AVIATION WEEK & SPACE TECHNOLOGY

SPECIAL TOPIC

HYPOXIA

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The U.S. military has a growing problem. An increasing number of pilots are experiencing a condition called hypoxia – that in worst cases can cause them to black out in the cockpit, leading to a fatal crash. During 2017, Aviation Week Pentagon Editor Lara Seligman produced a series of stories detailing the increase in incidents across the Air Force, Marine Corps and Navy and exploring the potential causes of hypoxia that continue to elude the government.

Lara's reporting went way beyond government-produced reports or congressional testimony. Pilots were reluctant to talk, but she found a way to interview them, tracked down top experts in the field, and looked at the technology involved in circulating fresh, clean air through a fighter jet. An initial package detailing the problem and industry's response was so well written and thoroughly reported that more sources came to her with information about new instances of hypoxia involving additional aircraft, leading to more of the stories contained here.

These stories were a part of what enabled Lara to win two of the media industry's 2018 Jesse H. Neal Awards: one for the Best Range of Work by a Single Author, and another, a McAllister Editorial Fellowship associated with the Medill School of Journalism at Northwestern University. She also won the Military Reports and Editors Association's James Crowley Award for this body of work. Take a minute to check out this award-winning writer's take on one of the most pressing issues facing military pilots today.

Jen DiMascio
Managing Editor
Defense & Space

Fear Of Losing Oxygen Puts U.S. Fighter Pilots On Edge

Lara Seligman

Looking around the cockpit of his familiar F/A-18 Hornet, a former pilot recalls a terrifying realization: "I just remember looking around the airplane thinking, man, I'm not completely certain I know how to fly this airplane anymore."

The pilot was flying about 20,000 ft. above the ground, not expecting to feel the tingling fingers and blurred judgment caused by lack of oxygen. The A-model Hornet gave no warnings, alerts or cautions that the cockpit pressurization was not functioning. Looking back, the pilot still has no idea how he managed to recognize his symptoms so early.

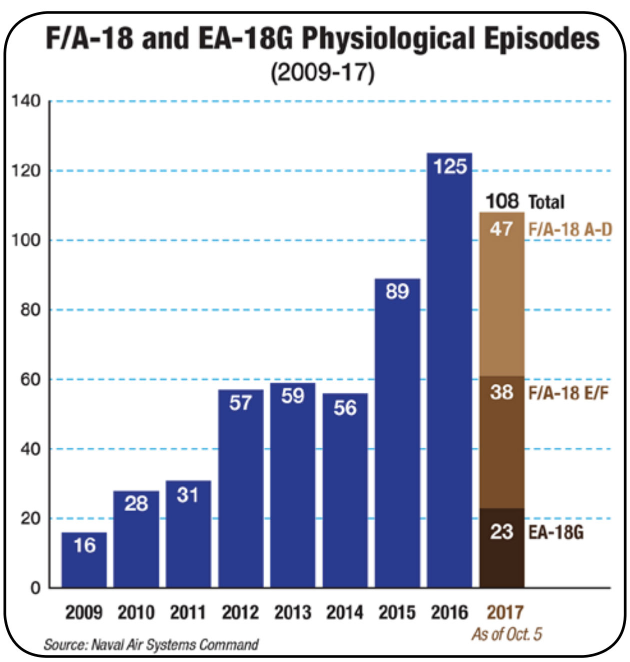
"When you spend your life inside an airplane you just intuitively know how to fly it," says the pilot, who requested anonymity to discuss a sensitive topic. "When you start wondering about just your fundamental flying ability . . . that's not the way you feel flying the aircraft every day."

Hypoxia Mystery

- Spike in physiological events leaves U.S. Air Force and Navy pilots short of breath, disoriented and shaken
- Congress has slammed military leadership for its failure to stop the incidents
- Experts say the problem can have a variety of causes, from a mechanical flaw to the pilots' state of mind
- Dedicated teams looking into the incidents are making slow progress

The pilot checked the cabin pressure gauge, which immediately revealed the cause of his symptoms. He quickly notified his wingman of his symptoms and began descending to a safer altitude. At some point, he remembers pulling the "green apple," a green ring in the ejection seat that provides a burst of oxygen to the pilot.

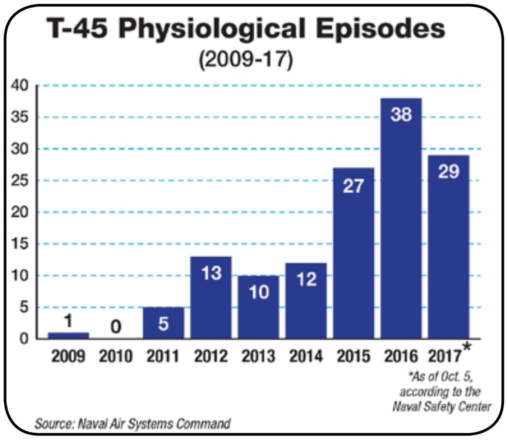
"I don't remember, I might've taken my gloves off, but it was evident based on the tingling and my cognitive ability that something was not right," he says.

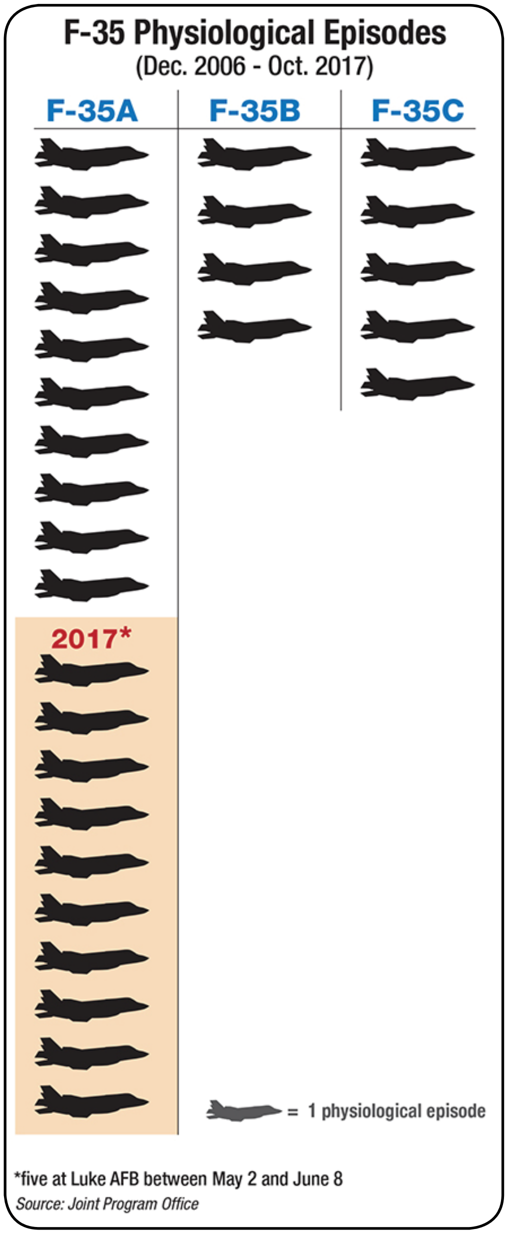


The symptoms eventually subsided, and the pilot landed safely. But those few blurry minutes could have been deadly. It turned out that the pilot was suffering from a lack of oxygen, a condition known as hypoxia that can lead to impaired cognition and blackout—potentially fatal when flying high-performance aircraft.

Across the U.S. military fleets, pilots are reporting more and more hypoxia-like cockpit episodes that, while not necessarily caused by true hypoxia, feature the same symptoms. The events leave pilots short of breath, disoriented and shaken.

The Navy's F/A-18 Hornet, EA-18G Growler and T-45 Goshawk trainer as well as the Air Force's new F-35A fleets have seen a significant surge in these so-called physiological episodes (PE) over the last few years. In the F/A-18 and EA-18G communities, the number of PEs increased almost eightfold from 2009 to 2016 and as of October was up to 108 for 2017 alone (see graph). In the T-45 fleet, PEs increased from just one in 2009 to 38 in 2012, and 29 have occurred so





far this year (see graph). There were just 10 PEs in F-35As in 2006-16; in 2017, the Joint Program Office so far has recorded another 10, doubling the overall number reported (see infographic).

The Navy's comprehensive review of the incidents notes that the apparent increase in PEs in 2010 was likely more reflective of a change in aircrew awareness and reporting mechanisms than a sudden rise in episodes. Still, the Navy deemed the number and severity of PEs across the fleet "unacceptable."

The rise in these incidents over the last decade is particularly troubling because the Air Force and Navy have a history of PEs contributing to fatal accidents. Air Force Capt. Jeff Haney died in 2010 when an engine bleed-air malfunction caused the control system on his F-22 Raptor to shut off oxygen flow to his mask. Meanwhile, the Navy has linked four F/A-18 pilot deaths over a span of 10 years to the pilots experiencing hypoxia-like symptoms.

The most recent incidents have not yet been directly linked to pilot deaths. But in a move that reflects the severity of the problem, due to the events the Navy this year grounded the T-45s in which Navy pilots train across the country, and the Air Force grounded F-35As at Luke AFB, Arizona, the Air Force's premier F-35 training base.

Although both types have resumed flight operations, the episodes continue. Tragically, a T-45 belonging to Training Sqdn. Seven based at NAS Meridian, Mississippi, crashed on Oct. 1 in East Tennessee during a training flight, leaving two pilots dead. The incident has not yet been definitively linked to PEs, but that possibility cannot be ruled out.

One of the most disquieting aspects of the spike in cockpit incidents over the last few years is the Pentagon's failure to identify the problem's cause and to fix it. Lawmakers have slammed military leadership, particularly in the Navy, for not addressing the issue.

"What's occurring in the Navy is absolutely unacceptable," said Rep. Mike Turner (R-Ohio), chairman of the subcommittee on tactical air and land forces, during negotiations on the defense policy bill this summer. "This is absolutely critical for our pilots, and it also goes to the confidence of the pilots, the ability of a pilot to know that their system is going to operate and they are not putting their lives at risk,"

"I have no doubt the Navy is taking that issue seriously," said Rep. Mac Thornberry (R-Texas), chairman of the House Armed Services Committee, during an October event at the Heritage Foundation. "But . . . I don't understand why we can't figure out what's causing the oxygen problem."

Current and former pilots, flight surgeons and aerospace physiologists across the services tell Aviation Week that getting to the root of the problem has proven so difficult because it involves the interaction of two extremely complex systems: high-performance fighters and the human body.

Just recognizing hypoxia can be tricky, as each pilot experiences different symptoms, ranging from tingling in hands and feet to disorientation and even personality changes. Air Force Maj. Joseph Teodoro, who commands the Aerospace and Operational Physiology unit at Langley AFB in Virginia, has seen a range of strange pilot behaviors, from hysterical giggling to belligerence and even some who, unaware of their critical situation, refuse to go back on oxygen.

But complicating the picture is the fact that many conditions not necessarily caused by a lack of oxygen share similar symptoms, explains Col. Jay Flottmann, an F-22 Raptor pilot and former flight surgeon. True hypoxia—a lack of oxygen in the blood—can easily be mistaken for any number of similar physiological states such as hypercapnia (high levels of carbon dioxide in the blood), histotoxic hypoxia (the presence of a toxin), decompression sickness or even simply dehydration, lack of sleep or nervousness.

Sometimes the issue is mechanical—it could be a problem with the Onboard Oxygen Generation System (OBOGS) or a piece of flight equipment can restrict pilots' breathing. A faulty valve, for instance, was determined to be a factor in a spate of dangerous cockpit events in the F-22 community. But sometimes physiological and psychological factors can induce changes in pilot breathing, Flottman says.

Despite the complexity of the problem, the PE investigations are making progress. In Super Hornets and Growlers, the Navy is for the first time linking a specific component failure to the cockpit events.

Across the U.S. military fleets, pilots are reporting a spike in hypoxia-like cockpit episodes that leave them short of breath, disoriented and shaken.

OLIVER COLE/U.S. NAVY

The service discovered that the avionics flow valve inside the aircraft's environmental control system (ECS)—essentially its air conditioning—has a tendency to freeze, blocking airflow in and out of the system, says Capt. Sara Joyner, head of the service's Physiological Episode Action Team. The valve controls the airflow through the ECS, which helps keep the cockpit environment stable, so a blockage could cause problematic changes in cabin pressure. The team is adding a heater blanket to the ECS avionics flow valve to keep it from freezing.

"We are not declaring victory, but we are declaring that we found something to fix, and we are fixing it," Joyner says.

The Navy also will embark on a broader ECS "reset" that will evaluate each part of the system carefully "to try to put it in the best state possible," she adds.

Meanwhile, in the T-45 fleet, the problem is insufficient oxygen flow to the pilot. The T-45's comparatively small engine cannot always provide sufficient flow to ensure easy breathing through all flight regimes, Joyner explains. This is likely due to T-45 system upgrades and additions, which have cumulatively begun to decrease the oxygen flow to the pilot. It is probably not due to the OBOGS.

The Navy is undertaking several efforts to optimize that flow, including refurbishing the heat exchangers to eliminate any obstruction or blockages and analyzing the piping to identify any flow loss.

In addition, the service is installing CRU-123 oxygen-monitoring systems in the T-45s, an upgrade from the CRU-99 system that monitors breathing gas pressure and oxygen content. As of Oct. 2, 113 of 170 T-45s had been outfitted with the new system, which also enables postflight download of data on cockpit conditions. All T-45 aircraft will have the CRU-123 installed by the end of the second quarter of 2018, the Navy expects.

On the F-35A, one constant in the three most recent incidents at Luke AFB may prove key to solving the problem. In each of the incidents, initiating the backup oxygen system did not immediately ease pilots' symptoms. This

indicates that the problem is not true hypoxia, says Col. Ben Bishop, commander of the Air Force's 56th Operations Group and an F-35 pilot.

Bishop believes pilots could be experiencing hypercapnia due to restricted breathing, potentially caused by the life-support system. He does not think the cause is hyperventilation.

"I think there might be something based on how the machine and the human are interacting that's altering the breathing," Bishop says.

The team is looking at all flight equipment for an indication of something that would restrict pilot breathing and taking steps to make the life-support system as robust as possible, he says. Already, the Air Force has made a number of changes to flight equipment to mitigate the potential for restrictions of breathing, including reducing the weight of the flight vest to making breathing easier and making changes to the exhalation valve on the mask to prevent sticking.

Bishop is confident the problem is not caused by air contamination or an OBOGS fault. There are no indications of carbon monoxide or other toxins on the ramp or during pilot examinations, he says. And recent testing of the OBOGS found the system is generating enough oxygen to safely support the pilot.

While initially there was a lot of concern in the pilot community at Luke over the PEs, pilots have begun to regain confidence both in the leadership and in the F-35, Bishop says. Today, although pilots realize the team may never find a single "smoking gun," they have high confidence that in the event of a PE, they will be able to turn on the backup oxygen system and safely recover the aircraft, he stresses.

"We are not going to make any pilot that's not comfortable flying the aircraft—who doesn't have confidence in the F-35's life-support system—we're not going to make them fly," Bishop says. "Up to this point, pilot confidence has been high enough that everyone has been able to return to fly."

In A Fighter Aircraft, Breathing Is No Easy Feat

Lara Seligman

Flying at 40,000 ft., the last thing a fighter pilot wants to be thinking about is the air he or she is breathing. But at the altitudes most fighters fly, getting sufficient clean oxygen to the crewmembers is a complex technological feat.

The human body is not designed to survive at extreme altitudes, where thinning air makes breathing a struggle. Modern technology allows fighter pilots to fly as high as 50,000 ft., but not without some risk of a dangerous "physiological episode" (PE), where a change in oxygen flow, cabin pressure or breathing rate can lead to symptoms ranging from tingling fingers to total blackout.

Incidents of PEs are on the rise across the U.S. Air Force and Navy. The surge in these potentially fatal cockpit incidents in the Lockheed MartinF-35A, Boeing/BAE Systems T-45 Goshawk trainer and Boeing F/A-18 Hornet fleets has led the services to take a careful look at the various complex systems involved in keeping pilots breathing during flight.

What's Happening Inside the Cockpit?

- Most newer U.S. fighters use the Onboard Oxygen Generation System (OBOGS) to provide oxygen to crewmembers
- OBOGS provides more opportunities for contamination or blockages than older methods of oxygen delivery
- The military has so far found no evidence there is anything wrong with the OBOGS in any of the affected platforms
- Cobham is pitching the AMPSS sensor suite to monitor a pilot's inhalation and exhalation throughout flight

The earliest method for providing oxygen to military aircrew was to store gaseous oxygen (GOX) at high pressure in metal cylinders or bottles. Over time, the military began using liquid oxygen (LOX) systems, which allow for more oxygen to be stored in a smaller container.

The main drawback of both GOX and LOX systems is the amount of oxygen that can be carried on an aircraft, limiting mission duration and flexibility. LOX is also extremely volatile and has a complex logistics tail. Today, GOX and LOX have been replaced in most newer fighters by a system that generates oxygen continuously during flight, called the Onboard Oxygen Generation System (OBOGS).

While the OBOGS revolutionized the way breathable air is provided to military aircrew, it also introduced a new set of problems. The OBOGS cycle typically begins at the engine and flows through various devices before it reaches the pilot, leaving countless opportunities for contaminants—such as a toxin or excess moisture—to enter the airflow.

Anatomy of an Onboard Oxygen Generation System

KEY SUPPLIERS:

Cobham: T-45, F/A-18, AV-8B, F-15E, A-10, F-16

Honeywell: F-35, F-22, B-1B, B-2B, Eurofighter, Gripen

CURRENT STATE

1 | OBOGS
Receives conditioned air from the aircraft's bleed system, separates the air into nitrogen vented to atmosphere and enriched oxygen to the cockpit

2 | Oxygen Monitor
Monitors aircraft oxygen supply

3 | Oxygen Regulator
Regulates aircraft oxygen

4 | Emergency Oxygen Supply
Pilot-initiated oxygen supplied from a pressurized cylinder

COBHAM'S PROPOSED NEXT-GEN SYSTEM

1 | Next-Generation OBOGS
Incorporates lessons learned from existing OBOGS

2 | Oxygen Monitor
Monitors aircraft oxygen supply, records critical flight data and provides low oxygen pressure warning in cockpit

3 | Electronic Breathing Regulator
Responds to inputs from the inhalation and exhalation sensors

4 | Emergency Oxygen Automatic Backup System
Automatically engages if pilot physiology demands it

5 | Inhale Sensor
Monitors pilot oxygen supply and cabin environmental supply system, provides real-time data analysis, alerts the pilot and auto-corrects if oxygen levels or cockpit conditions are unacceptable (includes manual override)

6 | Exhale Sensor
Monitors pilot physiology by measuring exhaled gas, monitors mask pressure, provides real-time data analysis, alerts the pilot and auto-corrects if expired levels are unacceptable (includes manual override)

In the Goshawk and Hornet, for example, the bleed air from the compressor section of the engine flows through a cooling heat exchanger and enters the Cobham-built OBOGS (in the F-35A, the OBOGS is built by Honeywell). There, it first passes through a heater, particulate filter and pressure reducer. The air is then directed through a zeolite material in molecular sieve beds inside two identical canisters. The sieve bed absorbs nitrogen, passing the concentrated oxygen to a mixing plenum and then to the pilot's regulator and mask. While one canister is generating oxygen, the other is being purged of the nitrogen absorbed by its sieve bed.

The ability of the OBOGS to produce usable oxygen depends on clean, dry air delivered at the right pressure and volume, flowing into the system. Moisture is a particular problem; due to the sieve bed's high affinity for water, any contaminants trapped there could be exchanged for moisture and then released from the OBOGS into aircrew breathing air. One solution is to install a water separator in the OBOGS bleed-air line to filter out any moisture from the airflow.

There is also the potential for a toxin such as carbon monoxide to enter the system via the flight line.

The OBOGS was an early suspect in the Pentagon's investigation into the recent rise in PEs. But so far, neither the Air Force nor the Navy has found evidence to suggest that a problem with the OBOGS itself is causing the spike. In the F-35A, the Air Force believes the life-support system may be causing restricted breathing. In the F/A-18 and EA-18G communities, the Navy believes the issue lies with the environmental control system, which provides thermal control, cabin pressurization, avionics cooling and air supply through various "pipes" throughout the aircraft (including the OBOGS). In the T-45, the latest thinking is that the aircraft is not producing sufficient oxygen flow throughout the system.

Still, monitoring the quality and quantity of air flowing into and out of the pilot through the OBOGS and the greater life-support system will be key to identifying and preventing these episodes.

The services already have various methods of measuring breathing-gas pressure and oxygen content in the air that comes off the OBOGS—for instance, the upgraded CRU-123 oxygen-monitoring system being installed in the T-45 fleet. The Pentagon is also considering different options to monitor the pressure and oxygen levels of air in the cockpit. However, there is currently no way to monitor the air that is actually entering and exiting the pilot's body.

A surge in potentially fatal cockpit incidents has led the U.S. services to take a closer look at the life-support systems that deliver oxygen to fighter pilots.

SPENCER C. ROBERTS / U.S. NAVY

Cobham believes it has a solution. The company's Aircrew Mounted Physiological Sensing System (AMPSS) monitors a pilot's inhalation and exhalation throughout flight, according to Rob Schaeffer, Cobham's product director for environmental systems. The AMPSS is made up of two separate modules, one on the inhale side and one on the exhale side, that monitor the airflow entering and exiting a pilot's body. The sensors assess that air for changes in pressure, humidity, temperature, oxygen concentration, flow rate, carbon dioxide—anything that might cause dangerous hypoxia-like symptoms.

The company earlier this year delivered eight inhalation sensor blocks to the U.S. Air Force School of Aerospace Medicine at Wright-Patterson AFB, Ohio, for testing and was set to deliver eight exhalation blocks to the service by the end of September, Schaeffer told Aviation Week that month. Cobham hopes the AMPSS will help the Pentagon collect data needed to identify the root cause of the PEs.

The next phase of development will focus on building a warning feature to alert the pilot of dangerously high or

low oxygen levels and tell him or her to take manual corrective action, Schaeffer says. The warning method could be a message on the head-up display, a vibration on the wrist or some other alert.

But the company is carefully considering how much the pilot really needs to know about his or her breathing conditions. A danger alert could cause a pilot to panic unnecessarily over a small change in oxygen concentration or cabin pressure.

“The big question would be if a pilot was able to see the data that was being collected real-time, what would he or she do with that data? Probably nothing, because he or she is not a doctor,” Schaeffer says. “You don’t need to panic somebody who is already under stress.”

Cobham is looking to include a mitigation capability that automatically adjusts the oxygen concentration being fed to the pilot based on data the AMPSS is providing, he says.

The ultimate goal is to build a next-generation, complete life-support system that will predict and preempt the onset of hypoxia-like symptoms.

For Pilots Losing Oxygen, 'Human System' May Be Weakest Link

Lara Seligman

When U.S. Air Force Col. Jay Flottmann climbed into the back of a U.S. Navy F/A-18, he was hoping to use his unique expertise as both a fighter pilot and qualified physician to help the Navy get to the bottom of the troubling surge in hypoxia-like cockpit episodes that leave aircrew short of breath, disoriented and unnerved.

Flottmann's findings, part of a new NASA study on physiological episodes (PE) in Navy F/A-18s and EA-18Gs, shed new light on a deadly problem with which the U.S. military has been grappling for years. The Navy's investigation has centered largely on finding a single mechanical cause for the episodes, according to NASA. But Flottmann's assessment points to a much messier answer: It is the complex interaction of the human and aircraft systems, not one or the other, that causes the events.

As part of the NASA Engineering and Safety Center's (NESC) independent review, Flottmann flew three sorties in the F/A-18—one in the D-model legacy Hornet, equipped with liquid oxygen (LOX), and two in an F-model Super Hornet equipped with an On-Board Oxygen Generation System (OBOGS). Flottmann, who is accustomed to Air Force procedures, flew with Navy flight equipment—including the helmet, mask, combination harness, survival vest, anti-G trousers and gloves, in addition to standard flight suit and boot.

Who Is to Blame—Man or Machine?

- Although hypoxia is the prevalent cause of the Navy's PEs, NASA found most events occur when there is an adequate amount of oxygen being generated
- The delivery of oxygen to the brain via the "human system" is therefore key, NASA concludes
- Pilot-physician Col. Jay Flottmann found differences in procedures and flight equipment between USAF and the Navy
- Some Navy pilots do not properly perform anti-G-straining maneuvers, and wear their masks inconsistently

Flottmann and the rest of the NASA team found subtle differences in flight equipment, pilot behavior and maintenance procedures between the Air Force and Navy communities that, coupled with the physical conditions of flight, could potentially lead to hypoxia.

Most notably, Flottmann observed troubling tendencies of the pilots themselves, such as not conducting the typical anti-G straining maneuver (AGSM) properly or at all. These tendencies, combined with the unforgiving F/A-18 flight environment and certain aspects of the flight equipment, resulted in constricted breathing and a noticeable cough, he concluded, according to a NESC report dated Sept. 14 and released Dec. 13. (He noted in a follow-up email to Aviation Week that this was a very small sample size, and it is not accurate to apply this conclusion to all Navy pilots.) The NASA report also noted certain improper practices in usage and maintenance of the mask.

A new NASA report indicates incidents of hypoxia across the U.S. military fleet are most likely caused by the human-machine interface.

U.S. AIR NATIONAL GUARD TECH. SGT. DREW A. EGNOSKE

In his assessment, Flottmann highlighted differences between Navy and Air Force flight equipment and procedures. He pointed out the Navy's propensity to tighten the chest strap much more than Air Force pilots typically do. In addition, the survival

vest equipment (including radio and first-aid equipment) is largely located along the lower torso, with much of the weight along the front and side of the abdomen. These two factors contributed to a perception of added weight across the chest that Flottmann described as a "slight 'squeeze' while breathing normally."

During the flights in the OBOGS-equipped Navy aircraft, Flottmann also noticed a subtle difference in flow and pressure when breathing from the OBOGS system. While in most Air Force breathing regulators (with the exception of the F-22 and F-35) the system provides air as the pilot inhales, the F/A-18F OBOGS seemed to provide a constant safety pressure blowing air into the mask. This "positive pressure" can result in subtle changes in the way a pilot is breathing, Flottmann wrote. Indeed, the front-seat pilot of Flottman's first F/A-18F mission admitted that on OBOGS-equipped aircraft he routinely coughs after nearly any maneuver, particularly high-G ones. Flottmann noticed the pilot coughing after even minor-G loads during the flight.

This cough indicated to Flottmann that the pilot displayed classic signs of "atelectasis" where the tiny air sacs called alveoli in the lung bases partially collapse. This happens because of a combination of high-G loads (which increase blood flow to the base of the lungs), the restrictive anti-G suit (which limits the ability to expand the rib cage) and the Navy's practice of using 100% oxygen at all altitudes, Flottmann tells Aviation Week. This last factor essentially "washes out" the nitrogen that, on the ground, helps keeps those air sacs open, Flottmann explains. By contrast, Air Force jets "schedule" the inhaled oxygen content according to the altitude of the cabin, keeping the nitrogen in the mix, he says.

"You and I breathe 21% oxygen on the ground and 78% nitrogen," he says, noting that during flights at 100% oxygen levels, "Once the oxygen is absorbed into the bloodstream, there is virtually nothing that keeps the alveoli open."

Flottmann himself experienced familiar sensations following the F/A-18F sorties—a mild chest tightness that reminded him of a sortie he flew in the F-22 during a safety investigation of PEs in the Raptor.

Col. Jay Flottmann, a fighter pilot and flight surgeon, provides critical expertise to the NASA and U.S. military teams studying hypoxia-like cockpit incidents across the fleet.

U.S. AIR FORCE SR. AIRMAN CHRISTINA BROWNLOW

He also found neither of the front-seat pilots, though experienced aviators, executed the standard AGSM that Air Force pilots typically perform to help their bodies cope with high G loads.

"Following both missions, I asked each pilot about his AGSM and both admitted that they really did not 'do that' very well," Flottmann wrote. "When I asked about debriefing the AGSM, it was my impression that he did not understand how to evaluate and instruct to the proper techniques shown to enhance G protection and endurance, namely an appropriate breathing pattern."

In addition, unlike in most Air Force fighter regulators, the F/A-18 does not provide a graduated increase in breathing air through the mask over 4gs to aid inhalation, called "positive pressure breathing for G" (PBG). If pilots are indeed not performing a typical AGSM, this would likely result in "acceleration atelectasis," Flottmann wrote.

"I am convinced that the 'elevated oxygen content' in the breathing gas (both LOX and OBOGS) coupled with the operation of the CRU-103 breathing regulator negatively affects human performance," Flottmann wrote, noting he spent the rest of the day clearing his ears, felt more fatigued than usual, had a mild headache, and noted subtle breathing changes he described as "a propensity to breathe deeply, as if I was trying to inhale deeply out of necessity."

Flottmann also noticed that while the function of the Air Force and Navy masks is similar, the ground "fit test" and custom fit procedures are vastly different. Unlike the Air Force, prior to the flight with the Navy, Flottmann's mask was not tested for air leaks with equipment that simulates altitude exposure and pressure breathing.

Other sections of the NESC's report also note problems in the Navy's procedures for mask use, based on site visits and interviews with pilots and Navy leadership. The NASA team found, as Flottmann did, the Navy has no functional preflight test of the mask and intercom before each flight. In addition, they found some Navy pilots do not wear the mask consistently because it is uncomfortable or fits poorly. One pilot noted the Navy's new mask, which has a hose exiting to the side with a separate exhalation valve, is "extremely uncomfortable and needs to be changed. The old mask was infinitely better."

But handling or removing the mask before or during flight potentially allows contaminants to enter the system, and increases the chance of other damage, according to the NESC report. On top of this, the NASA team found during site visits there is no routine, formal cleaning of the masks after each use.

"This makes it possible for surface bacterial or other bioactive contaminants to remain on the masks, and to potentially be inhaled or ingested later by the pilot," the report states.

The NASA team found no evidence that contamination has led to a PE. However, flying at 10,000 ft. with the mask down does have a physiological impact on the pilot, particularly a loss of color vision—a "clear indication" the pilot is experiencing some level of performance degradation, according to the report.

Overall, Flottmann's observations led him to conclude wearing the Navy's flight equipment, particularly the survival vest and harness, resulted in mild constriction and chest tightness, particularly in the OBOGS aircraft.

"Although the sensations were subtle and mild, it is apparent to me that they occurred as a result of the man-machine interface," he wrote.

Though much of the Navy's investigation of the F/A-18 PEs has focused on cabin pressurization, Flottmann had no such issues, he wrote.

Based on his observations, Flottmann recommends the Navy implement PBG in the current CRU-103 regulator, which will improve human performance especially during high-G flight and also will mitigate what he suspects is "absorption compounded by acceleration atelectasis." He also recommends the Navy investigate the potential of allowing the oxygen content of the breathing gas to be scheduled.

Finally, he urges the Navy to conduct centrifuge studies to compare and contrast the wear of the flight-gear ensemble and how it affects breathing. The Air Force conducted similar studies during the F-22 investigation and found flight-gear configurations and fit contributed to how hard the pilot has to work to breathe.

Flottmann's conclusions support the NASA team's overall findings. Although the NESC determined hypoxia to be the most prevalent cause of the incidents, most of the hypoxia PEs occurred when there was an adequate amount of oxygen being generated by the OBOGS. This finding necessitates a crucial distinction: Hypoxia is not solely a condition of insufficient levels of oxygen in breathing gas; it is insufficient delivery of oxygen tissues to the body.

"How is it possible to become hypoxic with sufficient O2 being produced in the F/A-18?" the NESC team asks in the report. "The answer is that hypoxia is not caused by low levels of O2 in the piping (where O2 is measured) leading to the pilot's mask. It is caused by an insufficient amount of O2 being delivered to the brain. The delivery process therefore is key," they wrote.

The problem is that the complex "human system" is particularly vulnerable to a number of factors that collectively lead to hypoxia. The human "subsystems"—the respiratory, pulmonic and circulatory (or cardiovascular) systems—and their interaction with the aircraft and environment are key to getting sufficient oxygen to the brain, according to the report. This is particularly vexing because it is difficult to collect direct evidence about the function of these human subsystems.

It is not yet clear whether the Navy will adopt the recommendations made by Flottmann and the NASA team, or what the Air Force team looking into parallel incidents on the F-35A will do with the NESC review. But one thing is clear: Failures of the man-machine interface during flights in high-performance aircraft can prove fatal.

Air Force Capt. Jeff Haney's death provides a particularly tragic example. Haney was flying over Alaska in late 2010 when an engine bleed-air malfunction on his F-22 Raptor caused the control system to shut off oxygen flow to his mask. For the next 30 sec., Haney struggled to activate his emergency backup oxygen supply, seeming not to notice as his aircraft rolled into a steep dive. At the last second, Haney tried to pull up, but it was too late. He struck the ground going faster than the speed of sound and died on impact.

Years later, many aspects of the crash remain unexplained. But officials suspect that the time Haney spent struggling to activate the emergency oxygen system—achieved by pulling on an inconveniently located, difficult to activate ring—while struggling to breathe and control a supersonic plummeting jet, decided his fate.

For A-10 Pilots, Oxygen Deprivation Is Recurring Problem

Lara Seligman

U.S. Air Force pilots flying the A-10 Warthog have for years been experiencing intermittent hypoxialike episodes that may indicate a problem with the installation of the aircraft's oxygen system.

The service temporarily grounded 28 A-10s from the 355th Fighter Wing at Davis-Monthan AFB, Arizona, in late 2017 after two pilots reported physiological events (PE) in flight, Aviation Week reported Jan. 9. That same week, a third pilot experienced a problem with the Onboard Oxygen Generation System (OBOGS) while still on the ground.

- A-10 pilots have reported 24 PEs in total since 2008
- Maintainers often see clogging in piping that carries oxygen from Warthog's engine to the pilot's mouth and nose
- Water accumulation could cause hypoxialike symptoms
- U.S. Air Force recently established a team to investigate the PEs across the fighter fleet

The grounded Warthogs returned to the skies just a week later. But these events are not isolated, and could be a symptom of a chronic problem within the portion of the A-10 fleet that has been upgraded from the legacy liquid oxygen (LOX) system to the new OBOGS. Of the 281 A-10s in the fleet, 54 have been upgraded from LOX to an OBOGS similar to the one that equips the F-16 Fighting Falcon, the U.S. Navy's F/A-18 Hornet and T-45 Goshawk trainer, all built by Cobham.

A-10 pilots have reported 24 PEs in total since fiscal 2008, including a recent spike of six in fiscal 2017 and three so far in fiscal 2018, according to data provided to Aviation Week by the Air Force. There are no notable trends across the events, and the PE rates per 100,000 flying hours in the Warthog are consistent with those on other aircraft with similar sample sizes – for instance the F-16 and F-15 Eagle, says Air Force spokesman Capt. Mark Graff. The Air Force is in the process of updating the PE data for the entirety of its fighter fleet, he notes.

But a 2016 investigation by Paragon Space Development Corp., a Tucson, Arizona-based firm that specializes in extreme-environment life-support systems, found recurrent incidences of "OBOGS anomalies" on the OBOGS-equipped A-10s at Davis-Monthan, company CEO and co-founder Grant Anderson tells Aviation Week.

In a conversation over dinner in early 2016, a Davis-Monthan official indicated to Anderson that such incidents are not uncommon. "It wasn't, 'We've had an incident or two.' . . . It was an emphatic, 'Oh yes, we've had them,' " Anderson says of the conversation.

An Air Force spokesman, Capt. Josh Benedetti, says Davis-Monthan only had records of one other OBOGS-related PE, in December 2016. However, such events have traditionally gone underreported, perhaps because pilots fear being grounded, or because they do not understand or recognize their symptoms.

Anderson has been studying the growing rate of PEs among Air Force and Navy pilots across the fleet for years. Following the dinner conversation, he and his team visited Davis-Monthan to inspect and photograph the installation of the OBOGS on the Warthog, and also speak to flightline personnel responsible for maintaining the OBOGS. Separately, Anderson was invited to NAS Patuxent River, Maryland, to discuss the PEs on the Navy's F/A-18s with Dennis Gordge, an OBOGS expert and senior engineer at the Naval Air Warfare Center Aircraft Division.

Navy spokesman Cmdr. Scot Cregan confirmed Anderson's visit to Patuxent River in January 2016 and receipt of Paragon's subsequent, unsolicited report on aircraft OBOGS failures. The Navy also received a proposal and funding request from Paragon to conduct further testing on the OBOGS, Cregan says.

From Anderson's visits to Davis-Monthan and Patuxent River, Paragon put forth a hypothesis: the PEs on the A-10s and F/A-18s were caused by large amounts of moisture accumulating in the pipes that carry air from the engine,

through the OBOGS, and to the pilot's mask.

Navy officials reviewed Anderson's proposal, but found that it did not benefit the current investigation, Cregan says. Paragon's recommended efforts had either already been considered, were already underway at a Navy lab or were deemed "not practical to implement," according to the Navy's official response to the study.

"The ideas and recommendations proposed by Paragon are not new or novel and we do not recommend further pursuit at this time," the response states.

Clint Cragg, the lead for the recent NASA investigation into the Navy's F/A-18 PEs, reviewed the report at Aviation Week's request. He agrees with the Navy's conclusion that Paragon's findings are not new.

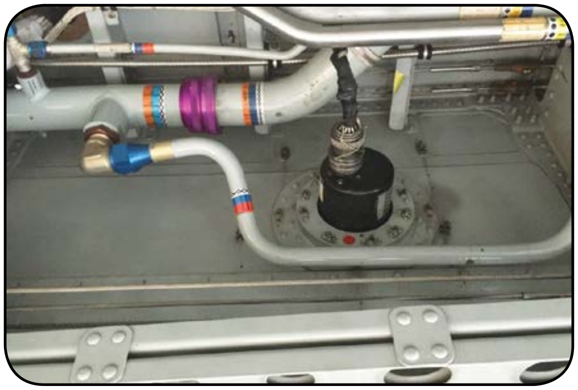
"Water accumulation is a known issue and has been investigated by the Navy and my team. While it is a concern, and a potential contributor, water accumulation did not stick out to us as the key driver of the Navy's Physiological Episodes," Cragg told Aviation Week. "The problem is much more complex than portrayed in Paragon's paper."

The Air Force has not officially responded to Paragon's report. But separate from the Navy investigation, the company's findings during its inspection of the A-10 fleet shed light on the problem at Davis-Monthan.

Anderson's team found that maintainers at Davis-Monthan often saw clogging in the coalescing water filter vent line, which offboards excess water prior to the air reaching the OBOGS. To clear the line, personnel would insert a wire into the vent line, releasing "brown gunk."

Paragon believes the clogging happens because the A-10 plumbing includes several "U joints" (see photo) that tend to collect water. Any space that consistently gets wet will eventually grow "microbial stuff"—hence the brown gunk, he says.

An independent investigation concludes that clogging happens in the A-10 pipes because the plumbing includes several "U joints" that tend to collect water.



PARAGON

In OBOGS-equipped A-10s, U joints are inevitable due to the aircraft's inherent design, Anderson says. While the oxygen system bleeds off the left engine, the water separator and the system itself are on the right side of the aircraft. Meanwhile, the OBOGS installation, given that it is a retrofit from a LOX system, lacks the room for the primary water separator within the OBOGS compartment, so it is located in the aircraft's gun bay, the report states.

This means the piping system that carries the air from the engine, through the water separator and into the OBOGS must run a circuitous route up and over the gun system, which includes multiple "low spots," Anderson says.

"At least in my limited study of the A-10 and the pictures I showed [in the report], there are plenty of places where you could collect almost a pound of water and not even realize it because these pipes are pretty big, and they are carrying a decent amount of airflow," he says.

Water accumulation is a known problem for OBOGS. The ability of the system to produce usable oxygen depends on clean, dry air delivered at the right pressure and volume, flowing into the system, experts say. Due to the molecular sieve bed's high affinity for water, previously absorbed nitrogen, excess water and any contaminants trapped there could be exchanged for the new moisture and released into aircrew breathing air.

The sudden oxygen-deficient, nitrogen-rich, moist air, combined with drops in pressure due to interruptions in the airflow, then would cause the pilot to experience hypoxialike symptoms such as headaches, respiratory dysfunction, disorientation, dizziness and even blackout, the Paragon report concludes.

In OBOGS-equipped aircraft, a water separator is typically installed in the OBOGS bleed-air line to filter out any moisture from the airflow. But Anderson says these systems are designed for small amounts of water.

"What happens when you hit it with 100, 200, 300 milliliters of water at once is a whole other question, and I know that they would not separate out the water in that case," Anderson says. "The water would overwhelm the system."

The Air Force temporarily grounded 28 A-10s from the 355th Fighter Wing at Davis-Monthan AFB, Arizona, in late 2017 after two pilots reported physiological events in flight.

U.S. AIR FORCE/SAMUEL KING, JR.

But under what circumstances would that much water enter the system? Depending on flight conditions, it is relatively easy for moisture to build up in the piping, Anderson says.

For instance, if an aircraft comes down from a high (and therefore cold) altitude into a high-moisture environment, such as a cloud, the cold piping combined with warm, compressed but high relative-humidity air would cause condensation to build up and potentially get trapped in low spots in the piping. Depending on weather conditions, this water could freeze in the plumbing, not enough to totally clog a pipe, but enough to prevent adequate drainage and cause further accumulation. Sudden unfreezing could potentially introduce a "slug" of water, overwhelming the water separator and allowing a large amount of moisture to enter into the OBOGS. Or, perhaps a flight maneuver could release the water.

The flight environment means that these events could be extremely random, Anderson says.

"Sometimes you will have three or four dry days, you fly and it might totally evaporate out the water, and now you have a dry pipe again. Or you may have a successive bunch of days where you keep building up the water," he says. "You would have to have the right combinations of temperatures, airflow, relative humidity, how many flights, what flight maneuvers [etc.] to build up this water."

Investigators at Davis-Monthan are still looking into the recent incidents. The team was able to identify and fix the problem with the aircraft equipped with the legacy LOX system, but the two incidents that occurred on aircraft outfitted with the OBOGS remain a mystery.

The wing has identified steps to better maintain the system by cleaning the water separator drain and associated piping with pressurized air, which may help prevent corrosion found in some of the piping. Additionally, they made the pilot-preflight OBOGS procedure more prescriptive, says Benedetti.

In recognition of the growing problem, the service recently established a team, headed by Brig. Gen. Bobbi Doorenbos, to investigate reported incidents on the A-10, F-35A, F-22 Raptor, F-15, F-16, and T-6 Texan II trainer.

"The Air Force takes flight safety and physiologic events very seriously and is working to investigate and address these events and implement recommendations to make operations safer," Graff says.

F-35 Pilot: 'I Didn't Know If I Was Going To Be Able To Get Back'

Lara Seligman

Flying at about 35,000 ft. on a scorching Arizona day, the F-35 pilot noticed the oxygen flowing into his mask catch for just a split second.

"That was odd," he thought.

At that moment, a high-pitched alarm rang, "deedle-deedle." A caution light flashed in the cockpit, warning that the Onboard Oxygen Generation System (OBOGS) had failed.

- Five PEs at Luke between May 2 and June 8, 2017, caused the Air Force to temporarily ground the F-35s there
- Pilot who reported first PE says he initially thought he had experienced true hypoxia, for which the F-35 system was to blame
- Now wing leadership and pilots believe incidents were likely caused by unique "man-machine" interaction
- Pilots have reported PEs since the standdown but continue to have confidence in the jet

The pilot, who requested anonymity to protect his privacy, immediately recognized the early symptoms of hypoxia he had experienced during training in the altitude chamber: tingling fingers, a warm sensation in his ears and on the back of his neck, and heavy breathing. Simultaneously, his vision began going gray, as if he had stood up too fast.

"It was a general kind of dimming of the lights, if you will," the pilot told Aviation Week in a Jan. 23 interview at Luke AFB, Arizona. "In my mind, regardless of what was going on, something was not right."

He did not know it then, but his experience that day was the first of five hypoxia-like physiological events (PE) that would be reported at the 56th Fighter Wing at Luke between May 2 and June 8—a spike that caused the Air Force to temporarily ground the F-35s at that base.

The aircraft returned to the skies just a few weeks later, but the root cause of the events remains a mystery. After months of investigating, the investigating team is still not sure whether the incidents indicate true hypoxia (lack of oxygen to the brain) or a number of similar physiological states, from hypercapneia (too much carbon dioxide in the blood) to simple nervousness.

As operations at Luke return to normal and airmen begin to feel at ease again, the pilot's experience on May 2 sheds light on a complex problem that may not have a single cause or solution. Wing leadership and the aviators themselves now believe the incidents were likely caused by the unique interaction between the machine and the human body.

After recognizing his symptoms that day, the pilot called "knock it off," signaling the end to the air combat training sortie he had been flying, and began a rapid descent. At that point, he believed the aircraft's Backup Oxygen System (BOS), which is designed to automatically activate in the event of an OBOGS fail, was still on.

"My priority at that point was to get on the ground as soon as possible because I was not feeling well," he says.

An F-35 pilot assigned to Luke AFB, Arizona, experienced a physiological event during a training flight on May 2, 2017—the first of a spate of similar incidents that caused the Air Force to temporarily ground the F-35s there last summer.

AIRMAN 1ST CLASS CALEB WORPEL/U.S. AIR FORCE

Below 10,000 ft. and pointed toward home, the pilot began to feel better, which he attributed to the BOS. But all of a sudden, it happened again: the tingling fingers, the warm sensation, the labored breathing.

At this point, he acknowledged, he was not thinking clearly—in fact, he was not sure he was going to make it home at all.

"There were a couple times in that sequence that I didn't know if I was going to be able to get back," he says. "I was significantly more impaired than I anticipated being."

The pilot was concentrating so hard on getting to the ground that he failed to notice that both the OBOGS fail light and the BOS had turned off seconds after they came on.

"I'll be honest, it was like a 55-deg. descent," he says. "I wasn't exactly looking inside; I was looking outside."

He was also frustrated. He did not trust that the OBOGS was functioning properly, and after the symptoms returned on the flight home, he lost faith in the BOS as well. He manually activated the BOS—an action he still cannot explain—but then dropped his mask so he was just breathing the ambient air in the cockpit.

"[For] most failures, you have a checklist; you have steps to do to at least remedy it," he says. "In that case, what do you do? I can't fix it. What do I do? I feel like crap, and I don't know how to fix it."

The pilot finally landed back at Luke, where he was met by a flight doctor. The doctor put him on supplemental oxygen as soon as he popped the canopy, and he was rushed to the clinic in an ambulance.

"My feeling of not quite being right lasted for hours after I landed," he says.

That day, the pilot was convinced his symptoms were caused by something in the F-35 system itself. But now, after watching the tape of his flight and consulting with flight doctors and engineers, he believes that what happened to him was caused by his body's physiological reaction to the initial OBOGS fail warning, coupled with the unique way pilots breathe in the F-35: against a constant positive pressure meant to protect the pilot's oxygen supply in the event of a chemical attack.

The F-35 pilot immediately recognized the early symptoms of hypoxia: tingling fingers, a warm sensation behind his ears and on the back of his neck and labored breathing.

AIRMAN 1ST CLASS CALEB WORPEL/U.S. AIR FORCE

"I think that [the OBOGS fail warning] caused a physiological response for me that changed my pattern and depth of breathing to a point where I kind of began to feel lightheaded, which is very similar symptoms to hypoxia for me," the pilot says. "So then I kind of a little bit put myself in a hurt locker, if you will, on the way down."

There are still unanswered questions. He still cannot explain why the symptoms recurred on the flight home, for instance.

But his theory is reinforced, he believes, by a second PE he experienced about two months later, on July 10, after the Luke F-35s had returned to flight.

He was flying a close-air support training sortie, which requires a lot of speaking over the radio. The positive pressure the jet supplies makes speaking in the F-35 slightly more difficult than in other platforms, and the pilot thinks that extra effort made him feel lightheaded. He checked the pulse oximeter he had started wearing after the first incident and saw it was reading a blood oxygen saturation level of 84%—much lower than the 98% or 99% reading he usually gets. He immediately called off the mission and headed home.

It turned out that the pulse oximeter had simply malfunctioned. When he checked the device again during the flight home, the reading showed his oxygen levels were normal.

Brig. Gen. Brook Leonard, commander of the 56th Fighter Wing, echoes the pilot's assessment, saying that many of the PEs happened directly after a "physiological or stress trigger," such as a correction from an instructor pilot or an unexpected scenario, that then resulted in a breathing change.

To deal with this challenge, the wing has begun teaching pilots to recognize their own unique reactions to stressful situations in addition to teaching them techniques to regulate their breathing, Leonard says. He also recognized that the positive pressure in the mask, or talking a lot during flight, may produce a change in breathing for some pilots.

"It was a general kind of dimming of the lights, if you will," the F-35 pilot told Aviation Week in a Jan. 23 interview. "In my mind, regardless of what was going on, something was not right."

STAFF SGT. JENSEN STIDHAM/U.S. AIR FORCE

"We put engineers and pilots together to learn that the jet is capable of taking care of you, you just have to follow these steps," he said during a Jan. 23 interview at Luke. "It's been really neat to walk down that path and see how we can basically arm the human to take care of this leading-edge technology."

In addition to educating the pilots, the wing has also made some physical changes to the F-35 flight equipment to ease breathing, such as reducing the weight of the flight vest and replacing faulty exhalation valves. The team investigating the PEs refined the OBOGS algorithm that controls the fluctuations in oxygen concentration levels, too, so the system delivers oxygen at a steadier rate.

For the pilot who reported that first PE on May 2, the education he received after the fleet was grounded, both on the way the aircraft's oxygen systems work and about his own physiological reaction, cemented his confidence in the F-35.

"Honestly, I'm not worried about it in the jet now," he says. "I'm confident that I can handle the situation. I'm confident the aircraft is providing me with the oxygen I need provided, and that whatever is making me feel odd is maybe a combination of the two."

Just as important was feeling that leadership took him seriously and actively tried to fix the problem, he says.

"I felt like I was believed," he says. "If I hadn't, then I wouldn't have flown, I honestly wouldn't have flown."

Other pilots have reported additional PEs since the fleet-grounding, but confidence in the aircraft has not waned, Leonard says.

He expects to continue seeing intermittent PEs in the F-35, as on any airframe, but pilots are confident they can safely recover the aircraft, he adds.

"I think the system both mechanically and software-wise can still be improved, don't get me wrong," Leonard says. "But at the same time I think we're learning that—based on the fact that we are at the cutting edge of the technology and trying to do as much as we can with the human still in the jet—we really have to continue to increase the human's understanding and knowledge and capability."

What's Wrong With The U.S. Navy's F/A-18s?

Lara Seligman

The U.S. Navy flag officer leading an investigation into a spike in unexplained physiological events across the service's fighter and trainer aircraft believes her team is turning the corner on finding a solution to the problem in the F/A-18 fleet.

But the Navy has a long way to go before pilots can climb into the cockpit without fearing potentially lethal changes in pressure or oxygen during flight.

The stakes are high for Boeing, which builds the legacy F/A-18A-D Hornet, the F/A-18E/F Super Hornet and the EA-18G Growler electronic-warfare variant, all of which have experienced a sharp increase in hypoxia-like physiological events (PE) in the last decade. During a Feb. 6 congressional hearing, Rep. Niki Tsongas (D-Mass.), ranking member on the House Armed Services tactical air and land forces subcommittee, stopped just short of calling for a production halt.

- A top lawmaker stopped just short of calling for halting production of Boeing's F/A-18s
- The Navy believes it is "turning the corner" on the F/A-18 PEs
- The service will issue an RFP for a new F/A-18 OBOGS
- NASA report points out potential design flaws in the F/A-18 ECS

"As we sit here today, new F/A-18s are rolling off the production [line] at a cost of around $69 million per aircraft," Tsongas said. "At some point, paying $69 million for an aircraft we know has serious problems with its life-support system has to be questioned."

Tsongas called on the Navy and Boeing to make improvements to the aircraft "that make them safer for our brave men and women in the military to operate, because we know there are lives at risk."

It seems the Navy is heeding her advice. Rear Adm. Sarah Joyner and her PE team currently believe hypoxia—defined as lack of oxygen to the blood—and decompression events are the two most likely causes of the recent PEs, according to Joyner's written testimony. In response, the service is looking to make a series of design changes to the F/A-18's Onboard Oxygen-Generation System (OBOGS) and Environmental Control System (ECS) that it hopes will make the aircraft safer to operate, Joyner said during the hearing.

The U.S. Navy's legacy F/A-18A-D Hornet, F/A-18E and F/A-18E/F Super Hornet and the EA-18G Growler electronic warfare variant, the backbone of naval aviation, have all seen a sharp increase in hypoxia-like physiological events in the last decade. Credit: Seaman Ryan Carter/U.S. Navy

The U.S. Navy's legacy F/A-18A-D Hornet, F/A-18E and F/A-18E/F Super Hornet and the EA-18G Growler electronic warfare variant, the backbone of naval aviation, have all seen a sharp increase in hypoxia-like physiological events in the last decade.

SEAMAN RYAN CARTER/U.S. NAVY

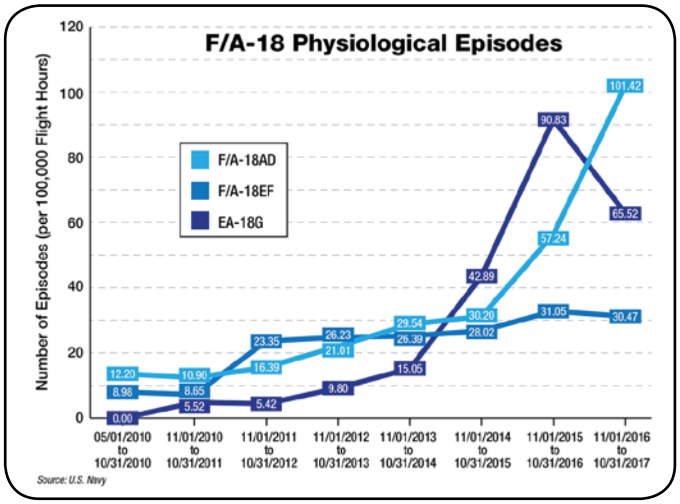
After almost a year of work, the team is beginning to see signs that the modifications are working, Joyner says.

"On F/A-18s, we are turning the corner," Joyner told the subcommittee. On the sidelines of the hearing, she told Aviation Week: "We are going after the ECS to make it as steady as possible. We are going after the oxygen system to make sure we understand exactly what is going on. . . . PEs are not going to

go away, but we are going to try to do our best to mitigate them and make them mild in nature as best we can."

Most notably, the Navy intends to issue a request for proposals (RFP) to industry in the near future for a new F/A-18 OBOGS, Joyner confirms. The current version is built by Cobham. In particular, the Navy wants to replace the concentrator, the heart of the system, to conform to the latest MIL-STD 3050, Joyner tells Aviation Week.

She wants the new F/A-18 OBOGS to adopt some of the features of the F-35 system, built by Honeywell, including inlet/outlet pressure and data monitoring, she says. She could not provide a time line for release of the RFP.



The Navy has also redesigned certain internal components of the existing OBOGS to provide an improved filter and to incorporate a catalyst that will prevent carbon monoxide from reaching the pilot, Joyner stated in her written testimony. These new components have been installed in 92% of the in-service F/A-18 fleet.

A NASA team looking into the PEs pointed out in its recent comprehensive report that the existing OBOGS was originally qualified and accepted with "dry air under steady-state flow conditions," which generally does not reflect actual flight operating conditions. The Navy intends to continue testing the OBOGS in realistic, off-nominal conditions, but Joyner tells Aviation Week that previous such tests have failed to make the system perform in an unsatisfactory manner.

"We've baked it, cooked it, soaked it, done tremendous badness to this concentrator, and we haven't managed to make it really perform poorly," Joyner says.

In addition to the OBOGS issues, the NASA report pointed out potential design flaws with the ECS, which is essentially the air-conditioning system of the aircraft. A problem with the F/A-18 breathing gas system as a whole is that the OBOGS gets fed last, according to the report. The enormous amounts of cooling air required for avionics and radars (particularly on the Growlers) means that the ECS controls "preferentially direct flow to them," it concludes.

This is a particular problem for the newer Super Hornets and the Growlers, which have substantially larger demands for airflow than legacy aircraft, due to the sheer amount of electronics stuffed onto the airframe. Despite the increased demand for cooling air, key ECS components and primary ducting systems are essentially unchanged, the NASA team writes.

They also pointed out that significant changes in cabin pressure can occur due to the way the Cabin Pressure System is designed. There is no active pressure control in the cockpit, and there is a general lack of data about how the ECS performs in a real-life flight environment, according to the report.

Further, the Navy appears to have little insight into elements of the ECS control programming logic, because this information was not part of the original contract deliverable for the F/A-18—which was first fielded in the 1980s—"and therefore may no longer be documented in any form," the NASA team writes.

Joyner disagrees with the NASA conclusion that the ECS controls preferentially direct flow to the avionics over the OBOGS. However, she agrees that the Navy needs to better regulate the ECS to ensure steady airflow.

The service is implementing eight "corrections" to the ECS to try to "smooth the flow," she told the subcommittee. Meanwhile the legacy Hornets are undergoing a phased ECS overhaul, which will include replacing several critical components such as valves, duct lines and brackets. In addition, the Navy is working with Boeing to upgrade the ECS software on the F/A-18 and EA-18G Growler to mitigate fluctuations in cabin pressurization due to moisture freezing in the system's piping, Joyner says.

The service also intends to develop and install a new system to monitor cabin air pressure and alert the pilots to any abnormalities as well as to replace the F/A-18's cabin pressure regulator valve, Joyner confirmed during the hearing. Right now, aircrew carry "SlamSticks," small pressure recording devices, on all sorties to help investigators track and collect cabin pressure data.

The Navy has constructed an ECS laboratory to further investigate the issue, according to Joyner's testimony.

She cited the success of the changes the Navy has made to the T-45 Goshawk trainer as reason for Congress to have confidence in the PE team's approach to the F/A-18. After a similar cluster of PEs caused the service to ground the Goshawk fleet in April, the T-45s are now fully operational, Joyner says.

In addition to updating maintenance and cleaning procedures for the T-45's OBOGS, the PE team also installed new sieve beds—to filter out contaminants—and a new water separator, and incorporated a carbon monoxide catalyst, according to Joyner's testimony.

The Navy also fielded new CRU-123 solid-state oxygen-monitoring units, which alert aircrew of changes in delivery changes. This ability to log data has provided "invaluable" insight into the performance of the T-45 oxygen system and given aircrew "new confidence," Joyner says. As of Jan. 24, a total of 163 new oxygen monitors have been installed.

The Navy has also released a draft RFP for a new T-45 oxygen concentrator, dubbed the GGU-25, which will be a "significant increase in capability" over the 1980s-era system the aircraft now uses, she adds.

"We have turned the corner on [the] T-45," Joyner says. But "we are not declaring victory. We have a Root Cause Corrective Analysis team that goes line by line, starting with the human, ending with the human, trying to find the root cause for both the T-45 and the F/A-18 [PEs]."

The Navy plans to install an automatic backup oxygen system on the T-45, but it has no plans to install a similar system at this time on the F/A-18, Joyner confirmed in response to questions from Tsongas.