heat exchangers and an ECS compressor/turbine to provide warm air for pressurization and heating; and cold, dry conditioned air for cooling. Warm air is provided for internal and external fuel tank pressurization, canopy seal inflation, Anti-G suit inflation, windshield anti-ice operation, windshield rain removal and on-board oxygen generation system (OBOGS) operation. Cold, dry conditioned air is provided for avionics cooling. Warm and cold air is mixed to provide temperature controlled air for cockpit heating, cooling, pressurization and windshield defog. A digital ECS controller is used to schedule ECS output, regulate system temperatures, monitor system health and detect and isolate faults.[7]

Although the majority of ECS design is common among FA-18 models, a few notable differences exist depending on Lot number. For example, Legacy Hornets up to Lot 12 use a liquid oxygen (LOX) system to provide oxygen to the aircrew and do not have OBOGS. The LOX system is a closed loop system that operates independent of cabin pressurization. For Legacy Hornets Lots 9 through 21, the ECS has a Cabin Exit Air System (CXAS) valve installed to provide additional cooling to the avionics bay. The CXAS valve is a significant configuration difference, as the rate of Physiological Episode (PE) pressurization-related events in aircraft with this component is higher than other FA-18s. The CXAS valve is not installed in the Super Hornet, Growler and Legacy Hornets Lots 8 and below.

The complexity and logistics required for LOX drove a desire for a replacement system, leading to the development and fielding of OBOGS in the Marine Corps AV-8 Harrier. A similar OBOGS was subsequently installed in Lot 13 and newer FA-18 aircraft.

OBOGS is designed to convert clean, dry air into breathing air by removing nitrogen and concentrating oxygen. OBOGS was not designed as a mechanical filter. OBOGS employs a nitrogen scrubber mechanism commonly referred to as a sieve bed to molecularly remove nitrogen from ECS-sourced air and provide concentrated oxygen to the aircrew. ECS-sourced air passes a heater, particulate filter and pressure reducer before entering the OBOGS. The ECS-sourced air is then directed to the sieve bed material which is loaded into two identical canisters. Each canister's sieve bed material absorbs nitrogen, passing the concentrated oxygen to a mixing plenum and then to the

[7] Refer to Annexes E (1) and F (2) for a description and diagram of the FA-18 ECS and OBOGS.

aircrew's regulator and mask. The nitrogen absorbed in the sieve bed is purged from the system by a rotating mechanism that periodically releases pressure (and nitrogen) from one canister while simultaneously sending ECS-sourced air to the other canister.

The ability for OBOGS to produce oxygen and pass, retain or release contaminants is a function of input air temperature, pressure and humidity. Sieve bed material has a high affinity for water, such that any entrapped contaminants could be exchanged for moisture in the sieve bed and the contaminants then released from OBOGS into aircrew breathing air. FA-18 ECS-sourced air provided to OBOGS can be provided through a path with a water separator or directly from a heat exchanger with no water separation. A regulating valve just prior to OBOGS input determines which path is selected based on pressure loading and ECS demands.

By approximately 2009, OBOGS original sieve bed material was obsolete and could no longer be procured by the manufacturer. Thus, for a period of time the manufacturer "re-baked" and re-used sieve bed material when OBOGS sieve bed canister refurbishment was required. After approximately four years of using "re-baked" sieve bed material, the manufacturer informed NAVAIR a next-generation sieve bed material capable of improved oxygen production was available and in use by other customers. Additionally, the new sieve bed would include a catalyst specifically designed to convert OBOGS-sourced air carbon monoxide to carbon dioxide. NAVAIR decided to install the upgraded sieve bed on all FA-18s. The decision to upgrade the sieve bed material gained further credence when contamination from FA-18 unique substances was discovered in T-45 OBOGS, indicating the "re-baking" process was inadequate for sieve bed re-use. The extent of government testing of the new sieve bed prior to acceptance could not be determined by this Comprehensive Review (CR) team; however, any testing conducted did not include an assessment of contaminants other than carbon monoxide. This sieve bed upgrade commenced in August 2015, is approximately 85 percent complete throughout the Navy and Marine Corps and approximately 99 percent complete aboard deployed aircraft.

FA-18 cabin temperature and pressurization controls are located on the ECS panel on the right side of the cockpit. The Cabin Pressure Switch controls the cockpit pressurization mode on this panel.[8]

[8] Refer to Annex E (3) for a description of FA-18 ECS panel, controls and pressurization schedule.

While ECS provides the pressure source for the FA-18 cockpit, a cabin pressure regulator controls exit airflow to maintain the pressure schedule. An additional cabin safety dump valve limits cabin pressure should the cabin pressure regulator fail to prevent cockpit over-pressurization. In accordance with FA-18 Naval Air Training and Operating Procedures Standardization (NATOPS),[9] aircrew monitor the cockpit altimeter when climbing through 10,000 feet mean sea level (MSL) and periodically during flight above 10,000 feet MSL, to verify the ECS is maintaining the correct cabin pressurization schedule.

A recommendation following two Class A mishaps (b) (5) caused by (b)(5) (b)(5) [10] was to add to a Cabin Pressurization Warning System (CPWS). As a result, in 2006 NAVAIR installed the CPWS in the FA-18 to monitor cabin pressure and warn the aircrew of potentially hazardous cabin pressurization conditions such as decompression. This system has a caution light that illuminates if cabin pressure reaches an equivalent to 21,000 +/- 1,100 feet MSL. The light will not extinguish until cabin pressure reaches a pressure equivalent to less than 16,500 feet MSL altitude. An additional caution light will illuminate to alert the aircrew if there is an impending ECS problem such as improperly positioned cabin pressurization controls.

FA-18 PEs

According to Naval Safety Center (NAVSAFECEN), four FA-18 mishaps resulting in the death of the aircrew can be attributed to (b)(5) occurred in (b) (5) [11] (b) (5) another FA-18 was lost due to (b)(5); fortunately, the pilot was able to safely eject. Subsequent to these mishaps, training to recognize the symptoms increased and procedures now stress the importance of selecting emergency oxygen as a first step. Correct application of emergency oxygen would have likely prevented these mishaps. (b) (5) (b) (5) there was an (b) (5) over-pressurization mishap resulting in aircrew injury. The causal factors of this event are known and mitigations to prevent future occurrence have been implemented.[12]

Over the past six years, there has been an increase in PE reports throughout the FA-18

[9] The NATOPS program prescribes general flight and operating instructions and procedures applicable to the operation of all U.S. naval aircraft and related activities. It is a pro-active approach toward improving combat readiness and achieving a substantial reduction in the aircraft accident rate.
[10] Refer to Annex E (4) for a summary of these mishaps.
[11] Refer to Annex E (4) for a summary of these mishaps.
[12] Refer to Annex E (4) for a summary of this mishap.

community: 31 in calendar year 2011; 57 in 2012; 89 in 2015; 114 in 2016; and 52 to date in 2017.[13] Figure 1 below depicts reports of PEs in FA-18s by Calendar Year. The increased number of reports can likely be attributed, in part, to increased awareness throughout the Fleet regarding the PE phenomenon and the realization of the potentially dire consequences of a PE. Contributing to this increasing awareness were: joint NAVAIR – NAVSAFECEN presentations provided to FA-18 aircrew at Whidbey Island, Lemoore, Beaufort, Miramar, Atsugi and Fallon; NAVSAFECEN new reporting guidance in a naval message;[14] an increased focus on PEs from the NAVSAFECEN during Squadron Safety Assessments; and continued engagement between the Physiological Episode Team (PET) and the Fleet.

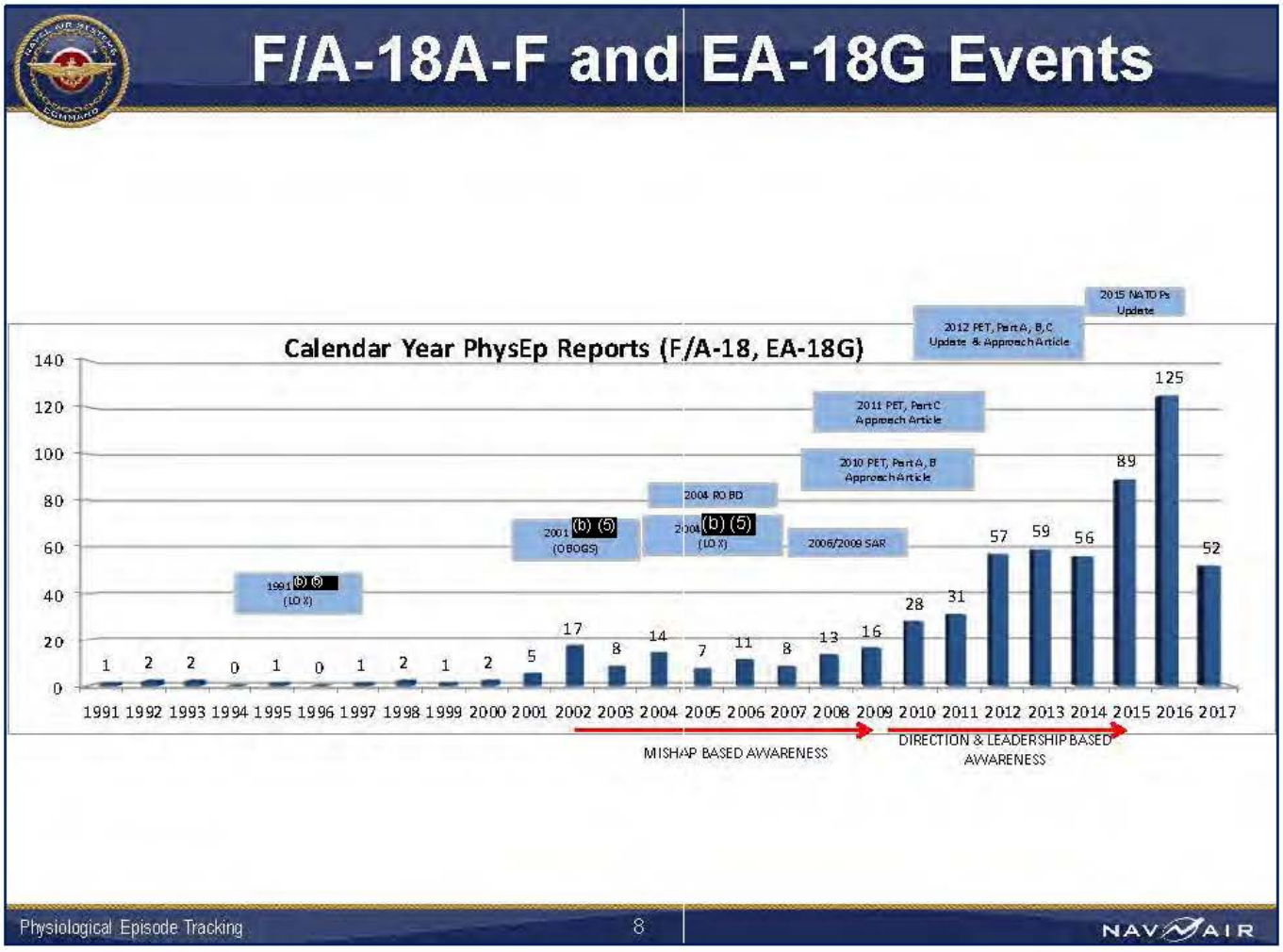


Figure 1 – FA-18 Physiological Episodes by Calendar Year

[13] Refer to Annex E (5) for NAE Historical PE Reporting Data for FA-18s.
[14] Refer to Annex E (6) for a copy of NAVSAFECEN's June 2016 naval message.

FA-18 OVERVIEW

Although FA-18 aircrew have experienced PEs attributed to breathing air problems, the majority of recent serious FA-18 PEs have been attributed to ECS-related issues and cabin pressurization malfunctions (fluctuating pressure, over pressurization and rapid decompression), resulting in symptoms associated with Decompression Sickness (DCS). The PET adjudication data shows that 41 percent of the total FA-18 PEs have been attributed to breathing air delivery system (27 percent possible contamination; 11 percent aircrew oxygen system; 3 percent breathing air delivery component) and 24 percent are adjudicated to be ECS component failure.[15] Despite breathing air problems being the larger percentage, these recent casualties have been effectively resolved with correct application of the NATOPS procedures.

Prior to May 2016, aircrew were trained to remain alert for unexpected cabin pressure fluctuations. In May 2016, a NATOPS interim change required execution of emergency procedures if unexplained pressure changes equivalent to more than +/- 2,000 feet of altitude was observed in a steady state flight condition. This NATOPS change recommendation came about at the August 2014 NATOPS conference after the PE reports began to show a correlation between cabin pressure fluctuations greater than 3,000 feet and DCS events. The work involved in determining the normal pressurization fluctuations, settling on the 2,000 foot number and publishing the new procedure delayed the NATOPS change until May 2016.

In January 2017, VADM Shoemaker sent a message to update the Fleet on PEs, which said: "Although the rate of overall PE events has been trending down slightly since my May 2016 P4,[16] [Naval Aviation Enterprise (NAE)] leadership and I are very concerned with a recent increase in ECS/pressurization related PEs for the legacy FA-18A-D fleet, as well as cockpit over-pressurization events on deck for FA-18E-G aircraft. PEs are a complex problem set that have challenged our ability to determine root cause for the failures and we aren't there yet. As I said, this is the NAE's number one safety priority and focus area and we are taking a 'resource unconstrained' approach to the problem, meaning our efforts to find a solution will not be constrained by manpower or cost."[17]

The aircraft cabin pressurization problems (fluctuating pressure, over pressurization and rapid decompression) are predominantly occurring in the FA-18 Legacy Hornet aircraft. The Legacy Hornet

[15] Refer to Annex E (7) for PET adjudication data.
[16] Navy uses the term "P4" or "Personal For" when referencing a personal message to a specific audience.
[17] Refer to Annex E (8) for a copy of CNAF's January 2017 message to the Fleet.

is experiencing about five times the rate of cabin pressure-related PEs than Super Hornets and Growlers.

It is worth noting that in a U.S. Navy-U.S. Marine Corps comparison of cabin pressurization-related PEs per 100,000 flight hours in Lot 9-21 Legacy Hornets, U.S. Marine Corps aircrew have reported an average of 8.6 reports and U.S. Navy aircrew have reported an average of 15.24. There is no definitive explanation for these differences, but it is illustrative of the challenge in capturing consistent data when a human is part of the system. Culture, physiological make-up and experience can result in variations in how an individual is physically affected by ECS or breathing air malfunctions and what is deemed necessary to report.

Life Cycle Maintenance

Legacy Hornet was designed and built with a 6,000 flight hour service life. Due to strike fighter management requirements, in 2002, the NAE conducted a Service Life Assessment Program (SLAP) to determine the airframe's capability to surpass its original service life. As a result, NAE extended Legacy Hornet service life to 8,000 flight hours beginning in 2006. A subsequent extension to 10,000 flight hours followed that same year. For a Legacy Hornet to fly beyond 8,000 flight hours, the aircraft requires an extensive examination known as a High Flight Hour (HFH) inspection.[18] HFH inspection entails the highest level of aircraft maintenance, normally conducted by organizations known as Fleet Readiness Centers (FRC). The HFH inspection is meant to ensure the structural integrity of the Legacy Hornet is sufficient to extend the life beyond 8,000 hours. Post-HFH inspection, Legacy Hornet requires multiple recurring inspections by Fleet maintenance personnel at various flight hour intervals to ensure the aircraft remains safe to fly to 10,000 flight hours. These recurring inspections are in addition to the operational maintenance requirements for aircraft with less than 8,000 flight hours.

ECS and several other Legacy Hornet systems initially employed a "fly to fail" lifecycle philosophy. Under this concept, only parts that have known malfunctions are replaced. Additionally, HFH does not inspect ECS components or OBOGS. Thus, equipment originally designed for 6,000 flight hours "fly to fail" are assumed to be satisfactory up to 10,000 flight hours. Recognizing the role the ECS might play in PEs and the shortfalls in the HFH inspection program, NAVAIR intends to

[18] Refer to Annex E (9) for the HFH requirements.

conduct an "ECS reset." This ECS reset will include replacement of several key ECS components and an analysis of additional components which will be replaced at a pre-determined periodicity.[19] The ECS reset has started and is currently projected to complete 48 jets per year.

There are reported instances where aircraft returning to the Fleet following post-HFH inspection do not have correctly operating ECS. For example, in May 2017, FRC Southwest intended to deliver an FA-18 Legacy Hornet to Marine Aircraft Group THIRTY ONE (MAG-31) at Marine Corps Air Station (MCAS) Beaufort, South Carolina. This aircraft had failed multiple Functional Check Flights (FCFs) due to cabin pressure fluctuations greater than the newly instituted NATOPS limit of +/- 2,000 feet. Marine Corps leadership was advised that FRC Southwest had exhausted their maintenance efforts without resolution and that Commander, Naval Air Force, U.S. Atlantic Fleet (CNAL) intended to fly the aircraft from FRC Southwest at Naval Air Station (NAS) North Island to MCAS Beaufort under a one-time flight waiver and defer additional repairs to squadron maintenance personnel. The waiver authority for this would have been NAVAIR. The Marine Corps rejected this proposed course of action. Ultimately, the NAE decided not to deliver this aircraft back to the Fleet and it still resides with FRC Southwest awaiting an ECS reset.

FA-18 test equipment lacks the ability to simulate some flight conditions, limiting the ability to troubleshoot dynamic systems such as ECS. For example, test equipment used to evaluate the adequacy of cockpit pressure in relation to the conditions outside the aircraft exclusively uses sea level pressure. This limits a maintenance crew's ability to identify and repair a failed ECS component that could induce a DCS-related PE. The limited ability to test the system at a shore facility is only exacerbated by the space limitations onboard an aircraft carrier which have driven the carrier-based test equipment to smaller and less effective designs. Additionally, operational level maintainers routinely state that the Navy Interactive Electronic Technical Manuals (IETM) often lead FA-18 maintenance personnel to a dead end, to where no solution to the discrepancy is provided. Of note, the ECS reset initiative includes reviewing IETM procedures to address this issue.

Timeline of NAE Actions to Address PEs[20]

[19] Refer to Annex E (10) for additional information on the ECS Reset.
[20] Refer to Annex C for the PE Timeline.

FA-18 OVERVIEW

The NAE has taken various actions to address the PE-related issues in the FA-18. These actions, which are mostly mitigation, include:

- In 2004, NAE implemented Reduced Oxygen Breathing Device (ROBD) training and mandated 24-month refresher training in 2015 to ensure aircrew were familiar with the symptoms of hypoxia. (Some local commands have increased the periodicity to annual.)
- In 2006, the Cabin Pressurization Warning System (CPWS) was installed as a means to alert aircrew when the cabin pressurization is not operating as intended.
- In 2010, NAVSAFECEN established new PE reporting protocols, requiring completion of Parts A (aircrew provided information) and B (maintenance-related information).
- In 2011 Part C (flight surgeon information) was added to collect more detailed aeromedical data on PEs.[21]
- In 2013, a Cabin Pressure System Test (CPST) was changed from a conditioned-based to a time-based periodicity – it is now tested every 400 hours and/or if conditions warrant.
- In 2014, a Test Port Pressure Test (TPPT) to be conducted at same periodicity as CPST was implemented for Legacy Hornets to evaluate ECS air and pressure supply. Of note, TPPT was already being automatically monitored every flight in the Super Hornets and Growlers.
- In 2014, specific ECS Maintenance Status Panel (MSP) codes in the Legacy Hornet were identified requiring maintenance actions post-flight. MSP codes are automatically generated aircraft self-diagnostic codes available after flight to squadron-level maintainers.
- In 2014, a FA-18 NATOPS change providing additional guidance on PEs as well as a rewrite of ECS-related emergencies and additional cautions and warnings was issued. Following a 2012 Class A mishap, FA-18 emergency procedures for bleed air malfunctions were changed, making the action to pull the emergency oxygen green ring step one instead of step two where it was previously.
- In 2014, NAVAIR began conducting 'road shows' to FA-18 bases to discuss PEs and the actions being taken to resolve the various PE-related issues.

[21] Refer to F (11) for sample PE forms (Parts A, B and C).

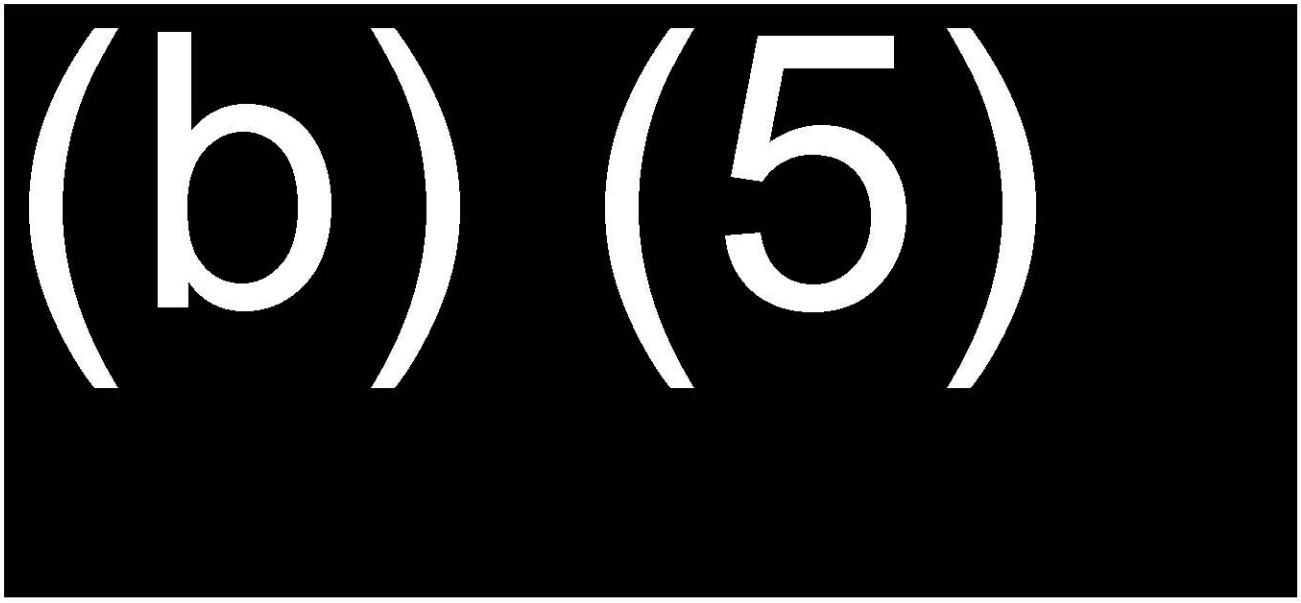
FA-18 OVERVIEW

- In 2015, specific ECS MSP codes were released for the Super Hornet and Growler. Also, the FA-18 started receiving the new sieve bed material. Over 620 of 986 FA-18s have been retrofitted and completion of all aircraft is expected by October 2017.

- In May 2016, a NATOPS interim change was made for the FA-18 limiting the allowable cabin altitude fluctuation to +/- 2,000 feet.

- In July 2016, procedures for FA-18 over-pressurization were released.

- Also in July 2016, a team of NAVAIR engineers was sent to work directly with Strike Fighter Squadron THREE SEVEN (VFA-37) to inspect a Legacy Hornet experiencing ECS malfunctions which led to multiple PE events. A standard protocol was established that every aircraft experiencing a PE event is down for maintenance until all the ECS and aircrew life support components suspected to be causal are removed and submitted for engineering investigations (EI). In addition to implementing this standard protocol, one of VFA-37's aircraft that experienced multiple ECS-related discrepancies was transferred to Patuxent River for in-depth testing by NAVAIR's engineering experts. Based on extensive testing and engineering analysis, changes were made to the maintenance criteria for ECS valves and sensor components, accelerating forced removal and replacement of parts after a certain number of flight hours, rather than flying to failure as done in the past.

- 

- In January 2017, NAVAIR authorized replacing all CXAS valves with a new valve.

- During this same period Slam Sticks – lightweight sensors designed to measure and record vibrations, temperature and air pressure – distribution began to FA-18 squadrons as another tool to record cabin pressure. Slam Stick data is downloadable post-flight at the squadron level to examine cabin pressure over time. This data is helpful in: determining if the cabin pressure was maintaining the design profile; and investigating if PE symptoms might have been caused by cabin pressurization irregularities.

- Hypobaric recording watches were purchased for all NAS Oceana-based FA-18 aircrew because the cabin altimeter gauge is challenging to read due to its size and location; and its audible warnings are ineffective throughout the flight envelope.

- Also pursued in January 2017 were aircrew-worn sorbent tubes. The sorbent tubes measure certain aspects of the aircrew breathing air.[22] The original intent of the sorbent tube was to monitor the progress of the new sieve bed material in the OBOGS concentrator and to determine the amount and types of contaminants in the breathing air as the new sieve bed material ages. Subsequently they have been used to capture data during a PE if contamination was suspected. Efforts continue to develop a better monitoring device that will provide aircrew real-time data on the quality of air they are breathing during flight.

- In January 2017, Fleet Forces Command directed the placement of Transportable Recompression Systems (TRCS) with embarked technicians onboard the deploying USS GEORGE H. W. BUSH and USS CARL VINSON to promptly treat all DCS symptoms while Legacy Hornets were embarked. DCS symptoms are significantly improved when medical treatments are quickly administered, and these portable chambers can provide immediate medical care in the event of a PE. To date, two aircrew have been successfully treated for DCS while deployed.

- In February 2017, NAVAIR incorporated Airframe Bulletins 814 and 815, establishing the scheduled removal and replacement of critical ECS components at 400 or 800 hours intervals (part dependent).

- In March 2017, PMA-265 and Boeing established the Root Cause and Corrective Action (RCCA) team to begin data analysis of PE cases along with a commissioned NASA independent review.

[22] Refer to Annex E (12) for a description of sorbent tubes.

FA-18 OVERVIEW

- In April 2017, the Aeromedical Crisis Action Team (ACAT) was stood up to address the T-45 PEs, but their mission has subsequently been expanded to include FA-18 PEs.

- In May 2017, NAVAIR established an "ECS reset" plan to restore the FA-18 ECS to like-new condition. The ECS reset consists of a review of IETM procedures; a review of Acceptance and Test Procedures (ATP) for ECS components at production and overhaul facilities; and a Material Condition and Inventory Inspection bulletin to replace seven critical ECS components in designated Legacy FA-18 aircraft.

Conclusions

NAE Efforts. With multiple interrelated potential causal factors contributing to PEs, root causes remain unidentified; however, several mitigating actions have been taken to ensure aircrew safety while root cause determination continues.

Emergency Procedures / System Safety Risk Assessment. Physiological episodes are but one of the inherent hazards of Naval Aviation. While the increase number and severity are concerning, aircrew expressed confidence in the safety of the aircraft and in the efforts being pursued to prevent future PEs. This confidence stems, in part, from the measures in place and treatment available to mitigate and reduce the risk of loss of life or aircraft from PEs. Specifically, breathing air problems appear to be manageable and combatted using NATOPS procedures. Cabin pressure malfunctions that lead to DCS are initially treatable with 100 percent oxygen and follow-on treatment in a recompression chamber. Overall, NAE appears to have appropriately assessed and categorized the risk and is continuing to manage it while applying a multi-faceted approach to resolve the malfunctions related to OBOGS and pressurization issues with FA-18s.[23]

ECS Performance. Contributing factors for the ECS issues are age of the system; a failure of maintenance procedures to keep up with complex ECS failure modes; and the additive effect of incremental improvements to a system being made without a holistic evaluation of the resulting system. As aircraft age, identifying problems in complex systems such as ECS becomes increasingly difficult, with multiple component failures often frustrating basic troubleshooting techniques.

Maintenance Resourcing. The combination of aging aircraft and ECS, more restrictive cabin pressure tolerances and static or declining maintenance resourcing make it increasingly difficult for the NAE to repair and deliver mission capable aircraft to the Fleet. For similar reasons, it has also become increasingly challenging for the squadron level maintenance departments to maintain and repair the FA-18 ECS.

Cockpit Altimeter Display. The cockpit altimeter gauge does not adequately display cabin pressure, inhibiting proper determination of exceedance of NATOPS limits; specifically the ability to determine a 2,000 foot fluctuation is nearly impossible. Additionally, the cabin pressure does not

[23] Refer to Annex E (13) for system safety risk assessments.

record during flight; alert aircrew of pressurization deviations; or provide playback capability during post-flight debrief to determine exactly when and what variations occurred.

T-45 OVERVIEW

T-45 Background

Naval Air Systems Command (NAVAIR) Naval Undergraduate Flight Training Systems Program Office (PMA-273) was chartered to develop a rigorous, diverse, carrier-capable Naval Flight Training System where Student Naval Aviators (SNA) and Undergraduate Military Flight Officers (UMFO) acquire mission-critical aviation skills necessary to carry out current and future missions of the U.S. Navy. The acquisition, development and maintenance of six trainer aircraft fall under the purview of PMA-273 for its customer, the Chief of Naval Air Training (CNATRA). Those aircraft are T-45, T-6, T-44, T-34, TC-12 and TH-57. Each aircraft and associated support infrastructure includes related simulator suites, academic materials, computer-based training integration systems and contractor logistics support.

The T-45 Goshawk is a tandem-seat, single engine jet trainer whose mission is to train Navy and Marine Corps Naval Aviators and Naval Flight Officers (NFO) for jet carrier aviation and tactical strike missions during the intermediate and advanced portions of their training pipeline. An integrated training system, the T-45 series includes the T-45 Goshawk aircraft, operations and instrument fighter simulators, academics and a training integration system. There are two versions of T-45 aircraft, the T-45A and T-45C. The T-45A, which became operational in 1991, contained an analog design cockpit. The new T-45C, which began delivery in December 1997, was built around a new digital "glass cockpit" design. T-45A underwent a Required Avionics Modernization Program (RAMP), bringing all Goshawk aircraft to a T-45C configuration. T-45C aircraft are based at TW-1 (Meridian, Mississippi) and TW-2 (Kingsville, Texas) for SNA training and TW-6 (Pensacola, Florida) for UMFO training.[24] Currently there are 197 total T-45s in the active U.S. inventory. All T-45 organizational, intermediate and depot-level maintenance efforts are provided by civilian contract services.

[24] For the remainder of this report, they will be referred to as: TW-1/Meridian; TW-2/Kingsville; TW-6/Pensacola.

T-45 OVERVIEW

The primary liaison between NAVAIR and Fleet operators is a Type Commander (TYCOM) organization known as the "Class Desk," with one for each Type, Model and Series. For FA-18, the "Class Desk" function is executed by Commander, Naval Air Force, U.S. Atlantic Fleet (CNAL) Aircraft Material and Engineering/Material Department, with a senior officer (usually a Commander or Lieutenant Colonel) assigned as lead. For T-45, the "Class Desk" is executed as a collateral duty by the CNATRA Aviation Maintenance/Material Officer, with a single government civilian as lead for T-45 and all other training aircraft. During interviews, T-45 aircrew expressed considerable dissatisfaction with the lack of information they were receiving from NAVAIR; whereas FA-18 aircrew did not express similar concerns.

T-45 OBOGS System Description

The T-45 on-board oxygen generating system (OBOGS) is comprised of an oxygen concentrator (GGU-7), an oxygen monitor (CRU-99) and aircrew-worn breathing air regulator (CRU-103).[25] The oxygen monitor continuously samples oxygen enriched air for the proper concentration level just prior to entry into the regulator. When the oxygen level drops below an acceptable level, the oxygen monitor illuminates the OXYGEN warning light, alerting the aircrew of a potential system malfunction.[26] The light also warns the aircrew when OBOGS inlet supply air exceeds 250 degrees.

The oxygen monitor does not detect contaminants in the breathing air, which may be odorless and tasteless. A potential cause of contamination is prolonged OBOGS operation in the vicinity of aircraft exhaust, which contains toxic by-products of fuel combustion. Risk of contamination also increases with uncontrolled oxygen flow, which occurs when removing mask(s) without securing the OBOGS flow or from system or mask/hose leaks.

The chest-mounted, breathing air regulator is designed to provide aircrew demanded oxygen flow at all altitudes up to 50,000 feet, exceeding the T-45 maximum altitude of 41,000 feet. A separate emergency oxygen system is integral to the Naval Aircrew Common Ejection Seat (NACES) survival kit (SKU-11). Aircrew also use an oxygen mask (MBU-12 or MBU-23) which is supplied from the breathing air regulator and wear an Anti-G suit (CSU-13 or CSU-15). The majority of OBOGS components are operated until they fail. OBOGS maintenance is normally performed by shipping disassembled components to the manufacturer for repairs.

[25] Refer to Annex F (1) for T-45 OBOGS diagram and description.
[26] Refer to Annex F (2) for acceptable oxygen threshold levels and effects at various altitudes.

T-45 OVERVIEW

Planned upgrades for the T-45 OBOGS include a solid-state oxygen monitor (CRU-123) and an Enhanced Emergency Oxygen System (EEOS). The solid-state oxygen monitor adds a breathing air pressure alarm to the existing oxygen concentration and temperature alarms, as well as improved reliability features such as a built-in test (or BIT). The EEOS is expected to double the system's capacity, which is currently 10 to 20 minutes.

OBOGS and Environmental Control System (ECS) are separately supplied bleed air from the compressor section of the T-45 engine. OBOGS employs a nitrogen scrubber mechanism commonly referred to as a sieve bed to molecularly remove nitrogen from the bleed air and provide concentrated oxygen to the aircrew. The bleed air flows through a cooling heat exchanger and enters the OBOGS, where bleed air passes through a heater, particulate filter and pressure reducer at the input of the device. Bleed air is then directed to the sieve bed material which is loaded into two identical canisters. Each canister's sieve bed material absorbs nitrogen, passing the concentrated oxygen to a mixing plenum and then to the aircrew's regulator and mask. The nitrogen absorbed in the sieve bed is purged from the system by a rotating mechanism that periodically releases pressure (and nitrogen) from one canister while simultaneously sending bleed air to the other canister. Although there were no initial specifications for OBOGS to serve as a contaminant filtration media, experience indicates the device has the ability to trap a number of substances that might enter aircrew breathing air.

The ability for OBOGS to produce oxygen and pass, retain or release contaminants is a function of input air temperature, pressure and humidity. Sieve bed material has a high affinity for water, such that any entrapped contaminants could be exchanged for moisture in the sieve bed and the contaminants then released from OBOGS into aircrew breathing air. T-45 bleed air provided to OBOGS has no moisture separator prior to the inlet.

When OBOGS is powered off and engine bleed air is not isolated from the system, pressure is applied to a single sieve bed canister. This pressure can potentially force contaminants into the selected sieve bed canister, driving deeper contaminant accumulation and potentially leading to what is known as a "burp". The T-45 valve isolating OBOGS from the engine is known as the bleed air isolation valve. Due to reliability concerns, the bleed air isolation valve functionality was removed from the T-45 in the 2010 timeframe. However, without the bleed air isolation valve, there is nothing to stop pressure application to a single sieve bed canister when OBOGS power is secured or to prevent moisture from entering the OBOGS inlet piping when the engine is not operating. To reduce the

pressure application risk to the sieve beds, T-45 NATOPs procedures were changed in March 2016 to ensure OBOGS was powered on at engine start and off at engine shutdown.[27]

By approximately 2009, OBOGS original sieve bed material was obsolete and could no longer be procured by the manufacturer. Thus, for a period of time the manufacturer "re-baked" and re-used sieve bed material when OBOGS sieve bed canister refurbishment was required. This "re-baking" practice continued until FA-18 unique substances were discovered in T-45 OBOGS, indicating the "re-baking" process did not fully sanitize the sieve bed material. At approximately the same time, the manufacturer informed NAVAIR a next-generation sieve bed material was available, and that it would include a catalyst specifically designed to convert bleed air carbon monoxide to breathing air carbon dioxide.

Initially, OBOGS with next-generation material was installed on FA-18. However, after the cross-contamination discovery and with increasing concern about PEs, PMA-273 decided to install the upgraded sieve bed on all T-45s. This upgrade was conducted between approximately December 2016 and March 2017 with an assumption that the new sieve bed would perform as well or better than the older material when installed in the aircraft.

T-45 Cockpit Pressurization System Description

T-45 cockpit pressurization is provided by ECS air from a port on the final stage of the engine compressor. ECS air is separate and independent from the bleed air used by the OBOGS, and is used solely for temperature control, cockpit pressurization, ram air control, canopy seal and heat exchanger inducers. Cockpit pressurization commences once the aircraft is airborne and increases approximately linearly with altitude.[28] This "linear" pressurization schedule is different from most Fleet tactical aircraft (FA-18) which maintain constant "isobaric" cockpit pressurization from ~8,000 – 24,500 feet. For a quick comparison at an aircraft altitude of 24,000 feet, the T-45 cockpit altitude will be 14,000 feet while the FA-18 cockpit altitude will be at 8,000 feet.[29]

In the event of cockpit pressure control system failure, a safety relief valve ensures that cockpit differential pressure is not exceeded. The safety valve also incorporates a pressure relief function to ensure that cockpit differential pressure is not exceeded. If cockpit pressure is lost or exceeds 24,500 ±500 feet, the CABIN ALT warning light will illuminate.

[27] NATOPS Interim Change #36.
[28] Refer to Annex F (3) for the T-45 ECS description and diagram.
[29] Refer to Annex F (4) for graphical comparison of T-45 and FA-18 cockpit pressurization schedules.

T-45 Physiological Episodes

As previously discussed, the apparent PE increase in 2010 was likely more reflective of a change in aircrew awareness and reporting mechanisms than a sudden rise in PEs. Thus, comparison of pre- and post-2010 PE could lead to inappropriate conclusions. Since December 2011 there have been 112 T-45 PEs. Of these, 81 have been adjudicated by the Naval Aviation Enterprise (NAE). Analysis of the remaining 31 PEs is ongoing. Of the 81 adjudicated cases, 48 percent were determined to be aircraft system failures or human factors (i.e., fatigue, diet, procedural error); 28 percent were determined to be possible contamination; 24 percent were determined to be inconclusive.[30] Figure 2 below depicts reports of PEs in T-45s by Calendar Year. The aircraft system failures include two documented pressurization PEs since May 2016.

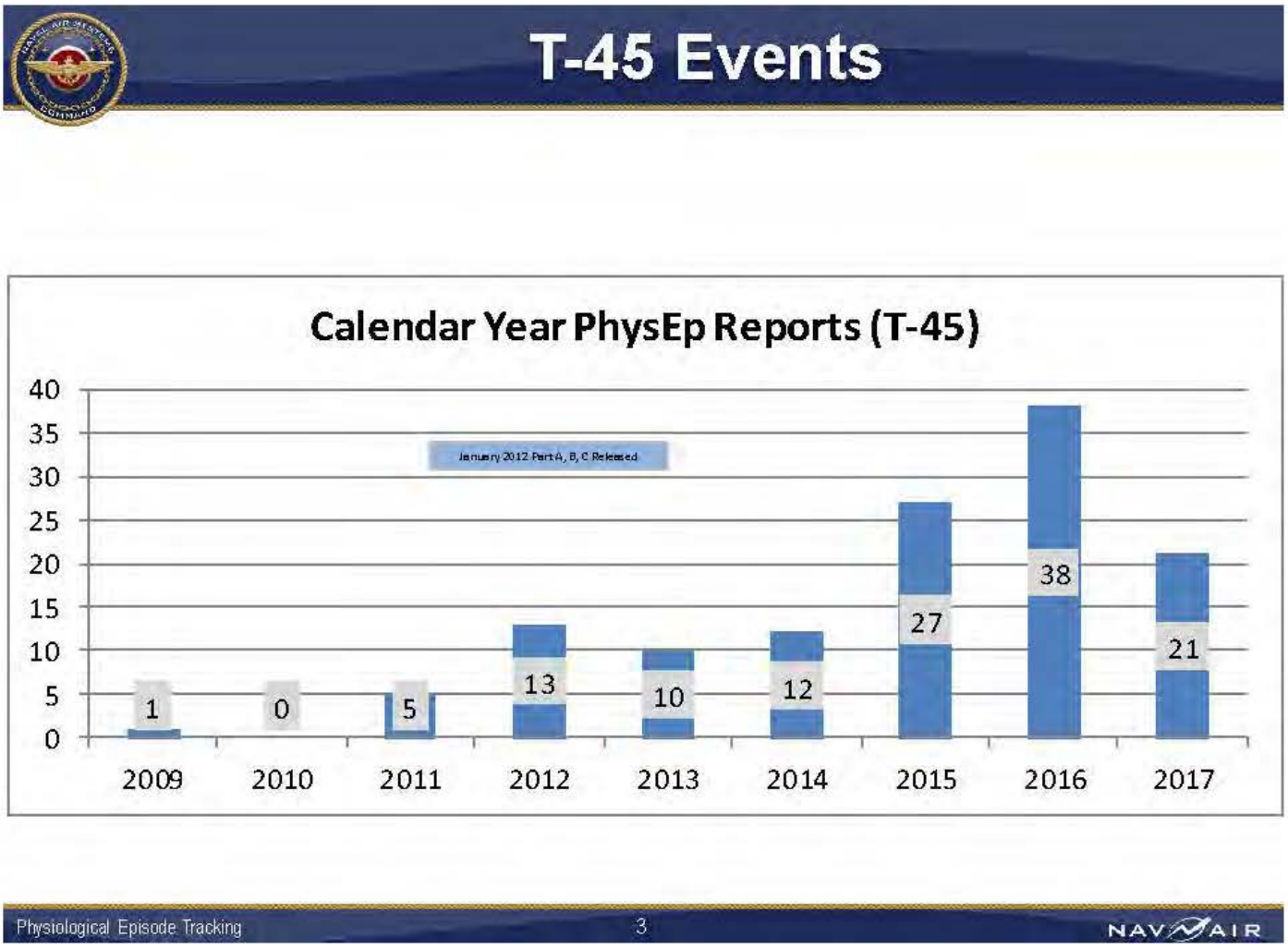


Figure 2 – T45 Physiological Episodes by Calendar Year

[30] Refer to Annex F (5) for breakdown of T-45 adjudicated PE categorizations.

T-45 OVERVIEW

The majority of reported T-45 PEs have an oxygen warning light with no symptoms, meaning aircrew have a visual indication of a possible malfunction with sufficient time to execute emergency procedures, preventing hypoxic effects.[31] Based on the relatively small number of T-45 pressurization PEs, the NAE has focused efforts on breathing air related PEs. One T-45 (b) (5) mishap (b)(5) [redacted], (b) (5) [redacted] The review of this mishap, however, is not yet final; it is pending endorsement by the Naval Safety Center.

Actions specific to the T-45 to date include:

- In March 2016, a T-45 NATOPS change updated OBOGS power on/off procedures.
- In October 2016, aircrew-worn breathing air contamination monitoring devices known as sorbent tubes were provided for select T-45 flights.
- In December 2016, installation of next-generation OBOGS sieve bed material commenced that included a carbon monoxide to carbon dioxide catalyst. T-45 installations were completed in March 2017.
- In March 2017, T-45s reporting a PE event are impounded pending additional analysis.
- In April 2017, CNAF limited flight profiles to 10,000 foot cockpit altitude and directed aircrew to remove OBOGS breathing air supply from their masks. This is commonly known as "snorkel mode" breathing.
- In April 2017, CNAF further limited T-45 flight profiles to a 5,000 foot maximum allowable aircraft altitude, except for Functional Check Flights.
- In April 2017, T-45 Airframe Bulletin 262 was released, which deals with T-45 OBOGS / ECS hygiene and system integrity testing procedures.

Actions in progress or planned include:

- In June 2017, begin installation of breathing air pressure warning for aircraft fitted with the solid-state oxygen monitor (CRU-123).
- Develop an aircrew-worn carbon monoxide and hydrocarbon detection and warning system.
- Develop a next-generation OBOGS known as GGU-25.
- Develop OBOGS replacement part intervals for select components previously operated until failure.

[31] Refer to Annex F (5) for PMA-273 T-45 PE Brief on T-45 PE trends and actions taken to date.

T-45 OVERVIEW

T-45 Timeline Narrative[32]

The T-45 PE issue spiked when numerous aircrew decided to use ORM principles and opt out of flying the T-45 on 31 March. What follows are the major events that led up to that decision.

Prior to 2016, T-45 PE resolution primarily leveraged aggressive FA-18 Program Manager (PMA-265) and Aircrew Systems Program Manager (PMA-202) efforts. However, (b) (5) a T-45 mishap (b)(5) elevated the NAE's awareness of T-45 specific issues. In general during the fall/winter of 2016, the T-45 training community's perception of the engineering effort was considered satisfactory due to post-mishap communication and information exchanges with NAVAIR. Though T-45 PE events for 2016 resulted in the highest annual number ever, the CNATRA team (CNATRA, Training Wings and Training Squadrons) were leveraging the information they received from NAVAIR to assure their aircrew that the Navy was engaged in a meaningful effort to address the T-45 PE problem. (b) (5) the Aviation Mishap Board (AMB) completed the Safety Investigation Report (SIR) for review and final endorsement.

From 2014 to 2016, the number of reported PE events more than tripled. Additionally, some PE events were occurring in unexpected flight regimes, such as low altitude. During this period, NAVAIR conducted a PE Safety System Risk Assessment (SSRA) and identified the most hazardous T-45 PE scenario as both aircrew being symptomatic and no oxygen warning light, assigning it Hazard Risk Index (HRI) score of 6 (Serious Risk) based on "occasional" frequency and "critical" severity.[33]

The increase in reported PEs in 2017 along with the apparent rapid onset[34] or the delayed recognition of symptoms in some instances led many aircrew to speculate they were experiencing histotoxic hypoxia due to a contaminant. Histotoxic hypoxia symptoms are highly variable across individuals; may not be immediately recognized; and 100 percent emergency oxygen may not quickly alleviate the symptoms. Aircrew stated they were losing confidence in their aircraft due to the lack of a viable procedure to mitigate this hypoxia hazard and that there was no clear diagnosis and no distinct root cause.

At the squadron level, aircrew were submitting required PE documentation. Despite this, they had a growing perception of inadequate progress by NAVAIR engineers and Naval Safety Center

[32] Refer to Annex C for the PE Timeline.
[33] Refer to Annex F (6) for NAVAIR T-45 SSRA, also contains a description of the HRI.
[34] Rapid onset of physiologic episodes is defined as unanticipated incapacitating sudden altered mental and or physiologic status as a result of the PE causal factors described in Annex D (1).

(NAVSAFECEN) personnel coupled with insufficient/poor communications/feedback. This eroded their confidence in leadership ability to recognize and effectively address the problem. Although instructor pilots (IPs) were unable to articulate this risk formally through Operational Risk Management (ORM) risk matrix terminology, they became less confident with the aircraft and voiced that concern to their squadron and wing leadership.

Dissatisfied with lack of explanation of what was happening with the aircraft, Training Wing and Training Squadron staffs (Safety Officers /Aviation Medical Safety Officers) and squadron aircrew began to conduct their own independent analysis and investigative efforts and share their data and experiences among their internal organizations through email and social media. Due to the increased aircrew concern and hypersensitivity with PE-related aircraft incidents,[35] any reported PE event was quickly broadcast among T-45 aircrew. In many cases these internal PE notifications were happening in advance of the normal reporting process and may have been based on initial reports that lacked sufficient detail to describe what had occurred.

In response to feedback and concerns received earlier through the normal safety reporting process, CNATRA developed a plan to have the NAVAIR T-45 engineers visit each of the T-45 training locations. The goal of these road shows was to solicit aircrew feedback on their concerns and instill confidence that the NAE was fully engaged in finding a solution. CNATRA, having been constantly engaged with NAVAIR, CNAF and subordinate commanders regarding the NAVAIR PE mitigation efforts in development, was confident "many of the aircrew's concerns would be alleviated once they hear from the engineers."

The cumulative effect of increased PE awareness in the T-45 community due to safety hazard reports (HAZREPs), mishaps and PE Reports (Part A, B, C),[36] ready room training, social media discussions and widely disseminated emails of aircrew's personal accounts and experiences, along with unsatisfying responses from the engineering community and a growing concern about contaminated breathing air reached a tipping point for IPs in late March 2017.

An Aviation Mishap Board (AMB) was established to investigate the causal factors of the August 2016 TW-2/Kingsville T-45 mishap in which the aircrew ejected. (b) (5) [redacted]. Aircrew in TW-

[35] Refer to Annex D (4) for a NAVAIR Annual PE tracker by T/M/S.
[36] Refer to Annex F (7) for T-45 PE forms (Part A, B, C).

2/Kingsville soundly rejected this potential conclusion, reinforcing the growing belief among aircrew that "leadership" didn't understand the full scope and severity of the T-45 PE problem. Although the report is not yet final, as it has not been endorsed by the Naval Safety Center, the AMB ultimately concluded that (b)(5) [redacted], was causal in the mishap.[37]

(b) (5) [redacted]

[37] Safety Privileged Source: Safety Investigation Report (b) (5) [redacted]
[38] Refer to Annex F (8) for IP's email account of this incident.

(b) (5)

Following a scheduled video teleconference (VTC) on 29 March, the TW-1/Meridian, TW-2/Kingsville and TW-6/Pensacola Commodores relayed to CNATRA that several of their IPs had expressed significant concerns regarding the safety of the aircraft OBOGS. CNATRA acknowledged the concern and relayed that he would expedite a previously planned NAVAIR roadshow on the PE efforts. NAVAIR agreed to come the following Monday, 3 and 4 April. CNATRA's expectation was that the visit would help restore confidence throughout the T-45 IP cadre.

(b) (5)

On 30 March, TW-1/Meridian leadership had a telephone conversation with PMA-273 personnel and the Physiological Episode Team (PET) members regarding the recent increase in PEs. The TW-1/Meridian Commodore expressed dissatisfaction with the discussion as he believed the PMA-273 engineers and the PET members were downplaying the risks associated with PEs. In the opinion of the TW-1/Meridian Commodore, the engineers appeared to be trying to redirect the cause of the PEs from system failures to aircrew behavior. Additionally, the Commodore believed he was unable to convince PMA-273 that the risk of flying T-45 had increased.

On the evening of 30 March, the TW-2/Kingsville Commodore informed the TW-1/Meridian Commodore that rumors were circulating about the IPs' decisions not to fly using the ORM tool on 31 March. The TW-1/Meridian Commodore more fully articulated the IP angst in an email to CNATRA on the evening of 30 March.[39] The first 12 flight cancellations for IP-ORM occurred this evening according to the completed VT-9/Meridian flight schedule.[40]

On the early morning of 31 March, the CO of Kingsville squadron VT-21 was alerted by his team that 10 of his IPs were going to use the ORM tool and cancel their flights. The CO alerted the TW-2/Kingsville Commodore, who alerted CNATRA. The scale of the collective ORM decision was

[39] Refer to Annex F (9) for email from TW-1/Meridian Commodore to CNATRA.
[40] Refer to Annex F (10) for completed VT-9 30 March flight schedule.

not known or communicated to CNATRA. The intention of all three Training Wing Commodores was to continue to execute the flight schedule, assess the impact and determine what NAVAIR had to say when they arrived with the road show the following week.

On the morning of 31 March, the TW-6/Pensacola Commodore concurred with the assessment set forth in the TW-1/Meridian Commodore's email from the previous evening. On mid-day of 31 March, CNATRA responded to the email and reiterated about the upcoming NAVAIR visit and his belief that it would restore confidence.[41] By this time, concerned IPs were already in the midst of cancelling flights based on ORM.

On 31 March, 51 of 129 aircrew scheduled to fly events at the three Training Wings decided to cancel their flights due to their individual risk assessment after their pre-flight NATOPS brief. Some flights continued that day. TW-1/Meridian had 33 of 57 aircrew cancel their flights due to ORM concerns. In TW-2/Kingsville, one squadron had 10 of 29 aircrew cancel their flights due to ORM concerns. The second Kingsville squadron had no ORM cancelations because squadron leadership had previously rewarded their O-3 instructors with special liberty on 31 March as a reward for high operations tempo over the previous months. TW-6/Pensacola had 8 of 17 aircrew cancel their flights due to ORM concerns.[42]

Following the aircrew's decision to cancel for ORM, during the weekend of 1 – 2 April, TW-1/Meridian flew 25 sorties; TW-2/Kingsville conducted 12 training sorties; and TW-6/Pensacola scheduled and flew 2 sorties. On 3 and 4 April, the IPs who had decided not to fly on 31 March flew in some squadrons and not in others.

Also on 3 and 4 April, NAVAIR briefed all three T-45 Training Wing personnel. It was not well received at any of the three sites. The IPs felt the NAVAIR team lacked urgency and discounted the severity of a rapid onset hypoxia or the histotoxic condition by telling the IPs they were probably hyperventilating. IPs were told there was no evidence of contaminants, so it "must be something else."

Previously scheduled commitments prevented CNATRA and CNAF from visiting the Training Wings and being present for the 3 and 4 April NAVAIR briefings. During those dates, CNATRA was in Pensacola for the selection of the next Blue Angel Commanding Officer and CNAF was participating in talks with the United Kingdom followed by travel to Yuma, Arizona. Despite their

[41] Refer to Annex F (11) for email from CNATRA to Training Wing Commodores.
[42] Refer to Annex F (12) for summary of ORM flight cancellations by squadron.

scheduling conflicts, both CNATRA and CNAF remained heavily engaged on the emerging issue, to include gathering facts and circumstances surrounding the use of ORM to cancel flights for updating senior leadership; for use in congressional testimony; and for responding to news inquiries. Specifically, on the morning of 3 April, CNAF fielded an inquiry from a news outlet and subsequently coordinated an interview with the reporter and two senior Naval officials, one from NAVAIR and one from OPNAV, to provide context for the article that would run the following day.

On 4 April, the initial news report titled "Navy Instructor Pilots Refusing to Fly Over Safety Concerns; Pence's Son Affected" was released.

After two days of gathering information into the events leading up to and following the use of ORM to cancel flights and following a discussion with CNATRA concerning the change in risk calculus from January 2016, CNAF instituted a T-45 operational pause for 5 through 7 April to "engage with the aircrew, hear their concerns and discuss the risk mitigation efforts that are ongoing to correct this issue." On 5 April, senior NAE leadership, to include CNAF, CNATRA and TYCOMs, met to ensure full understanding of the issue from the various stakeholder perspectives and assess the effectiveness of actions to date, to include the NAVAIR engineering briefings to the Training Wings.

On 6 April, CNAF visited NAS Kingsville followed by visits to NAS Pensacola on 7 and 8 April and NAS Meridian on 8 through 10 April. During these discussions, the Commodores articulated that the risk associated with flying the T-45 had increased and was not correctly characterized in the current, approved risk assessment. The approved risk assessment relied on the following assumption: "progressive self-recognition of symptoms required of at least one aircrew in order to employ preventative measures to affect safe recovery." In other words, it assumed that the PE would not be rapid onset and that emergency oxygen would allow a safe recovery. Both assumptions were faulty in the minds of the Training Wings, Training Squadrons and IPs. CNAF, after reviewing the Commodores' information,[43] concurred that the current risks were not accurately captured in the SSRA signed January 2016.

[43] Refer to Annex F (13) for TW-1 T-45 Reassessment Brief.

Conclusions

NAE Efforts. With multiple interrelated potential causal factors contributing to PEs, root causes remain unidentified; several mitigating actions have been taken to ensure aircrew safety while root cause determination continues. However, the effort has lagged the Fleet problem. Additional resources are now required to restore full aircrew confidence in the aircraft, specifically the OBOGS.

Use of Operational Risk Management Principles.[44] The use of the ORM process to cancel scheduled flights on 31 March 2017 was consistent with the Navy's established safety principles.

There was no single event that triggered the ORM-based flight cancellations on 31 March, rather a synthesis of the following dynamic factors in the IPs' risk calculus:

- Waning confidence in OBOGS due to increased number and perceived severity of PEs;
- Waning confidence in NAE ability/urgency to fix the issue; and
- Perception by some IPs that CNATRA leadership placed higher priority on aircrew production vice risk to aircrew.

On or about 30 March, many IPs, across all Training Wings, communicated amongst each other their continuing aircraft safety concerns and perceived leadership inaction via text/social media. The TW-1/Meridian and TW-6/Pensacola IPs were the epicenter of these communications; TW-2/ Kingsville IPs had internalized and to a large degree, accepted the risks in the OBOGS, after the August 2016 Aviation Mishap Board was concluded. Not being included in the circle of social media, Squadron, Wing and CNATRA leadership had a general sense of the IPs concerns but were not cognizant of the exact content of the communications or the level of concern. The farther leadership was from the IPs, the less the understanding existed of how dire their concern was.

CNATRA and Training Wing leadership were, as late as Friday (31 March) morning, trying to understand, define and communicate the IPs' perceived change in the risk. Leadership was late to recognize they were being confronted with a wide-spread and simultaneous sharing of ideas. IPs failed to understand how sharing their individual risk calculus simultaneously and broadly through social media allowed their thought process to quickly travel horizontally, but not vertically up the chain of command, throughout the organization.

[44] Refer to Annex I for a description of the ORM processes.

Applying the Navy's ORM instruction or the Training Wing's ORM instruction would have put structure and rigor into the concerns being expressed by the IPs and would have been a better method to communicate their concerns to CNAF and NAVAIR. TW-1/Meridian Commodore was on the verge of establishing a Training Wing or CNATRA Risk Assessment Team to re-evaluate and update the risks of flying the T-45 using the most current data. He presented this updated risk assessment to CNAF on 8 April. This updated risk assessment informed CNAF's decision to direct the in-progress operational pause continue.

Both TW-1/Meridian and TW-6/Pensacola conducted safety AOM during the week of 27 – 31 March based on PE events experienced by their aircrew. On 31 March, when it became evident that several IPs were using ORM-based principles not to fly, the Squadrons or Training Wings should have conducted a safety AOM with the IPs and SNA to more completely understand the depth of the concerns and attempt to resolve them.

Design Shortfalls. The bleed air piping into the T-45 OBOGS was designed without a moisture separator or in-line mechanical filter. The lack of this functionality potentially allows contaminants to enter the system including the breathing air provided to the aircrew. The physiologic monitoring, life support system performance specifications and maintenance policies have been inadequate to consistently ensure flight crew health and performance. Institutional barriers between NAVAIR program management and supporting engineers has contributed to suboptimal life cycle maintenance of the integral aircraft life support system.

The SSRA Review Process. The periodicity of the risk assessment review, apparent latency of the data and potentially the membership of the reviewing entities all contributed to not incorporating recent increase in PEs, the cases of rapid onset hypoxia or the cases of potentially histotoxic hypoxia into a current risk assessment.

T-45 Class Desk Integration. A potential factor that contributed to the lack of communication in the T-45 community was the lack of a robust T-45 Class Desk to act as a liaison between NAVAIR and the operators. This may have been a contributing factor for the need to conduct a NAVAIR road show to interface with the fleet operators in response to perceptions that not enough was being done to address the PE issues.

Safety Issue Identification and Resolution. "The problem outpaced the process" noted one T-45 squadron CO. Established safety data capture and analytical efforts were not sufficiently responsive to quickly determine negative safety trends and implement root cause mitigation efforts. The effort lacked coordination across and within organizations and effective feedback to the operating forces.

T-45 Operational Pause Impact. A comprehensive return-to-flight plan must be developed and communicated broadly to the NAE.

CNATRA jet student production was strained in periods prior to the CNAF mandated T-45 operational pause. The IPs are primarily concerned that post-operational pause, their day-to-day tempo will increase even further to mitigate the lost fly-days, leading to more 6-day work weeks with 3 flights per day and little chance of attaining the quality of life expected while on shore-duty.

The students' main concern is how this delay will impact their career and career timing.

MEDICAL OVERVIEW

Medical Diagnosis and Treatment

In general, health care professionals use Clinical Practice Guidelines (CPGs) to assist with patient diagnosis and treatment. They do not however have a CPG to use when treating and diagnosing aviation-based PEs, like hypoxia. The lack of a standardized CPG for aviation-based PEs coupled with the lack of thorough understanding of the subtle differences between hypoxia,[45] hypocapnia,[46] and decompression illness (DCI)[47] hinders the health care professional's prompt recognition, diagnosis and treatment of PEs. Further compounding the issue is the fact the aircrew's symptoms often resolve themselves without leaving any identifiable marker to assist with diagnosis and treatment, thereby requiring diagnosis and treatment to rely solely on self-diagnosis and self-reporting by potentially cognitively impaired aircrew. It is the inherent challenge of accurately diagnosing the patient in these circumstances that ultimately leads to potentially inaccurate treatment regimens or characterizations of the PE.

Exacerbating this diagnosis and treatment issue is the potential for aircrew to develop hypocapnia (due to hyperventilation) in reaction to an emergency. Prior to the Air Force's review into the circumstances surrounding the increase of PEs in F-15s,[48] the Air Force had moved away from teaching breathing control to its aircrew. The Air Force review recommended teaching breathing control and altering emergency procedures to account for breathing (rate and depth).

Contributing, Naval Safety Center (NAVSAFECEN) issued supplemental guidance for PE reporting in April 2017, changing the reporting requirement from a diagnosis-based to a treatment-based classification system. This revised guidance required PE events be classified and reported as a Class D mishap[49] based on treatment provided to the aircrew as opposed to diagnosis.[50] This modification created concern that classifying a PE (or suspected PE) based on treatment (to include precautionary treatment) criteria could exert undue pressure on health care professionals to modify treatment based on a reporting category and not actual diagnosis or it could lead to an artificial

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[45] In other words, low oxygen or ability to use oxygen.
[46] Hyperventilation, or low carbon dioxide.
[47] In other words, bubbles of gas in body tissue. Of note, decompression sickness (DCS) is a subset of DCI. Refer to Annex D (1) for a more detailed description.
[48] Air Force F-15C/D Physiology Incident Independent Review Team (IRT) Final Report, found in part, at Annex D (2).
[49] Refer to Annex D (3) for an explanation of Naval Reporting Requirements
[50] Refer to Annex D (3) for the April 2017 NAVSAFECEN naval message: "AVIATION PE REPORTING REQUIREMENTS". Paragraph 3B reads: CLASSIFICATION OF SEVERITY. Post-flight treatment protocols consisting of 100 percent oxygen, IV fluids, emergency room admission, or hyperbaric chamber therapy are greater than first aid treatment and are therefore classified, at a minimum, as a Class D mishap when treating physiological episodes.

inflation of a PE to a mishap due to a precautionary treatment. A common example provided referenced the use of medical oxygen administered during post-flight treatment. In this example, giving the aircrew precautionary oxygen automatically changes the report from a hazard report (HAZREP) to a Class D mishap.

The increase in occurrence of PEs has caused an increase in demand for hyperbaric chamber treatments and specialists qualified to operate the chambers. Currently, only undersea medical technicians (enlisted) under the oversight of a physician (undersea medical officer (UMO) or residence in aerospace medicine (RAM) trained Senior Medical Officer) can operate the pressure chambers. Neither the flight surgeon nor the RAM curricula incorporate hyperbaric training for chamber operations. Like the undersea medical community, the aeromedical community is a low density/high demand specialty. This potentially lends itself to a situation where demand for chamber qualified technicians and supervisors exceed availability. NAS Oceana flight surgeons cited that aircrew usage of the chambers exceeds that of the diving community. Recognizing the shortfall, many aeromedical personnel have requested additional training and hyperbaric chambers for Naval Air Stations.

Along the lines of DCI-related PEs, aircrew expressed concern that having a second DCS PE requiring decompression chamber treatment would automatically result in a permanent grounding status. Naval Aerospace Medical Institute (NAMI) states this belief is incorrect. The belief is rooted in the diving community's policy of two barometric chamber treatments for DCS episodes resulting in a medically disqualified status. NAMI policy is to review each episode on a case-by-case basis with the intent to return the aircrew to flight status if possible, regardless of treatment required.

Experience and Peer Review

The levels and experience of flight surgeons vary. Prior to arriving at a squadron, a junior flight surgeon undergoes six months of specialty training which includes a thorough flight training curriculum as well as two months of classroom work, resulting in an intern-level basic trained flight surgeon without Fleet experience. A resident-level trained flight surgeon completes a two- to three-year residency program focused on aerospace medicine training after initial flight surgeon training. Once the residency is completed, they are referred to as RAM-trained flight surgeon.

The demands on the Aerospace Medicine community make assignment of RAM-trained flight

surgeons challenging. As of March 2017, the Aerospace Medicine community had 38 RAM-trained specialists to fill 61 RAM-trained positions. Of the 38, 17 are assigned to non-RAM-trained positions like Military Treatment Facilities (MTF) and executive medicine for professional development and career progression, leaving 21 RAM-trained specialists to fill the 61 RAM-trained billets, resulting in a 34 percent fit-fill as opposed to a 62 percent if all the RAM-trained specialists were filling RAM-trained billets. Aerospace Medicine is the least manned of the 27 medical coded specialties where the aggregate level of manning for the Medical Corps (Designator 210X) is 99.7 percent.

To mitigate the RAM-trained personnel gaps, junior flight surgeons are being fleeted up to serve as the mentor and peer review for other more junior flight surgeons. While these intern-level trained flight surgeons have typically a year or more of experience, they lack the breadth and depth of a RAM-trained flight surgeon. Without a RAM-trained flight surgeon in the Wing or MTF, the other option for peer review and mentorship comes from non-aeromedically trained MTF staff. In general this is adequate but the specificity of portions of aerospace medicine (i.e., the evolving concern of DCS in naval aviation) makes this a less than optimal solution.

Research

In the past, to familiarize aircrew with the symptoms and emergency procedures for aviation-based PEs like hypoxia, NAE required all aircrew participate in pressure chamber training. NAE, however, has since discontinued the use of pressure chamber training in light of the chambers exceeding service life and introduced the use of a Reduced Oxygen Breathing Device (ROBD). The ROBD provides aircrew the same hypoxia training benefits as the chamber without the risk of inducing decompression illnesses (DCI), which includes decompression sickness (DCS) or arterial gas embolisms. The downside with ROBD training, however, is it does not cover all the potential situations an aircrew may experience. For example, not all PEs occur due to lack of oxygen; some occur during rapid cycling of cabin pressure.

Naval Survival Training Institute (NSTI) is in the final stages of acquiring the next-generation ROBD (ROBD 2). Like the currently fielded version, the ROBD 2 will be used to train aircrew on the effects of hypoxia. ROBD 2 delivers three main improvements:

- Generates gas mixture internally and not reliant on gas cylinders
- Delivers air to the mask more representative of the delivery of air in the aircraft
- Its portability may provide an opportunity to train aircrew directly in the simulator

MEDICAL OVERVIEW

The leading source of PE aerospace medicine research for the Navy is Naval Medical Research Unit-Dayton (NAMRU-D). NAMRU-D pursues grants/funding to conduct research and even with a continually high NAE ranking for PE research, funding has not been readily available.

On 6 April 2016, the Air Force released their Final Report into their Independent Review of PEs associated with F-15C/Ds.[51] Instead of using an OBOGS system like found in the FA-18 and T-45 aircraft, the Air Force F-15C/D aircraft use Liquid Oxygen System (LOX). Despite the difference, there are correlations to the causes and effects of PEs from the F-15 to the FA-18 and T-45. Hypobaric PEs, in particular hypocapnia/hyperventilation, was one of three inter-related areas the Air Force Independent Review identified as contributing factors to the increased rate of PE incidents. The Air Force concluded hypocapnia is the most likely cause of hypoxia-like symptoms in a hypobaric environment when the pilot was wearing their aircrew flight equipment. Accordingly, the Air Force Review recommended training for hypocapnia and inclusion of hypocapnia into the hypoxia/oxygen system malfunction procedures. Of all the Naval medical personnel interviewed, the significant majority feel hypocapnia is a contributing factor but is not the majority factor involved in Navy's PEs.

Consensus from those interviewed was to install cockpit- and pilot-monitoring systems. Ideally, the monitoring system would cue the aircrew in real-time. At a minimum, the data would be time-synchronized and retrievable after landing, resulting in a more precise diagnosis, treatment and characterization of the PE. Subject matter experts universally cited the following list of parameters to measure:

[51] Refer to Annex D (2) for a copy of Air Force's Review, in part, titled: Air Force F-15C/D Physiology Incident Independent Review Team (IRT) Final Report.

MEDICAL OVERVIEW

- Cockpit Instrumentation:
  - Oxygen Concentration
  - Cabin Pressure
  - Temperature
  - Toxins
  - Audio/Video Monitoring
- Individual Aircrew Instrumentation:
  - Blood Oxygen Concentration
  - Partial Pressure Oxygen/Carbon Dioxide
  - Temperature
  - Mask Positive Pressure
  - Heart Rate
  - Ventilation and Flow Rate
  - Toxins

Also learned from Air Force's Independent Review is their use of Real-Time Air Quality Sensors (RTAQS) to monitor the air quality in the cockpit. The Air Force loaned the Navy two RTAQs.

MEDICAL OVERVIEW

Conclusions

Medical Efforts. Navy Medicine is a critical supporting partner in the effort to reduce PEs. However, the medical community could be providing a more holistic service to the NAE if their approach were unconstrained. The recent establishment of the ACAT aligns key medical community stakeholders to support more accurate identification and characterization of PEs. Additional medical resources are required to better understand PE causes and effects and to develop viable methods for physiological monitoring of the cockpit and aircrew.

Clinical Practice Guidelines. Inaccuracies in the diagnosis and characterization of PEs can negatively affect treatment of the patient. A large contributing factor is the lack of standard guidance and case definitions for aviation-based PEs – namely, a Clinical Practice Guideline. This lack of guidance increases subjectivity by reducing standardization. Compounding the lack of guidance, junior flight surgeons feel ill-equipped to conduct a PE evaluation early in their tenure at the squadron and rely heavily on more seasoned flight surgeons to provide guidance.

Atmospheric Air Quality Measurement. Capturing audio and video of the aircrew while in the cockpit as well as measuring and evaluating the cockpit's atmospheric habitability to include the breathing air provided by OBOGS will provide situational awareness for the aircrew and enable more precise post-event diagnosis, treatment and aid in mechanical problem resolution.

Experience Level at the Wing and MTF. There is a need for resident-level aerospace medicine trained specialists at the Wing and local MTF level. The lack of more experienced aerospace medicine specialists in the Wing and at the local MTF can lead to less accurate diagnosis, treatment and characterization of PEs. Actions are in place to improve the inventory of RAM-trained specialists but the results will have a lag of two to three years.

Aeromedical R&D Resourcing. There is a deficit in investment in Naval Aeromedical Research and Development (R&D). As the Navy continues to build more capable and maneuverable aircraft, research is needed to better understand the physiologic effects of hypoxia, hypocapnia, DCI and repeated Environmental Control System (ECS) pressure swings on the human anatomy/physiology. While PE research has been a top NAE priority for study, few research projects have been funded.

MEDICAL OVERVIEW

Research Partnership. While there is a partnership between the Navy's NAMRU-D and the Air Force's 711th Human Performance Wing (HPW), there are opportunities to expand this cooperation in the areas of engineering and human systems integration. In many ways, the Air Force is ahead of the Navy in terms of flying instrumentation to measure both the cockpit and the aircrew air quality in the wake of the F-22 and F-15C/D studies. There is merit in combining knowledge and lessons learned from the Navy Medicine stakeholders and the Air Force 711th HPW. In addition to the Air Force, other services, inter-agencies (Federal Aviation Administration, National Transportation Safety Board, etc.), other countries and academia are conducting research and should be leveraged.

Hypocapnia Inclusion in NATOPS. As the effects of hypocapnia (hyperventilating) become better understood, incorporation of hypocapnia corrective actions should be incorporated into NATOPS. The symptoms of hypoxia and hypocapnia are similar with only subtle differences. The current NATOPS casualty procedure only accounts for hypoxia and DCS.

Physiological Curriculum Review. A joint review by NSTI and NAMI would ensure alignment between the aerospace medicine and physiology programs and produce a curriculum best suited to educate aircrew on the differences between hypoxia, hypocapnia and DCI as well as instill confidence in the aircrew, promote better clinical outcomes, facilitate a faster return to flying and produce higher quality data.

Enhanced ROBD Training. ROBD training is useful in familiarizing aircrew with the onset of hypoxia and reinforces training for the hypoxia casualty procedure. ROBD 2 provides a more realistic air delivery system in a more transportable unit. Given its transportability, there is an excellent opportunity to incorporate ROBD 2 into the flight simulator curriculum. Incorporation of the ROBD 2 would allow a hypoxic event to be cued at any time during the simulation and would add an additional measure of realism to the simulation process.

UMO Training for Flight Surgeons. As barometric chamber treatments have increased for the aviation community, a gap in training has been exposed. As long as chambers are being assigned to deploying aircraft carriers there will likely be an increased demand signal on the undersea medical community.

NAMI Policy for Multiple Barometric Chamber Treatments. NAMI's waiver policy for PE treatments involving multiple visits to a barometric chamber is not well known to the Fleet.

COMMON ISSUES

Overall, this review revealed numerous facts and circumstances germane to the entirety of the Physiological Episode (PE) problem. This section summarizes these findings and provides associated conclusions in the following areas: unity of effort; communications; change management; data collection management; and life support systems and engineering rigor. These are not necessarily separate and distinct, as several findings overlap. For the purpose of this review, life support system refers to the integration of devices which maintain and monitor the aircrew and cockpit environment. This life support system definition should not be confused with Aviation Life Support Systems (ALSS).[52]

Unity of Effort

PMA-265 and PMA-273 program management and Naval Air Systems Command (NAVAIR) engineers' responsibilities are aligned by specific product lines and functions, with each aircraft program leading separate PE adjudication and mitigation efforts. During interviews, NAVAIR personnel identified varying levels of communication and coordination across these programs, but that no single organization or individual is responsible for addressing the interrelationship between human physiology and machines, recognizing PE mitigation gaps across programs or assessing overall PE mitigation effectiveness. Additionally, they stated that while most aircraft program PE mitigations address the deficiencies in a specific system or component, an integrated approach addressing hardware, software and the human element does not exist.

As PE awareness has grown, Naval Aviation Enterprise groups addressing various aspects of the problem are multiplying. Numerous teams (e.g., FA-18 PET, T-45 PET, FA-18 PE-IPT, T-45 PE-IPT, ACAT) are now supplementing or supplanting pre-existing command alignments or efforts. Most of these groups lack formal duties and responsibilities, a charter or a prescribed structure for their interrelationship with each other. Medical community involvement has mostly been limited to supporting PE event classification and flight surgeon emergency response.

Oxygen generation, cockpit pressurization and human interfaces such as physiological monitoring are managed by separate and distinct programs at NAVAIR, where most individuals acknowledge changes to one life support system component could occur without comprehensive

[52] Naval Aviation commonly uses the term "ALSS" to refer to oxygen equipment, helmets, ejection seats, exposure suits, life vests and other miscellaneous aircrew support items

consideration for the impact to other system components. Additionally, until recently there has been no overarching, high level acquisition requirement for an integrated life support system or equivalent. Examples where these factors influenced life support systems include:

- Replacement of reprocessed OBOGS sieve bed material with a next-generation product was necessitated by a number of factors. However, differences in air temperature, pressure and humidity between FA-18 and T-45 bleed air into OBOGS were not fully evaluated.
- Aircrew alerting PE mitigations have been primarily limited to devices worn by individuals. Engineers stated this "wearable device" approach was driven by a perception that aircraft-mounted equipment would be too costly or require excessive time to field.
- At least one Office of Naval Research funded prototype physiological monitor embedded in aircrew clothing stalled prior to fielding due to a lack of a formal requirement.

The Royal Australian Air Force (RAAF) flies an identical FA-18F as the U.S. Navy and has significant PE concerns with their FA-18F. They also operate a training aircraft similar to the T-45 but the OBOGS in this aircraft is from a different manufacturer and has experienced few PEs.

Although there is a RAAF exchange officer assigned to NAVAIR whose duties are primarily to synchronize FA-18 PE efforts, coordination has not been seamless. For example, an opportunity to test the FA-18 OBOGS breathing air by RAAF chemists was lost when the RAAF could not acquire sieve bed material from the U.S.

When interviewed, the medical community in Pensacola, Fleet FA-18 pilots, IPs at three T-45 training locations and IP Wing-level leadership all questioned NAVSAFECEN's role in the PE efforts. Numerous individuals commented that squadrons were submitting required PE reports, yet received no feedback, recommendations or aggregated analysis from NAVSAFECEN. Those interviewed implied that the NAVSAFECEN should not only have warned the NAE of the observed increase in PE periodicity and severity, but also should have proposed corrective actions.

Risk assessments have been defined and accepted by the NAE, but NAVSAFECEN is not formally tasked to participate in, comment on, or concur with NAVAIR risk assessments. However, NAVSAFECEN has assisted NAE's Aeromedical Crisis Action Team (ACAT) and NAVAIR's Physiological Episode Team (PET).

COMMON ISSUES

Communication

As PE concerns increased, NAVAIR attempted to assure aircrew that mitigations were actively being worked. A series of local squadron briefings known as road shows were developed and executed. However, road show implementation was often suboptimal and tended to further exacerbate aircrew frustration, particularly T-45 aircrew, that their concerns were not being heard or addressed.

During interviews, squadron aircrew expressed dissatisfaction with poor PE engineering communication to the operator at the squadron level. When interviewed, these individuals regularly stated data is provided up the chain of command from the squadrons, but results are rarely pushed back down and shared with the squadron level operators.

Similar to aircrew, flight surgeons indicate they are largely unaware of ongoing PE efforts, are not provided comprehensive PE feedback and are often left to speculate regarding their reports and diagnosis. As a result, many flight surgeons are questioning the value of their PE reports, especially considering the amount of time each report requires. Lacking feedback, many flight surgeons indicated their focus should be on patient evaluation and treatment, not burdensome administrative paper work.

The Air Force experienced a two year period of heightened PE awareness and a six month grounding of all F-22s starting in 2010. Until recently, the NAE did not incorporate F-22 PE lessons in their PE mitigation strategy, including insights provided by the Navy Experimental Diving Unit (NEDU) to the Air Force. PMA-265 and PMA-273 program management and NAVAIR engineers recently included recommendations provided by NASA.[53]

Every segment of the Navy has critical lessons from significant events that have enduring training value. To capture these lessons for future use, several Navy communities develop multi-media training products concurrent with noteworthy safety investigations for long-term fleet use. Aircrew interviews indicated their mishap awareness training is mostly in the form of Safety Investigation Reports (SIRs), emails, bulletin posted messages and one-time road shows. Most acknowledged the NAE could improve the techniques used to inform next-generation aircrew of key PE lessons.

[53] NASA recommendations were a result of congressionally mandated Independent Review Team.

COMMON ISSUES

NAVSAFECEN produces a quarterly Hazard Analysis Report to provide safety trends to the Fleet. In fiscal years (FY) 2016 and 2017, NAVSAFECEN released reports highlighting recent PE trends and recommending NAVAIR accelerate engineering solutions. Additionally, in December 2016, NAVSAFCEN recommended: "To mitigate physiological episodes, NAVAIR on-board oxygen generating system (OBOGS) enhancements must be accelerated and improvements to the T-45 warning system should be developed and implemented. Continued proactive Aeromedical Safety Officer (AMSO) education for aircrew is essential. Maintenance training and compliance with required test kits/procedures for maintaining OBOGS and Environmental Control System (ECS) should be a top priority."[54]

Change Management

When interviewed, PMA-265 and PMA-273 program management and NAVAIR engineers discussed a PE mitigation path with three key themes: aircrew alerting, aircrew protection and aircraft improvement. However, each provided a different vision of optimized aircrew alerting and protection in the near- or mid-term. For example, PMA-273 intended to incorporate the next-generation oxygen sensor (CRU-123) and its breathing air pressure alarm in the T-45. PMA-265 does not intend to field the CRU-123 on the FA-18. No individual interviewed indicated Human Systems Integration (HSI) was a dedicated focus area for their office or program.

Numerous personnel provided an opinion that their organization is under considerable stress to resolve PEs, with each event creating pressure to change or do something. For example, the NAE is procuring hypobaric watches with pressure alerting functionality in an attempt to provide aircrew concerned with DCS an additional cockpit pressure alert. However, these watches have not undergone NAVAIR testing for accuracy and dynamic range for this application. NAVAIR engineers expressed concern these watches could provide a false sense of security.

Interviews indicate NAE training, procedure and maintenance update practices are well established and generally trusted by aircrew and maintainers, but some interviews indicated seams may exist.

[54] Refer to Annex G, Naval Safety Center.

COMMON ISSUES

Data Collection and Management

Many entities are engaged in PE data collection, analysis and trending. However, most participating in data management acknowledge they are focusing on outliers and anomalies due to a lack of baselines for comparison, an understanding of "normal" parameters and limited testing methodologies. Examples where engineers cited data shortfalls as a factor in comprehensive aircraft statistical analysis include:

- FA-18 and T-45 cockpits are not equipped with permanently installed cabin pressure recording devices. Until the recent addition of aircrew worn Slam Stick pressure recording devices, the ability to correlate DCS events with actual data has been impossible.[55]

- Clean, dry air is used in lieu of jet engine bleed air during OBOGS testing at NAVAIR. Due to design limitations, input air to OBOGS on the FA-18 and T-45 is not necessarily clean or dry. Engineers acknowledge the difference between OBOGS input aboard aircraft and in their test beds limits the ability to draw conclusions from laboratory testing.

- Aircrew breathing air oxygen levels have not been monitored by a recording device. To date, engineers assume breathing air oxygen concentration is adequate as long as an oxygen alarm light provided by the CRU-99 is not observed.

- When a PE event occurs, the subject aircraft is impounded; OBOGS and other select components are removed, sealed and shipped to NAVAIR; and laboratory analysis of residual gas from the disconnected devices is conducted. Mass spectrometry of this residual gas has identified contaminants in OBOGS input and output. However, this technique lacks the ability to identify the time contaminants passed or their concentration.

- Aircrew sorbent tubes can't detect "small molecule" contaminants (e.g., carbon monoxide or nitric oxide) known or suspected to exist in aircrew breathing air.[56]

PMA-265 and PMA-273 program management and NAVAIR engineers indicated the primary NAE metrics used to evaluate PE corrective measure success are the number of PEs; rate of PEs over a selected period; or number of PEs in a certain category. They also expressed difficulty evaluating PE

[55] Refer to Annex I (1) for Slam Stick description
[56] Refer to Annex I (2) for Sorbent Tube description

mitigation success, as PE reporting relies almost exclusively on aircrew self-diagnosis and self-reporting. Examples where aircrew self-diagnosis and self-reporting influence the accuracy of PE mitigation analysis include:

- One pilot reported cockpit pressure fluctuations to the flight surgeon, but he did not recall experiencing any DCS symptoms and did not report a PE. As he subsequently evaluated developing symptoms, he was conflicted as to whether he was suffering from DCS or non-flight related factors (e.g., tired from limited sleep). The pilot subsequently developed significant DCS symptoms, reported the PE and eventually required emergency hyperbaric chamber treatment.
- One pilot reported no unusual conditions during post-flight questioning. However, a cockpit video during a post-flight critique provided evidence of an in-flight PE lasting several minutes. The pilot had no recollection of this event.

There is no specific requirement to record audio/video during flight, nor is there any audio/video recording functionality aboard most T-45s. The FA-18 can record audio/video with the aircrew's heads up display (HUD), but recordings are limited by storage capacity in older systems and are generally over-written shortly after post-flight debrief. Due to a shortage of cockpit video and audio recordings, PE adjudication processes have been limited in their ability to assess aircrew behavioral factors.

PE reporting is conducted by aircrew, aircraft maintainers or medical personnel. With PE awareness and concern mounting, in 2010 the NAE sought to improve data usefulness by implementing a revised reporting structure. The NAE supplemented the hazard report (HAZREP) submitted to NAVSAFECEN for all PEs with a multi-tiered approach.[57] If required, HAZREPs (submitted via NAVSAFECEN Web Enabled Safety System (WESS)) and PE Reports (Parts A, B and C) (submitted via email) are added to the numerous reports the NAE requires after a normal flight. These reports could include Naval Aircraft Flight Record (NAVFLIR), Optimized Organizational Maintenance Activity (OOMA), Aviation Safety Awareness Program (ASAP), Sierra Hotel Advanced Readiness Program (SHARP), Bird Aircraft Strike Hazard (BASH) and potentially one or more local squadron requirements.

[57] PE reports are discussed in Annex D (3) Naval Reporting Requirements

COMMON ISSUES

PMA-265 and PMA-273 program management are currently responsible for PE adjudication for events in the FA-18 and T-45, respectively. Currently, neither PE adjudication process applies a standardized methodology to analyze PE categories, including human factors. Instead, system experts across a broad range of disciplines are gathered after preliminary investigations to assign PEs into mutually agreed categories based upon general consensus. PE adjudication typically takes more than six months to complete. PE adjudication results are widely distributed among NAE leadership, but there is no mechanism for direct feedback to aircrew, maintainers or medical personnel.

The NAE utilizes several databases with varying degrees of automation, access and distribution to capture and record when aircraft maintenance has been completed. Logistics managers and engineers expressed a lack of confidence that existing data is sufficiently accurate to determine component replacement periodicity as the NAE moves past its traditional "fly to fail" component replacement practice.

Life Support Systems and Engineering Rigor

The individual components of NAE aircraft, including OBOGS and ECS, are built and tested to prescribed standards. However, PMA-265 and PMA-273 program management and NAVAIR engineers indicated standards and testing for the integrated life support system aboard these aircraft is limited. They also indicated the lack of integrated standards may have created instances where systems operating per prescribed specifications individually may not be adequately supporting the integrated life support system.

By approximately 2009, the original OBOGS sieve bed material was no longer supported by the manufacturer. With no other option, the manufacturer began "re-baking" sieve bed material during routine OBOGS unit refurbishment. NAVAIR eventually ended the "re-baking" practice and procured a new type of OBOGS sieve bed material which included a new carbon monoxide removal catalyst. Because the filtration properties of the old material were thought to be reasonably well known through years of service and the new sieve bed material was viewed as an upgrade, the ability of the new sieve bed to remove, pass or periodically expel contaminants into breathing air was limited to a carbon monoxide testing on FA-18.

The systems which supply OBOGS inlet air vary greatly depending on aircraft type, ranging from a relatively simple arrangement on T-45 to a complex system of valves, regulators and heat

exchangers on FA-18. To varying degrees, these systems have been modified as lessons are learned and additional functionality is added to aircraft. For example, the FA-18 ECS has been modified to support upgraded avionics and electronics. While these modifications were often deemed necessary to address specific ECS performance issues, engineers indicated that in aggregate this incremental change approach may have had unintended consequences impacting the integrated aircraft life support system.

Due to the potential of introducing combustion by-products and ingested contaminants into the aircraft engine's bleed air, input quality to OBOGS and cockpits can vary. In interviews, engineers stated that as a result of maintenance and operations, it is likely fuel, hydraulic fluid, lubricants, bearing materials, coolants and other substances are periodically introduced to OBOGS inlet. However, testing to quantify and understand composition of the OBOGS input under different environmental conditions has been limited to one recent series of tests. In this analysis, FA-18 engine bleed air sampled with RAAF test equipment indicated a broad spectrum of contaminants, albeit at relatively low levels. Observations of aircraft hangar maintenance and cleanliness standards confirmed opportunities exist to potentially introduce foreign material and contaminants.

After a recent PE, local aircraft maintenance personnel separated the aircrew's breathing air tube from several CRU-103 breathing gas regulators. Visual inspection revealed soot and "white flakey material" in the regulators' breathing air filter screens. Further inspection by this site found 6 of 71 regulators contained similar material. NAVAIR analysis confirmed presence of soot. The "white flakey material" was determined to be natural fiber material and aluminum particles, possibly from system connector friction during regulator assembly. Swab analysis also identified fluorinated grease. Fluorinated grease is used in the regulator and on some fittings upstream of the regulator. Although its presence is expected, quantities appeared excessive. There is no periodic inspection requirement for these screens.[58]

When interviewed, NAE engineers and maintenance personnel stated that as aircraft age it becomes increasingly difficult to identify problems in complex systems such as the FA-18's ECS, with multiple component failures or incorrect replacement parts often frustrating troubleshooting techniques. They also stated manufacturer expertise can aid aging aircraft troubleshooting, but vendor knowledge usually erodes when the aircraft production line is complete unless a contractual

[58] Refer to Annex I.

relationship is retained. For example, until a recent Systems Engineering and Program Management (SEPM) contract was established with Boeing, the T-45 program had limited connectivity with the aircraft's manufacturer.

T-45 and FA-18 test equipment lack the ability to simulate some flight conditions, limiting the ability to troubleshoot dynamic systems such as ECS and bleed air. For example, test equipment used to evaluate cockpit pressurization systems only uses sea level pressure to replicate ambient conditions outside the aircraft.

Equipment designed to protect aircrew experiencing high G forces during maneuvers (e.g., Anti-G suit) is an important interface between aircrew and the aircraft's ECS. Despite limited testing and analysis, many within the NAE dismissed this equipment and its interface with the ECS as a potential factor in PEs.

The Air Force experienced a period of heightened PE awareness that grounded all F-22s in 2010. In the early stages of F-22 PE corrective actions, efforts were initially biased towards contamination as the singular cause. Factors deemed unlikely by system experts were dismissed. When the Air Force adopted a methodical root cause and corrective action (RCCA) plan that included all previously dismissed causes, PE resolution improved dramatically. During 2012 testimony to the House Armed Services Committee, senior Air Force reported the F-22 PE problem had essentially been solved in just two years.

NAVAIR recently adopted a RCCA approach to methodically identify all potential PE causes, develop fault trees and systematically eliminate factors found not to be contributory. To execute this methodology, PMA-265 established a joint military – Boeing PE integrated product team (PE-IPT) where both entities have an equal voice in potential root cause resolution. PMA-273 is establishing a similar PE-IPT, but functional details have yet to be decided.

Although PEs can occur without real-time aircrew awareness, there are no installed systems to detect these occurrences or take action to mitigate their risk aboard T-45 or FA-18. Other fighter aircraft possess this technology. For example, the F-22 employs an Auto Ground Collision Avoidance System to detect a minimum acceptable altitude and direct aircraft recovery without aircrew action.

COMMON ISSUES

A consistent theme provided by PMA-265 and PMA-273 program managers and NAVAIR engineers was the lack of skilled, experienced personnel available to resolve PE issues and the problems this lack of a deep "bench" was creating at NAVAIR.

COMMON ISSUES

Conclusions

General

Driving PEs to Zero. Finding a solution to the high performance jet aircraft PE issue is an elusive problem that is not unique to the U.S. Navy. In addition to the two broad PE aircraft malfunction categories currently being addressed by the NAE (breathing air and cockpit pressurization), PEs can be caused by numerous human factors such as fatigue, dehydration, diet, nutrition, anxiety, panic, hyperventilation and procedural error. The complexity of the human-machine interface and unforgiving environment where aircrew and tactical aircraft operate will continue to result in PEs when systems do not operate as intended or human physiology is a factor. The solution will require a multifaceted, systematic NAE approach that should be able to almost completely eliminate PEs.

Unconstrained Resources. The NAE and Naval leadership view PEs as the number one safety priority and are taking an "unconstrained resource" approach to finding a solution. CNAF's direction to apply an unconstrained resources approach has been clearly communicated and is very widely understood within NAE. Despite this, the Navy's approach to problem solving is usually resource constrained and this culture prevents some from fully embracing unconstrained issue resolution solutions.

Unity of Effort

Resolution Authority. The occurrence of physiological episodes is not new; however, solving the complex multi-variable PE problem requires more than a well-intended collaborative effort. When a complex problem exceeds the ability of the current organizational model, the result will be an ineffective approach to the solution. Swarming the problem with expertise must simultaneously occur with the designation of a singularly focused organization that has both the responsibility for problem resolution as well as the authority to drive the prosecution of the problem.

Resolution Coordination. Throughout this review, it became apparent that every organization and individual involved in issues related to FA-18 and T-45 ECS and OBOGS systems were fully invested in trying to resolve the issues. But, there appears to be a break down in lateral communication amongst the various technical and medical organizations that would allow for a synergistic solution.

NAVSAFECEN. Commander, NAVSAFECEN and his staff, specifically the platform and medical analysts, are fully engaged and have identified the increasing PE incidents since 2015. For example, its proactive involvement addressing PEs with the Aeromedical Crisis Action Team (ACAT) and the Physiological Episode Team (PET) is noteworthy and should continue. However, despite being charged as the authoritative mishap and hazard data source for the Navy, NAVSAFECEN is generally not influencing risk assessments and lacks the organizational structure and NAE connectivity to drive PE decision making.

Communication

Communication Effectiveness. The lack of a comprehensive, integrated communications approach particularly down to the aircrew level has eroded aircrew confidence in PE mitigation efforts. Interviews with aircrew and their Wing leadership revealed frustration with poor communication between the aviation technical community, aircrew at the squadron level and the medical community. It has been expressed multiple times that data is provided up the chain of command from the squadrons and flight surgeons, but results are rarely pushed back down.

Information Sharing. Aircrew and squadron maintenance personnel often lack an understanding of the technical solutions being worked to resolve PE events. As PE awareness increased, PMA-265 and PMA-273 program management decided periodic 'road shows' with system expert briefs would be the best means to share information regarding ongoing efforts. In interviews, IPs, squadron leadership and Wing Commodores indicated these road shows generally provided inadequate PE assurances to aircrew. CNATRA attempted to mitigate road show shortfalls by sending a group of IPs to NAVAIR to witness and discuss the on-going efforts with the engineers. This provided the IPs the opportunity to see first-hand the work in progress and also fostered engineer-to-operator dialogue.

Flight surgeon trust and confidence in NAE PE efforts is also eroding due to lack of information and feedback from PE adjudications, NAMRU-D research and NAVAIR physiological monitoring developments.

Non-Traditional Support. In its attempt to resolve PE issues, the NAE inconsistently opened its aperture to potential PE solutions from "non-traditional" sources. The NAE lost at least three opportunities to more comprehensively address PE as a result of this approach. Specifically:

- NAVAIR did not seamlessly integrate RAAF into PE mitigation efforts.
- NAVAIR did not conduct regular, periodic exchanges with other organizations fielding life support systems for individuals performing tasks in highly demanding environments (e.g., NASA, USAF, NEDU). Additionally, coordination with these activities has been mostly episodic and engineering centric.
- NAE has not held a widely publicized PE industry day to field ideas from businesses throughout the country, academia and research organizations. Had this type of event occurred, insights into PE solutions might have been gained while simultaneously providing assurance to aircrew that the NAE is leaving no stone unturned.

NAVSAFECEN. While the information provided in the NAVSAFECEN Hazards Analysis Reports is useful and accurate, a disconnect remains between what Fleet aircrew expect of NAVSAFECEN and what it is actually capable of providing. While NAVSAFECEN can conduct limited trend analysis and some basic systems analysis, it is not equipped with the personnel or experience to make specific engineering solution recommendations.

Fleet Mishap Training. Major Navy incidents usually have one or two "banner" messages each generation should pass to the next. In general, the NAE lacks a comprehensive collection of multi-media products that are prescribed to support specific safety learning objectives.

Change Management

Human Systems Integration (HSI). With several near- and mid-term aircrew protection and warning technologies potentially ready for fielding, the NAE has not stepped back and considered how these should be fielded in an integrated, optimized manner. Without due consideration for HSI, the desired benefits from these technologies may not be fully realized. For example, HSI could resolve whether aircraft with the solid state oxygen monitor should employ a combination of sensors to illuminate the T-45 oxygen warning light or use the temperature, oxygen concentration and oxygen pressure sensors to provide separate and distinct alerts. Contributing, there is no organization with a focus on improved human performance and human systems integration

Change Follow Through. As PE corrective measures are instituted, it will be critical for the NAE to ensure change occurs exactly as intended or effectiveness will suffer. While confidence in

longstanding NAE change management processes is high among aircrew, there was some concern seams, which could impact PE corrective measure effectiveness, exist.

Data Collection and Management

Long-Term PE Analysis. In conjunction with increased attention to PEs throughout the NAE, the 2010 multi-tiered PE reporting format likely shifted aircrew towards a more forthcoming culture and increased reporting. These changes impede comparison of pre- and post-2010 PE reports, as earlier data is probably suffering from under-reporting. Also impeding PE analysis is the fact NAVSAFECEN HAZREPs and PE Reports (Parts A, B and C) are maintained on separate, non-interoperable databases.

Instrumented PE Data. The NAE generally does not possess a comprehensive plan to manage instrumented PE data. Although devices such as sorbent tubes and Slam Sticks have been fielded, a holistic approach to sampling points, parameters to be monitored, optimized instrumentation, sample frequency, analysis methodology, data sharing and archiving is not consistently employed.

PE Baseline. Based on its long-standing self-diagnosis and self-reporting paradigm and lack of recorded flight data, it is unlikely the NAE accurately understands its PE baseline or the contribution of human factors and biases. Moreover, it is not reasonable to expect or rely upon the self-diagnosis of cognitively impaired aircrew to accurately identify a PE occurrence.

Multi-Media Recording. PE analysis is significantly impacted by the lack of aircrew physiological data and audio/video from flights. Despite the fact unreported PEs have occurred, the NAE has not institutionalized audio/video requirements to detect PEs occurring to aircrews with impaired cognitive capacity.

PE Reporting Factors. Until recent NAE efforts emphasizing the importance of PE reporting, it was possible the significant quantity and scope of post-flight reporting impacted the number of instances aircrew chose to submit PE Hazard Reports and PE Reports (Parts A, B and C). It is also possible manning can influence reporting. For example, the addition of an Aero-Medical Safety Officer at the TW-1/Meridian training site after a six year gap appears to correlate with a local increase in reported PEs.

COMMON ISSUES

PE Adjudication. Current PE adjudication has numerous shortfalls. These include:

- The process is neither standardized nor formalized.
- Event categorization is susceptible to pre-existing biases of the experts conducting adjudication.
- The "human factors" category can mask actual causes such as behavioral or organizational issues, or misidentify outcomes (e.g., loss of cognitive capacity) as causes.
- The process is too lengthy, likely due to limited bandwidth by experts conducting adjudications and supporting investigations.
- Feedback is incomplete, as no enduring process exists to provide adjudications to aircrew, maintainers, or medical personnel.

Component Replacement Timing. Without improved material database accuracy, it's likely the NAE will struggle to identify components' useful life limits during its shift from a "fly to fail" to timed replacements.

Life Support Systems and Engineering Rigor

System Shortfalls. The combination of OBOGS, bleed air and ECS design; limited physiologic monitoring; aging aircraft systems; and inadequate maintenance practices does not consistently provide adequate life support to aircrew.

PE Mitigations. Automatic or semi-automatic safety features should be used to mitigate PEs, particularly those occurring with aircrew suffering cognitive impairment.

PE Resolution Approach. PE complexity indicates disciplined, methodical causal analysis will be required to achieve PE resolution. However, NAVAIR's approach to date has been reactive, engineering centric and lacks a systematic process to identify potential root causes, implement corrective actions and assess results. Contributing, the lack of a systematic approach to PE resolution has led to quick dismissal of potential root causes without full vetting.

ECS Sustainment. As aircraft age, troubleshooting can be difficult, particularly for the complex FA-18 ECS.

Specifications and Standards. Naval aircrew and divers perform physically stressful missions in challenging environments that require high quality breathing air. Yet, the performance specifications, preventive maintenance (e.g., inspections and cleaning) and corrective maintenance for

these communities' breathing air systems vary, with NAE practices generally more vulnerable to contaminant introduction.

Test Equipment. NAE test equipment generally lacks the ability to simulate a full flight profile and support evaluation of aircraft system performance under dynamic conditions. For example, test equipment limitations have been shown to impair a maintenance crew's ability to identify and repair a failed ECS component that could induce a DCS-related PE.

Manufacturer Connectivity. NAVAIR engineers and aircraft maintainers often struggle to solve complex failures aboard aging aircraft without vendor expertise. While there is a cost associated with retaining manufacturer design knowledge, experience indicates its value cannot be overstated.

Depth of Bench. NAVAIR lacks the sufficient, sustainable workforce in key specialties to ensure PE resolution and execute their other responsibilities. The ability of engineers and managers to focus on core responsibilities such as root cause analysis is limited by the number of staff experts and the persistent administrative burdens these individuals manage.

RECOMMENDATIONS

FA-18 Recommendations

1. **Execute depot-level deep dive inspection of the entire FA-18 ECS and OBOGS, to include all associated sub-components and piping.**

a. This effort would be in addition to the current ECS reset initiative. The intent being to conduct a comprehensive and holistic "end to end" inspection of the entire ECS and OBOGS beyond what the squadron maintenance level is trained to accomplish.

2. **Replace the cockpit altimeter.** Install a digital display cockpit altimeter that is more precise and easier for aircrew to monitor during flight. This cockpit altimeter should also provide an audible and visual alert to inform aircrew whenever cabin pressure fluctuations and the cabin pressurization schedule are not within NATOPS limits. Additionally add the ability to record cabin pressure during flight with a playback feature to provide aircrew the ability to review during post-flight debrief.

T-45 Recommendations

1. **Accelerate the technical solutions to improve the T-45 OBOGS.** This recommendation includes leveraging commercial industry expertise to augment NAVAIR engineers on a full-time basis until a permanent solution is determined and implemented.

2. **Develop a comprehensive return to flight plan for T-45.** CNAF should develop a comprehensive T-45 return to flight roadmap that includes, key milestones and pre-conditions and detailed SSRAs and required risk mitigation efforts for each phase. The plan should include the items similar to the following illustrative elements:

a. Phase I: T-45 resume normal flight operations:
   i. Contamination alert mechanism in place / ALSS in line air-filter
   ii. Conduct T-45 complete air breathing system hygiene and integrity check on all aircraft
b. Phase II: Integrate key system upgrades / modifications
   i. Incorporate a water separator into the T-45 OBOGS bleed air line prior to the concentrator
   ii. Reconstitute previous bleed air shutoff valve configuration; or leverage new/existing bleed air shutoff valves
   iii. Deliver and field CRU-123 monitor system
   iv. Explore advanced filtering options to filter non-hydrocarbon contaminants

c. Phase III: Long term analysis and sustainment

i. Continue T-45 air quality monitoring efforts, lab analysis and toxicology screening

ii. Develop, fund and field advanced aircrew physiological monitoring systems

d. Phase IV: Assessment of the Return to Flight plan

3. **CNAF, in conjunction with Chief of Naval Personnel, conduct a comprehensive review of all aspects of aircrew production.** This review should include:

a. A defined nominal sustained T-45 steady state and surge capacity. This should be based on resources available, not Fleet demand.

b. Trades between primary (T-6), advanced (T-45), the Fleet Replacement Squadron (FRS) and the Fleet.

c. Waivers of syllabus flights for high performing students.

d. Personnel tempo throughout CNATRA and FRS to ensure the authorization and apportionment of IPs is correct.

e. Development of a plan for the students, whose aviation skills are currently atrophying, to maintain proficiency in the short term.

4. **CNATRA schedule a PERS-43 visit to the Training Wings.** Discuss career implications of the ongoing operational pause with IPs and students. Briefs should include:

a. Student concerns with delayed initiation of the Minimum Service Requirement (MSR) commitment (8 years from winging date).

b. Student training delay effect on the Aviation Department Head Retention Bonus.

c. Student career timing concerns relative to peers.

d. Student timing and flow to Aviation Department Head.

e. Student impact on post-second sea tour education and opportunities that require more time (e.g., Test Pilot, Blue Angel).

f. Instructor return to Fleet implications.

5. **For the next CNATRA rotation, consider assignment of a Naval Aviation Flag Officer with increased seniority and experience.** Increased experience and seniority will help in the evaluation and assessment of the near term implementation/mitigation for T45 related PEs and the T45 return to flight assessment. This recommendation is for the next rotation only.

6. **Review the requirements for, and source as a full-time position, the T-45 Class Desk.** This recommendation should include funding and resourcing a full-time employee for the T-45 Class Desk; reviewing the T-45 Class Desk mission, role and responsibilities, to include enhancing communication and alignment with Fleet operator concerns.

7. **Embed a rotating T-45 IP in NAVAIR to function as liaison officer.**

a. The liaison officer will foster better two-way dialogue; the rotating officer will allow all Training Wings to provide periodic feedback while not adversely impacting flight schedules or rotations.

Medical Recommendations

1. **BUMED (NAMI) establish a solid case definition of PEs and develop Clinical Practice Guidelines (CPG) for the treatment and follow-up for PEs.** The following is also recommended:

a. Develop a community specific short course at the end of the flight surgeon curriculum to better equip new flight surgeons to conduct PE evaluations.

2. **BUMED accelerate PE research.** The following is also recommended:

a. Expedite fielding ROBD 2 to NSTI and Fleet concentration areas. Evaluate incorporating ROBD 2 into the flight simulator curriculum.

b. Conduct research on the physiological effects of cyclic and rapidly changing pressure in an aviation environment.

c. Conduct an aerospace medicine review of other service and inter-agency PE research efforts.

d. In collaboration with NAVAIR, evaluate administrative assignment of NAVAIR engineer(s) to NAMRU-D to contribute to Navy research and coordinated research with the Air Force's 711th HPW.

e. Evaluate the concept of a Human Performance Fleet Command similar to the Air Force 711th HPW

3. **BUMED alleviate the Aeromedical Specialist shortfall.** The following is also recommended:

a. Review placement and career progression metrics for operationally focused medical personnel.

b. Evaluate aerospace medical specialist training and protocols to include barometric pressure chamber diagnosis, treatment and chamber operation.

RECOMMENDATIONS

4. **BUMED (NAMI/NSTI) conduct a collaborative review and update of the physiology curriculum to address emerging and evolving PE concepts.** The following is also recommended:

   a. Review and evaluate ROBD requirement training and periodicity.

5. **BUMED/NAVAIR evaluate a change to NATOPS to augment the emergency procedures to incorporate hypocapnia into the hypoxia and DCS procedure.** The following is also recommended.

   a. In conjunction with a change, update the associated physiology training given by NSTI and the ASTCs.

6. **BUMED/NAVSAFECEN consider classification of a PE event as a Class D Mishap using the diagnosis vice the treatment.**

7. **CNAF (BUMED support) send a naval message to the Fleet regarding NAMI's case-by-case position on multiple barometric chamber treatments.**

Common Issue Recommendations

1. **Establish a single, dedicated organization to lead the Naval efforts to resolve the physiological episodes.** The following is also recommended:

   a. This organization should be led by a Naval Aviator Flag/General Officer.

   b. There should be an organizational charter to clearly define duties and responsibilities.

   c. Include all PE stakeholders in the organizational charter, including allies.

   d. Formalize subordinate organizations (e.g., PE-IPT, ACAT).

   e. The organization should be temporary – no more than 12-24 months.

2. **Continue ongoing RCCA efforts until root cause fault trees are fully adjudicated.** The following is also recommended:

   a. Coordinate under singular Naval Aviator Flag/General Officer PE leadership.

   b. Employ separate root cause fault trees for each aircraft.

   c. Incorporate all previously dismissed potential root causes.

   d. Ensure PE-IPT is provided time, bandwidth and skills to properly execute RCCA.

   e. Develop a more robust, deep pool of subject matter expertise at NAVAIR.

   f. Disestablish PE-IPTs when root cause fault tree corrective actions are complete.

RECOMMENDATIONS

3. **Re-design aircraft life support systems as required to meet OBOGS input specifications.** The following is also recommended:

a. Incorporate water separation prior to OBOGS input.

b. Ensure inlet temperature, pressure and flow parameters meet OBOGS requirements.

c. Incorporate filtration or other means to ensure air quality meets OBOGS requirements.

d. Provide margin for equipment and material deterioration (e.g., valve wear, sieve bed age, filter clogging).

4. **Develop a comprehensive NAE PE communications strategy.** The following is also recommended:

a. Assign communication strategy responsibility to the NAE PE singular lead.

b. Provide continuous, accurate information both within and outside the NAE and aeromedical community.

c. Account for social media, including leadership training on social media's potential impact.

5. **Consider PE mitigation technologies for instances where aircrew are cognitively impaired.** Technologies could include but are not limited to:

a. An automatic ground collision avoidance system.

b. Automatic or semi-automatic initiation of emergency oxygen.

c. Physiologic monitoring and alerting.

6. **Standardize PE adjudication.** The following is also recommended:

a. Formalize PE adjudication, including required personnel, process, timelines, etc.

b. Specify PE categorization criteria and apply a single standard to all aircraft.

c. Re-examine human factors category to ensure other causes are not masked by this categorization.

d. Specify PE adjudication timeline and provide resources to ensure adherence.

e. Institutionalize a timely feedback mechanism to provide PE adjudication to aircrew, maintainers and aeromedical personnel.

7. **Develop comprehensive PE-resolution instrumented data plans including multi-media in-flight audio/video recording.** The following is also recommended:

a. Identify desired parameters to be monitored (e.g., cockpit pressure, OBOGS inlet temp).

b. Establish scope of monitoring (e.g., number of aircraft, percentage of flights).

c. Identify optimal data collection (e.g., aircrew worn sensors, aircraft mounted equipment) and transfer functionality (e.g., wireless transmission, shipped sensors).

d. Identify methods to establish parameter baselines.

e. Identify long-term data analysis, sharing and archiving requirements.

f. Establish periodic data analysis reporting requirements.

g. Establish requirements for audio/video aircrew monitoring with existing aircraft equipment.

h. Investigate, acquire and implement new equipment to improve aircrew audio/video recording functionality.

8. **Establish an integrated life support system program at NAVAIR.** The following is also recommended:

a. As a minimum, incorporate oxygen generation and connecting systems, cabin pressurization and physiological monitoring.

9. **Review adequacy of test and evaluation infrastructure.** The following is also recommended:

a. Develop methods to simulate flight conditions, particularly for ECS-related test equipment.

b. Create an OBOGS test methodology that more closely replicates actual system operating conditions and vulnerabilities.

10. **Conduct a comprehensive NAVSAFECEN review in regards to PEs.** The following is also recommended:

a. Include role(s), command relationships and mechanisms for applying conclusions from data analysis.

b. Assess feedback mechanisms between NAVSAFECEN and aircrew providing data via Aviation Hazard Reports, Safety Investigation Reports, or PE reporting forms.

11. **CNAF conduct a well-publicized industry day, openly soliciting PE resolution ideas and recommendations.** The following is also recommended:

a. Ensure this industry day receives appropriate media coverage before, during and after execution.

b. Include entities outside long-term or sole-source affiliates.

c. In addition to businesses, invite academia, medical and research organizations.

RECOMMENDATIONS

12. **NAVAIR institute periodic exchanges with other organizations managing life support systems required for highly demanding environments.** The following is also recommended:

a. At a minimum, include NASA, Air Force and NAVSEA.

b. Include both engineering, physiological and aeromedical experts.

c. Until mature and reliable technology is fielded, include physiological monitoring efforts.

13. **Establish or retain formal connectivity with manufacturer expertise after aircraft production ends.** The following is also recommended:

a. Sustain recent PMA-273 SEPM or equivalent.

b. Establish and fund PMA-265 SEPM or equivalent when FA-18 production ceases.

14. **Review life support system specifications and maintenance practices.** The following is also recommended:

a. Ensure aircrew breathing air system cleanliness and foreign material exclusion practices are comparable with Navy diver standards.

b. Coordinate with NAVSEA to compare and contrast life support specifications and maintenance practices.

c. Include both corrective and preventive practices (e.g., periodic inspections, cleaning).

d. NAVAIR validate the quality of life support system replacement parts.

15. **Optimize aircrew PE alerting and protection for each aircraft.** The following is also recommended:

a. Utilize HSI or equivalent expertise.

b. Determine which monitored parameters should have indications, alarms, or both.

c. Determine optimal alarm logic (e.g., "and", "or").

d. Determine ideal location for monitored parameters (e.g., aircrew worn, aircraft mounted, integral to HUD).

e. To the maximum extent feasible, provide leading indicators of breathing air problems.

16. **Streamline post-flight reporting and database management.** The following is also recommended:

a. To the maximum extent possible, consolidate existing post-flight reports.

b. Leverage other Navy community efforts to minimize post-flight reporting workload.

c. Leverage other Navy community efforts to maximize awareness of causal factors in post-flight reporting, including human factors.

d. Assess NAVSAFECEN's role in PE reporting.

e. To the maximum extent possible, centralize PE databases. Where centralization is not possible, develop means to improve database interoperability.

17. **CNAF develop multi-media training products for significant PE events.** The following is also recommended:

a. Develop products concurrently with PE investigations/adjudications.

b. Institute requirements for periodic Fleet training on these products.

18. **Standardized ORM Process.** CNAF develop a standardized ORM pre-flight briefing sheet for each Type Model Series aircraft.

a. ORM models that addresses multiple simultaneous risk factors and provides an approval hierarch should risk levels be elevated.

19. **Standardized Risk Assessment Review Process.** Standardize the periodicity and membership of the risk assessment process for NAE.

20. **Fully implement an unconstrained resource approach.** Despite the unconstrained messaging provided by NAE leadership, there is an element of organizational resistance to viewing the problem through an unconstrained lens. Thus, continued reinforcement will be required. For example, Navy medicine and the Office of Naval Research will need to adopt the same unconstrained approach to affect PE mitigation. Though many of the recommendations below are addressed in other sections, this consolidated list provides this report's prioritization of specific actions.

a. **Immediate**

i. Resource (personnel and funding) a single organization to lead the Naval efforts to resolve PEs.

ii. Resource accelerated technical improvements to T-45 OBOGS bleed air supply, to include leveraging commercial industry expertise to augment NAVAIR engineers on a full-time basis.

iii. Resource full-time administrative support personnel to assist the PET PE adjudication effort to improve analysis timeliness and feedback.

iv. Resource desired ROBD capacity.

v. Sustain recent PMA-273 SEPM or equivalent.

vi. Resource T-45 Class Desk manning.

b. **Near-term (1-6 months)**

i. Resource a depot level "deep dive" inspection of the FA-18 ECS, to include all associated sub-components, piping, wiring, etc.

ii. Fund equipment and personnel to complete comprehensive contaminant analysis.

iii. Resource research on the physiological effects of rapid, cyclic pressure changes on aircrew.

iv. Develop and resource a community-specific short course at the end of the flight surgeon curriculum to improve flight surgeons PE evaluations.

v. Expedite fielding of ROBD 2 to NSTI and fleet concentration areas.

c. **Mid-term (6-12 months)**

i. Establish and resource an integrated life support system program at NAVAIR.

ii. Resource cabin altimeter technology that alerts aircrew to pressure deviations from designed schedules, records pressure throughout the fight, and supports post-flight analysis.

iii. Resource resident-level aerospace medicine trained specialists at Wings and local MTFs.

iv. Develop and resource ECS and OBOGS test and evaluation infrastructure which more accurately reflects flight conditions.

v. Resource aerospace medical specialist training and protocols, including barometric pressure chamber diagnosis, treatment and chamber operation.

vi. Provide an experienced NAVAIR engineer(s) to improve NAMRU-D and Air Force 711th HPW research coordination.

vii. Create multi-media training products for significant PE mishap events and commence periodic Fleet training.

d. **Long-term (12 months and beyond)**

i. Develop and implement an aircrew physiological monitoring and alerting system.

ii. Develop and implement an aircrew breathing air monitoring and alerting system integral to the aircraft.

iii. Resource incorporation of ROBD 2 into flight simulator curriculum.

iv. Develop and implement an automatic ground collision avoidance system or equivalent.

v. Develop and implement an automatic or semi-automatic aircrew emergency oxygen initiation system.

vi. Establish and fund PMA-265 SEPM or equivalent when FA-18 production ceases.