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HOUSE ARMED SERVICES COMMITTEE  
SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES  
U.S. HOUSE OF REPRESENTATIVES

DEPARTMENT OF DEFENSE

PRESENTATION TO THE  
HOUSE ARMED SERVICES COMMITTEE  
SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES  
U.S. HOUSE OF REPRESENTATIVES

SUBJECT: F-22 Pilot Physiological Issues

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Director of Operations, HQ Air Combat Command

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## **Introduction**

The F-22 Raptor contributes significantly to our nation's vital interests by providing Air Dominance, when and where ordered, to protect and enable the joint U.S. military force. Today, we have F-22's forward deployed to support the objectives of geographic combatant commanders in the Central Command and Pacific Command areas of operations. This forward presence reassures our allies, enhances joint and coalition interoperability, and demonstrates our resolve for lasting global partnerships. We also have CONUS-based F-22's contributing to Homeland defense while the remainder of the fleet conducts combat mission ready training, formal replacement unit training and operational test & evaluation. The F-22's attributes: stealth, supercruise, maneuverability and integrated avionics ensure our ability to project power anywhere on the globe; including anti-access and area denial environments. Simply stated, the F-22 fleet, combined with complimentary capabilities from our joint partners allows us to "kick down the door" and enable joint operations in the most demanding environments that exist now and in the foreseeable future. The F-22's multi-mission capabilities allow us the ability to seize the initiative, achieve air superiority, attack those who challenge us in the skies and to defeat those who would challenge us from the ground. The F-22 contributes significantly to protect the joint force from attack and enables the joint force to conduct offensive operations.

The capabilities of the F-22 weapon system are compelling, but without the contributions of the men and women who fly, fix and support F-22 operations, the Raptor would not be able to contribute to our nation's objectives. Flying high performance fighter aircraft is not risk-free, but the risk is measured against mission priorities and probabilities of success. Just as other Airmen and members of the joint force accept risk in the conduct of their daily military duties,

we accept risk in operating the F-22. However, in May 2011 the Air Force faced with grave concern the number of unexplained physiological incidents occurring in F-22 training operations. This concern was amplified by the ambiguity of a fatal F-22 flight accident at Elmendorf AFB on 16 November 2010. Although the total percentage of physiological incidents at the time of the stand-down was less than 0.1%, that small number was not good enough to meet our service-established safety standards. The risk to the safety of our Airmen, posed by uncertainty and ambiguity, exceeded our threshold.

The Air Force made the decision to stand-down the fleet while increasing investigative efforts and took time to measure risk carefully. The Air Force expanded analytic capabilities beyond the use of normal governmental resources to include additional expertise from the public and private sectors. After months of research and analysis, the USAF Scientific Advisory Board's aircraft oxygen generation quicklook study group provided recommendations to the Air Force in September 2011 for a path to safely return the F-22 fleet to flight operations with an acceptable level of risk. The recommendations were accepted, implemented and the F-22 fleet returned to flying status on September 21, 2011. Between September 2011 and now, the Air Force has continued to analyze the root cause of previously unexplained physiological incidents, implemented/adjusted risk mitigation measures, and incorporated corrective actions to enhance the safety of the F-22 Raptor fleet. The Scientific Advisory Board's aircraft oxygen generation quicklook study group, hereafter referred to as the SAB study group, completed its effort in January 2012. Following the SAB study group's presentation to Air Force leaders, the Secretary of the Air Force commissioned the F-22 Life Support Systems Task Force to continue the analytic effort to determine root cause and implement corrective actions. The scope and impact

of these collective efforts are outlined below in response to your questions posed to Secretary of the Air Force Michael Donley on July 23, 2012.

### **Investigation Efforts and Explanation Timeline**

The Air Force began initial F-22 operational testing in 2003 and achieved initial operational capability in December 2005 at Langley AFB. From 2003 to the spring of 2008 the total number of physiological incidents in the F-22 was six (6). From the spring of 2008 to May 2011, when the stand down occurred, the total number of physiological incidents increased. The increase during this timeframe, combined with the ambiguity surrounding Captain Haney's tragic accident, and the inability to determine a root cause gave the Air Force grave concern. This concern prompted a series of investigations and advisory boards to find and fix the conditions creating the incidents. A "physiological incident" is anything affecting the pilot, either external or internal to the pilot, resulting in reduced or impaired human performance. Pilots have experienced symptoms both in-flight and after landing. Physiological incidents are self-reported by pilots and support personnel. It is important to note that physiological symptoms such as dizziness, cognitive impairment, headache and light-headedness are common symptoms that cross the boundaries of hypoxia, dehydration, fatigue, toxic exposure and hypocapnia. This ambiguity of matching symptoms to root cause proved to be challenging and in some cases unresolved.

From 2003 to the spring of 2008 there were no "physiological unknown" incidents. Following the third "cause unknown" physiological incident in 2008 the F-22 System Program Office (SPO) established the Root Cause and Corrective Action (RCCA) team. The Air Force

recognized the reported F-22 physiological incident rate was significantly higher than other Air Force aircraft and expanded the investigative effort beyond the RCCA in 2009.

As systems vulnerabilities were discovered, the Air Force implemented material and non-material changes, including; imposing altitude restrictions, amending onboard oxygen system use procedures and other minor hardware/software changes. Notably, the Air Force directed pilots to select the “MAX” setting on their oxygen regulator panels to increase the oxygen concentration delivered to pilots during flight operations. This guidance will be discussed later as contributory to a further increase in F-22 pilot physiological symptoms.

A fatal F-22 crash on 16 Nov 2010 at Joint Base Elmendorf-Richardson, Alaska ended tragically with the loss of Captain Jeff Haney. This tragedy further raised concerns of the viability of the aircraft’s life support systems. The Air Force convened a General Officer-led safety investigation board followed by a separate General Officer-led accident investigation board to determine the cause and factors surrounding the conditions of this fatal mishap. Additionally, the Air Force initiated a life support system quick-look review in December 2010. This life support system analysis of F-22 physiological incidents operated in parallel to the ongoing Lockheed Martin root cause and corrective action (RCCA) analysis. Air Combat Command also established an integrated process team (IPT) to review the findings of the quick-look review and to assess the F-22 onboard oxygen generating system (OBOGS). In January 2011, the Commander of Air Combat Command expanded the investigation by directing a General Officer-led review of current oxygen systems in the A-10, F-15E, F-16, F-22, F-35 and T-6 aircraft by creating an OBOGS and aircrew flight equipment safety investigation board.

This multi-aircraft review safety investigation board, in conjunction with the RCCA, directed F-22 comprehensive ground, flight and life support systems component testing. These tests collected air, fluid, and surface samples taken from the onboard oxygen generation system (OBOGS), environmental control system, aircraft engines, and cooling systems. This testing and analysis was conducted to determine the possibility of toxic compounds entering the pilot's air breathing system.

Expected aircraft fluids were identified throughout the aircraft. Those expected fluids were polyalphaolefin (PAO), engine oil, hydraulics, and JP-8 grade aviation fuel. Although there were indications of these fluids existing throughout the system, they were detected at levels significantly below hazard quotients. Of note, most of these fluids are not unique to the F-22 and are present on multiple aircraft weapons systems in the U.S. inventory.

The breathing regulator anti-G (BRAG) valve component testing began at Yeovil, United Kingdom by Honeywell (OBOGS manufacturer) in December 2010. The BRAG valve is one of the life support system components that permits the flow of oxygen from the OBOGS to the pilot. The purpose of these tests was to characterize the performance of the BRAG at various pressures. The tests showed the BRAG valve performed as specified in the F-22 design.

OBOGS carbon monoxide testing was conducted for the Air Force at Patuxent River, VA by the US Navy from January to March 2011. This testing focused on the possibility of carbon monoxide passing through the OBOGS units to the pilot at various input concentrations and

pressures. Testing also assessed transient conditions that might allow carbon monoxide to enter the pilot's breathing oxygen supply and to simulate typical F-22 oxygen usage profiles for possible carbon monoxide contamination. The Navy concluded the F-22 OBOGS filters carbon monoxide better in the pilot-selectable MAX operating mode than in the pilot selectable AUTO mode. Both modes' performance characteristics are comparable to OBOGS units installed on other Air Force and Navy aircraft in today's inventory (e.g. B-1, F-15, F-16, F/A-18).

Carbon monoxide site surveys and tests were conducted at all F-22 installations from January through March 2011 by the US Air Force School of Aerospace Medicine (USAFSAM). The purpose of these surveys and tests was to determine expected carbon monoxide levels in typical F-22 installation environments. Recorded carbon monoxide levels were unremarkable, with peak flight-line measurements at less than 50ppm (parts per million). The highest carbon monoxide level detected on the F-22 was 26 ppm for a period of less than 15 minutes.

To place this in perspective, the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) defined for an 8-hour time weighted average is 50 ppm and the short-term exposure limit (STEL) is 200 ppm for a 15 minute exposure. The American Conference of Governmental Industrial Hygienists (ACGIH) has established 25 ppm as the threshold limit value (TLV) for continuous exposure during an 8-hour workday/40 hour work-week schedule. The levels detected on the F-22 were well below the hazard index.

Command-directed Phase I F-22 flight testing was conducted at Edwards AFB from March through May 2011 to verify the veracity of the F-22 oxygen delivery system. Extensive

F-22 aircraft instrumentation allowed in-flight data recording and post-flight data analysis to verify the performance of the oxygen delivery system. This flight test effort and subsequent analysis allowed investigators to rule out specific environmental control system (ECS) and life support system components as contributory to previously reported unexplained physiological incidents. Analysts reviewed recorded F-22 flight data and eliminated low system pressure, pressure imbalances, OBOGS malfunctions, and electrical interruptions as systemic concerns.

OBOGS nitrogen bolus testing began in March 2011 by Honeywell, the OBOGS manufacturer, at their facility in Yeovil, United Kingdom under the supervision of the Air Force's F-22 system program office and Boeing's life support integrated product team. This testing was conducted to determine if a nitrogen bolus (or surge/burp) could be produced by the OBOGS and penetrate the oxygen delivery system into the pilot's breathing air supply. This testing was performed due to feedback from pilots reporting in-flight symptoms similar to symptoms induced during their ground-based hypoxia training. The Air Force uses the reduced oxygen breathing device for ground-based training so pilots become accustomed to their personal physiological symptoms in a controlled environment prior to flight operations. Several conditions were demonstrated in these tests to induce a nitrogen bolus from the OBOGS. No nitrogen "burps" were exhibited that dropped oxygen levels to a point of concern.

A few months later on 3 May 2011, the Commander, Air Combat Command directed a fleet-wide F-22 "stand down". The stand down followed a cluster of four F-22 physiological incidents occurring in a 6-day period (28 Apr – 3 May). The combination of the remaining ambiguities/uncertainties surrounding Captain Haney's fatal mishap, the recent cluster of in-



flight reports, discovery during investigative efforts, and feedback from the F-22 community led the commander to a decision to take a strategic pause in F-22 flight operations until a better understanding of the F-22 oxygen delivery system could be achieved. Simply stated, the risk to continue flight operations under these circumstances exceeded the threshold for service-accepted safety standards. The general officer-led OBOGS and aircrew flight equipment safety investigation board presented their findings to the Secretary of the Air Force (SECAF) and Chief of Staff of the Air Force (CSAF) on 10 May 2011. This group reported they were unable to determine root cause of events and recommended further investigation.

Additional ground testing was conducted at Joint Base Elmendorf-Richardson (JBER), Alaska in May 2011. Incident investigations were performed on the three JBER-based incident aircraft that were involved in the Apr-May cluster. The investigation team suspected the possibility of contamination in the oxygen delivery system based on the physiological symptoms reported by incident pilots. Testing including taking samples from the pilot breathing air supply, cockpit ambient air, and the OBOGS inlet air. The samples were sent to Columbia Analytical, an independent CONUS-based laboratory, for testing to determine the presence of volatile organic compounds (VOCs). These samples did not contain VOCs at a level that would result in symptoms or present a physiological risk to the pilot.

It was important to explore the potential of pilot and ground crew exposure to volatile organic compounds (VOCs) in the F-22. VOC exposure, in sufficient concentrations, can result in central nervous system effects that may impair performance. VOCs are present in all aircraft, examples are: petroleum, oil, hydraulic and other fluids. In order to evaluate this possibility, the

team obtained samples from the aircraft's oxygen delivery system and surrounding areas. Because of earlier concerns relating to the potential of contamination, this was key test data gathered during the stand down period.

The Air Force also tested air samples from the airflow surrounding the aircraft engines, or "bleed" air, at JBER to determine the presence/absence of contaminants which could produce physiological symptoms. These samples were sent to two independent laboratories (Columbia Analytical and Air Analytics) to check for the presence of volatile organic compounds (VOCs). The laboratories did not find VOCs at a level that would result in symptoms or present a physiological risk to the pilot.

Contaminant testing for the OBOGS, a key component of the oxygen delivery system, was conducted at Honeywell, Des Plains IL, from May to June 2011. Previous F-22 incident investigations on OBOGS units from incident aircraft suspected contamination as a cause based on pilot symptoms. OBOGS unit testing induced air and gas samples with known contaminants into the OBOGS inlet, then measured the OBOGS outlet for the VOCs to determine if the OBOGS had the ability to block the flow of contaminants and not allow them to proceed downstream to the pilot. Numerous contaminants were introduced to determine the OBOGS filtration capabilities. Test conditions included humidity variability and pressure transients to see if contaminants could pass through the system under those circumstances. The OBOGS, when exposed to multiple contaminants during testing, was able to filter them effectively. After many attempts, engineers were not able to create a condition that released a contamination bolus into the airstream.

Following the F-22 fleet wide stand down, on 3 May 2011, the Secretary of the Air Force directed the Air Force to convene a Broad Area Review (BAR) team to investigate ongoing systems safety issues involving aircraft oxygen generation and life support systems. The Chief of Staff of the Air Force selected General Gregory S. Martin (USAF, Ret'd) to lead the BAR to continue the evaluation of the F-22 oxygen system to identify the root cause of reported hypoxia and similar physiological incidents.

The Air Force also directed the Air Force Safety Center to establish a comprehensive safety investigation board to continue the investigative efforts originated by the OBOGS and aircraft flight equipment safety board which deliberated from Jan-May 2011.

Later in Jun 2011, the Secretary of the Air Force commissioned the AF Scientific Advisory Board (SAB) to redirect the Broad Area Review into a comprehensive quick look study on aircraft oxygen generation (QLSAOG), led by Gen (Ret'd) Martin. This process change leveraged the capabilities of the Scientific Advisory Board study group's ability to provide advice as stipulated in the Federal Advisory Committee Act of 1972.

The Air Force Safety Center's investigative board worked in consultation with Gen (Ret'd) Martin's SAB study group and facilitated quick access to safety, testing and analytic data. The Air Force Safety Center's goal was to complete the ongoing contaminant testing, test an aircraft-mounted independent oxygen warning system, determine the need for an air filter system, and aid the F-22 fleet's return to flight operations.

During the stand down period, Phase II flight testing continued at Edwards AFB from July through September 2011. The purpose of this test phase was to further examine the oxygen delivery system's ability to provide the proper oxygen "quantity" and "quality" to F-22 pilots. This test phase added an aircraft engine and an OBOGS unit from two separate reported physiological incidents. Test profiles were developed to determine if the incident engine, which had produced oil leaks, would permit the ingestion of volatile organic compounds (VOCs) into the oxygen delivery system. The OBOGS unit was tested to determine if the volume of airflow under certain conditions would produce less air quantity than required to meet physiological demands by the F-22 pilot. These tests produced satisfactory results for both the quality and quantity of air provided to the cockpit.

On 9-10 August 2011, the Air Force presented a comprehensive review of the previous F-22 safety investigations, status of ongoing investigations, and ground/flight test results to F-22 wing commanders and major command directors of operations and logistics. The Air Force deemed necessary this "community" engagement session to communicate directly from the investigators and testers to the leaders who were charged with the daily conduct of flight and ground operations across the F-22 community. The session was well received by the commanders and they used the information gained during this session to communicate directly with their pilots, maintenance and support personnel, as well as, family members about the status of the F-22.

Later in August 2011, the Air Force determined they had gained sufficient knowledge, identified key life support systems vulnerabilities, and mitigated future flight risk by implementing protective measures that would permit the safe return to flight operations. The SAB study group presented recommendations to the Air Force which entailed a 5-step process: inspect the fleet, train the force, protect the crews, collect data, and analyze data. The recommendations were accepted by the Air Force and implemented by Air Combat Command, Pacific Air Command and Air & Education Training Command F-22 units. The Air Force conducted end-to-end recurring life support systems inspections on each aircraft, communicated root cause analysis and safety measures, enhanced safety measures with additional equipment and protocols, and improved the knowledge and understanding of physiological factors. Medical response protocols were developed to ensure rapid and thorough post-incident response and treatment. The medical community established blood and pulmonary baselines for all relevant F-22 flight/ground crew members. These baselines were stored and held for use in comparison to future post-incident blood, urine and pulmonary test samples to prove/disprove the presence of toxic exposure.

The Commander, Air Combat Command tasked me to implement the SAB study group's recommendations and to return the F-22 fleet to flight operations in late August 2011. The SAB study group's recommendations were:

1. Incorporate additional aircraft life support inspections and modifications
2. Standardize OBOGS equipment to the "-109" configuration
3. Implement an OBOGS ground-based maintenance inspection procedure

4. Modify pilot life support equipment to incorporate the use of the C2A1 chemical warfare filter
5. Implement new post-incident medical and logistics protocols
6. Collect medical baseline blood samples for pilots and selected maintenance personnel who perform engine ground-run tests
7. Conduct baseline pulmonary function tests for pilots
8. Incorporate finger-mounted pulse oximeters into aircrew flight equipment
9. Eliminate the 25,000' mean sea level altitude flight restriction
10. Communicate the results of the investigations, testing and the advisory board's findings

In addition, Air Combat Command directed F-22 units to accomplish life support academics, emphasized oxygen delivery/life support emergency procedure training, and initiated guidance that directed pilots to terminate flight operations at the first sign/symptom of a physiological event.

The F-22 community resumed flight operations on 21 Sep 2011 after the Secretary of the Air Force approved the F-22A "Return to Fly" Plan. The plan integrated the collective inputs of the operations, logistics, medical, safety and advisory board disciplines that had investigated the F-22 over the previous 3 years. The determination to resume flight operations balanced the current understanding of risk and the operational imperative to retain the readiness of the nation's Air Dominance fighter fleet. Pilot combat mission readiness skills are a perishable skill set. Some skills are retained through the use of flight simulators, other skills are not. Emerging

insights from the 16 Nov 2010 fatal mishap--insights delayed by the inability to excavate the crash site until the summer thaw in Alaska, new inspection criteria for F-22 life support system components which ensure the veracity of the components, testing which began to eliminate ambiguities/uncertainties of previous physiological incidents; all coalesced to permit a thoughtful calculation to resume flight operations.

The objectives of the "Return to Fly" Phase, which comprised the period September 2011-January 2012, were to: safely return to flight operations, provide enhanced protection to crews, collect and analyze data from future incidents which could contribute to mishap prevention, and return the F-22 community to pre-stand down readiness status. During this phase the Air Force flew more than 7,500 sorties totaling nearly 9,000 flight hours. The overall reliability of the life support systems, including the oxygen delivery system was 98.4%, in line with other Air Force high performance aircraft such as the F-15 and F-16. However, there were six (6) reported flight-related physiological incidents and six (6) reported ground operations-related physiological incidents. This incident rate showed an increase from pre-stand down incidents. We attribute this increase to higher-headquarters guidance to report incidents at the first sign of a symptom and increased sensitivity to physiological symptoms. Air Combat Command instructed pilots and support personnel to terminate their flight or ground-based activities at the first sign of a physiological symptom. This approach allowed the Air Force to respond quickly to all incidents, provide medical response to the incident member and then conduct further analysis on the incident aircraft. We believe this was a prudent measure to reinforce the "safety first" culture embraced by the Air Force. Later investigative research identified that physiological symptoms are ambiguous across the spectrum. Every incident

member was screened for blood, urine and pulmonary indications of toxic exposure and none recorded remarkable levels of toxicity.

The SAB study group and Air Force Safety Center's investigation board continued their research and analysis through the "Return to Fly" phase. As further insights emerged, they passed results to Air Combat Command, the lead command for operating the F-22 weapon system.

The SAB study group presented their final findings and recommendations to the Secretary of the Air Force and the Chief of Staff of the Air Force on 24 Jan 2012. At the conclusion of that presentation I was directed to lead the effort that would continue root cause analysis and corrective actions, in addition to my ongoing duties as the Air Combat Command Director of Operations, where I had led the effort implementing previous recommendations for the F-22 "Return to Fly" phase. We created the F-22 Life Support Systems Task Force to execute the tasks assigned to me by the Secretary of the Air Force, hereto referred to as the "Task Force". This marked the end of the "Return to Fly" phase. All of the SAB study group's initial recommendations were implemented, results were accepted by the Air Force and F-22 units had returned to pre-stand down readiness levels during this period of time.

25 Jan 2012 marked the beginning of "Transition Operations" as cited during the SAB study group's presentation to the Secretary of the Air Force. Air Combat Command's intention during the "Transition Operations" phase was to resume operational deployments and aircraft



transfer flights while continuing root cause analysis and implementing additional corrective actions to enhance safety.

The Task Force consists of a cross-functional, cross-command, multi-disciplinary, government/industry team of professionals who are dedicated to returning the F-22 Raptor fleet to normal operations while enhancing the safety margin for the men and women who fly, operate, maintain and support the weapon system. The Task Force's goal is to maintain the nation's 5<sup>th</sup> generation air dominance combat power to meet global combatant commander requirements. To do so, the Task Force incorporated and integrated all previous investigative efforts relating to the oxygen delivery system and expanded the investigation to include all components of the pilot's life support systems. Additionally, we have sustained the momentum of the government/industry team which was initiated by the SAB study group, continued root cause analysis and implemented corrective actions. The Task Force has done this while emphasizing regular and recurring communications with Air Force leadership and F-22 community members.

The Task Force's charter included accepting and completing eight (8) near-term actions recommended by the Scientific Advisory Board's study group. Those actions are:

1. Implement improved access to and ease of activation of the emergency oxygen system
2. Implement an independent post-breathing/anti-G O2 sensor providing indication, warning and recording capability
3. Field a helmet-mounted pulse oximeter

4. Consider installing carbon monoxide and carbon dioxide detectors in F-22 cockpits
5. Consider using a vacuum canister during maintenance engine runs to collect and assess breathing air should a ground-based incident occur
6. Leverage NASA or similar independent capabilities, develop and implement appropriate post-incident protocols for enhanced forensic analysis of the F-22 life support and cabin pressurization systems
7. Analyze data gathered from C2A1 chemical warfare filters to determine the effectiveness for safety and contamination considerations
8. Identify the need for contaminant mitigation measures for OBOGS and cockpit breathing air

The Task Force expanded analytic efforts by collaborating with the US Navy's Experimental Dive Unit (NEDU), the Naval Surface Warfare Center Panama City Division (NSWC-PCD), and the National Aeronautics and Space Administration (NASA). Sub-teams formed inside the Task Force, such as the Physiological team and the Toxicologists & Doctors team, included members from the Air Force, Navy, NASA, Lockheed-Martin, Boeing, Honeywell, and peers from academia. Additionally, NASA formed an independent analysis team to review the Air Force's investigative process with a focus on identifying gaps in our analysis and providing recommendations on post-incident response protocols. This independent analysis was included as a welcome contribution based on NASA's expertise in developing/operating life support systems for astronauts and their accident investigation expertise.

Once unit readiness was returned to pre-stand down levels in January 2012, the Task Force implemented the next step to build confidence further by reinstating long duration flights. The first long-duration flight was flown on 7 February 2012 between Holloman AFB, NM and JBER, AK; a duration of greater than seven (7) hours. Deployment procedures were added to enhance safety margin. We placed an experienced F-22 pilot on the refueling aircraft that accompanied the F-22s during their flight. This safety observer had technical orders and publications at his side, as well as, the ability to contact Lockheed-Martin for technical expertise real-time should the need arise. Additional fuel was added to the refueling aircraft, should the need arise, for an F-22 pilot to descend to a lower altitude (below 14,000' mean sea level) with a life support malfunction, "dump" his cockpit air and open valves to bring outside ambient air into the cockpit as an alternate breathing source. It should be noted that after more than 70 long-duration movements, no F-22s have experienced a life support malfunction - but this precautionary measure serves as a reliable alternative.

During this same time frame, Major (Doctor) Marsha Mitchum, an F-22 flight surgeon at Joint Base Langley-Eustis, conducted independent research with Duke University and the Naval Surface Warfare Center, Panama City, FL. Through her efforts and coordination the Naval Experimental Dive Unit became involved to offer an assessment on life support issues and breathing devices. This research opened a door for new analysis that had not been addressed to this point in the Air Force investigative process. This would turn out to be a decisive moment for the F-22 investigative efforts.

Despite continuing investigative efforts and risk mitigation steps, physiological incidents continued. Following a cluster of four (4) previously unexplained physiological incidents at Joint Base Elmendorf-Richardson, AK in a two-week period beginning on 15 February 2012, the Commander, Pacific Air Forces directed the creation of a safety investigation board (SIB) led by a General Officer from the Pacific Air Forces' staff. This SIB focused its' efforts on the recent incidents at Joint Base Elmendorf-Richardson. Their research and analysis was included in the Task Force's ongoing efforts. The SIB's findings and recommendations provided additional knowledge on localized conditions and other factors contributing to F-22 physiological incidents. Notably, we gained insights on the potential physiological effects created by multiple layers of clothing and aircrew flight equipment which are designed to protect crews across the high altitude, high-G, cold weather and water immersion environments. Additionally, the impact of event "clusters" and the human factors associated with two or more incidents occurring at a single location in a short timeframe began to emerge.

In March 2012, as a result of Dr Mitchum's collaboration, F-22 life support system impedance testing was initiated at the NEDU facility in Panama City, Florida. Emerging insights indicated previously unexplained incidents could be linked to causality associated with an inadequate quantity, or volume of air, reaching the pilot's mask. The need to characterize oxygen partial pressure drops between the BRAG valve, located in the cockpit, and the pilot mask was addressed. Also, based on the NEDUs previous research on Naval underwater diver physiological incidents, the team evaluated the level of effort, or "work of breathing", required to draw sufficient volume of air through the oxygen hose to satisfy the pilot's physiological demand. Oxygen partial pressure drops were characterized for all life support system

components (e.g. oxygen hoses, quick disconnects, pilot mask, BRAG valve) to determine the veracity of the overall life support system. The “work of breathing”, or the level of effort required to draw sufficient air volume, was judged excessive at high breathing rates by the NEDU.

At the same time from February to March 2012, we initiated unmanned altitude chamber testing at the Brooks City/Wyle Test Facility in San Antonio TX. The goal of this testing was to characterize the OBOGS’ performance and, similar to NEDU testing, evaluate the effects of air escaping from the oxygen delivery system’s components enroute to the pilot’s mask. OBOGS performance exceeded oxygen flow conditions specified for the F-22. The tests verified some air escaped from the components but not to a degree that would negatively impact flow to the cockpit. Testing also focused on the the possibility of diminished air pressure delivered to the BRAG valve located inside the cockpit. The team investigated decreased oxygen concentration during normal accelerations (g). A mask-mounted carbon dioxide (CO<sub>2</sub>) sensor and flow meter was evaluated for inclusion in future flight test. Observations of mask pressure compared to vest pressure during normal accelerations were noted. This test replicated the parameters for one of the February 2011 incident aircraft to identify systemic conditions in the oxygen delivery system. Oxygen delivery leakage did not affect g-suit or oxygen delivery performance to the pilot. Although the test showed reduction in oxygen concentration during sustained g’s due to the increased demand on air volume to fill the lower anti-g garment, this reduction did not create adverse effects to the pilot breathing air supply. The mask-mounted carbon dioxide sensor functioned intermittently but produced invaluable test data on airflow parameters. Both the man mounted flow and pressure sensors worked well throughout the testing and matched lab sensor

performance.

Additional pre-flight testing for life support system integrity and impedance occurred at Brooks City/Wyle in March 2012. This test period consisted of man-in-the-loop events to evaluate the breathing resistance in the altitude chamber to ensure adequate replication of the F-22's oxygen delivery system. The altitude chamber allowed the team to expose pilots to the representative flight altitude environment under controlled parameters. It was crucial for the team to observe and assess aircrew flight equipment configurations and the equipment's interaction at varying atmospheric conditions. Pilot evaluations noted the altitude chamber's system impedance was slightly less than the actual aircraft, but deemed a satisfactory replication.

The F-22 Restricted Breathing Working Group (RBWG) convened on 10-11 April 2012 at Langley AFB. The Task Force facilitated this session which consisted of F-22 pilots, engineers, medical and safety professionals from Air Combat Command, 1<sup>st</sup> Fighter Wing, 633<sup>rd</sup> Medical Group, 711th Human Performance Wing (HPW), Navy Experimental Dive Unit (NEDU), Naval Surface Warfare Center-Panama City Division (NSWC-PCD), NASA, Naval Air Systems Command (NAVAIR), Wyle Labs, Lockheed-Martin and Boeing. The purpose of the RBWG was to analyze F-22 pilots' breathing system and associated physiological risks.

Events throughout the two-day working group included an introduction to F-22 aircrew flight equipment (AFE) provided by an experienced F-22 instructor pilot (IP), and a demonstration of the various AFE configurations used in flight operations; cold weather immersion suit, advanced technology anti-G suit (ATAGS), Combat Edge upper pressure

garment vest, harness and life preserver units. Pilot testimony and a subjective breathing system/AFE overview was provided by four pilots who had extensive experience in the F-15, F-16, T-38 and F-22 aircraft. This interaction between F-22 pilots and members of the analytic community proved to be a key event in root cause analysis.

In April 2012, we began the manned altitude chamber testing at the Brooks City/Wyle facility. The man-mounted sensor suite measured the pilot's breathing rate, mask and Combat Edge upper pressure garment (UPG) pressure, as well as, exhaled CO2 levels. Initial insights from this testing showed the first indication of vulnerabilities in the Combat Edge upper pressure garment as integrated into the F-22 life support system. The C2A1 filter also showed breathing resistance but met the international-accepted air standards coordinating committee (ASCC) air breathing standard.

The C2A1 filter use was implemented as a "Return to Fly" mitigation to permit filtering of potential VOCs in the oxygen delivery system. Rather than discarding the filters after each flight, the task force collected and sent the C2A1 filters to the Columbia Analytic laboratory to determine whether VOCs were present, and if so, at what levels. C2A1 filters from incident aircraft, as well as a random sampling of non-incident aircraft, were analyzed to determine if there was a high enough levels of contaminants in the breathing system that could impair a pilot's central nervous system.

The process of testing and analyzing C2A1 filters was lengthy and took several months to develop. This was a ground-breaking effort that had not been used before. After the process was

in place, it took several months to analyze a sufficient number of filters to provide statistical relevance. While the Task Force awaited filter analysis results, some pilots expressed concerns about the presence of charcoal particles in the breathing lines and about the breathing impedance created by wearing the filter during F-22 flight operations. Although the charcoal was inert, the Task Force directed medical personnel to perform throat swab tests to determine if particles were entering the pilots' mouth and lodging in their throats. No presence of particles was found during these tests. The Task Force directed Boeing to test the filter impedance and to quantify the C2A1 canister analysis results. The tests showed the filter impedance performed within the chemical-biological aviation standards coordinating committee's (ASCC) standard and conclusively showed that there were no significant levels of VOCs found in the C2A1 canister.

Boeing, the lead for filter analysis, presented results to the Task Force in early April 2012. Acting on the Task Force's recommendation, the Commander, Air Combat Command, directed the removal of the C2A1 filter from further use in F-22 flight operations. Analysis revealed low levels of VOCs, well below hazard levels and this risk mitigation was no longer deemed necessary..

In May 2012, we initiated manned centrifuge testing continued at Brooks City. The team evaluated the performance of the man-mounted sensor suite with a variety of pilot ensembles under g-acceleration forces that replicated F-22 flight operations. This test evaluated F-22 pilots from the two bases where in-flight physiological incidents had occurred during the post-stand down period to see if cold weather gear, or other life support system ensemble equipment, contributed to the in-flight incidents. The sensor suite measured the pilot's breathing rate, mask



and Combat Edge upper pressure garment (UPG) pressure, as well as, exhaled CO<sub>2</sub>. This testing corroborated the impacts of UPG breathing restrictions and C2A1 chemical warfare filter breathing impendence. The man-mounted sensor suite performed well throughout the testing and served as a viable collection method for subsequent in-flight testing.

The task force began to address acceleration atelectasis as the potential cause for “Raptor cough”. “Raptor cough” is one of the symptoms that is systemic in the F-22 pilot fleet. Pilot testimony revealed pilots felt the urge to cough sometimes during, but mostly after flying F-22 sorties. The cough is caused by the high oxygen concentration levels provided by the OBOGS which displaces nitrogen from the breathing air supply. Nitrogen is an inert gas which is slowly absorbed into the blood stream through the lungs in normal breathing air. In a non-oxygen rich environment, the nitrogen normally remains in small sacs in the pilot’s lungs, known as alveoli, and the oxygen flows to the blood stream. When exposed to high levels of oxygen, the alveoli will naturally collapse due to the lack of nitrogen. Once re-exposed to ambient air conditions after flight, nitrogen enters the pilot’s lungs and the alveoli begin to re-inflate. The natural human response to aid in the re-inflation of the alveoli is either deep breathing or coughing. Atelectasis is common in high oxygen rich aviation environments and has been well documented in aviation studies dating back as early as 1965 by the US Navy.

In Aug 2012, we began Phase III flight testing at Edwards AFB to validate the ground testing performed at the Brooks City/Wyle altitude chamber and centrifuge facilities. The team measured in-flight mask pressure, Combat Edge upper pressure garment (UPG) pressure, pilot breathing rates, as well as, exhaled CO<sub>2</sub>. Initial flight data review shows similar results to

ground test events and validates conclusions reached from the earlier testing. One significant finding from flight test indicates system impedance, an impediment to oxygen flow through the life support system, appears to be more of a factor in the aircraft than seen in ground testing at Brooks/Wyle. Additional flight test data will be captured in the coming weeks to enrich our understanding of impedance.

Analysis and testing through August 2012, in an integrated manner across governmental and industry partners, led to an acceleration of knowledge gained to solve the previously unexplained F-22 physiological incidents. The Lockheed-Martin Root Cause/Corrective Action (RCCA) team, in collaboration with the Air Force Research Laboratory (AFRL), 711<sup>th</sup> Human Performance Wing (HPW), Air Force Research Labs, US Air Force School of Aerospace Medicine (USAFSAM), the Naval Surface Warfare Center Panama City Division (NSWC-PCD), the Navy Experimental Diving Unit (NEDU), NASA life support team and a team of military and civilian physiologists, toxicologists, were integrated through the Task Force's investigative process. This collaborative cross-industry, cross-government, multi-service effort increased breadth of experience, enhanced scope of knowledge, and provided additional impartial expert analysis, which was critical in the determination of contributing factors to previously unexplained physiological incidents.

To date, in the Transition Operations phase, we have flown more than 11,600 sorties totaling over 14,900 hours and have encountered six (6) previously unexplained in-flight and zero (0) ground-related physiological incidents. Importantly, we have not encountered an

unexplainable incident since March 8, 2012 and we have flown more than 9,500 sorties totaling nearly 12,000 flight hours since that incident. The “cause unknown” physiological incident rate during the Transition Operations phase is 0.05% per sorties flown or 1 incident per 1,933 sorties flown. The trend is on a positive vector not seen in years.

On 28 August 2012 the F-22 system program office-direct root cause & corrective action (RCCA) analysis team presented their findings and recommendations to the Task Force. The RCAA investigative process identified and closed 414 fault branches, identified 10 factors, and provided four (4) recommendations. Those recommendations are:

1. Redesign the upper pressure garment fill/dump valve
2. Revise the OBOGS oxygen (concentration) delivery schedule
3. Redesign the oxygen delivery hose pass-through panel
4. Assess internal impedance in oxygen delivery hoses and connection points

On 30 August 2012, the Task Force provided an update to the Scientific Advisory Board’s study group. The update included a review of the task Force’s activities, recent investigation results, findings and recommendations. Those findings and recommendations will be discussed below.

### **Characterization of Hypoxia Events**

The Air Force has experienced a physiological incident rate with the F-22 weapon system that is significantly higher than comparable high performance aircraft. That said, none of these incidents have involved loss of life or loss of aircraft control. Each of these incidents resulted in

the safe and controlled recovery of the F-22 aircraft. None of these incidents have resulted in long-term or lingering physiological effects. Pilots and mission support member who have reported a physiological incident has been medically screened by Air Force aerospace physicians and returned to normal duty status.

Two hypotheses were developed by the Scientific Advisory Board's (SAB) study group to define root cause analysis. These hypotheses and associated research conducted by the SAB study group were the starting point for the Task Force's analysis. The hypotheses are:

Hypothesis 1: Oxygen quantity - The F-22 oxygen delivery system is failing to deliver adequate O<sub>2</sub> to the pilot, resulting in hypoxic symptoms that threaten safety of flight;

Hypothesis 2: Oxygen quality - The F-22 oxygen delivery system is either producing or failing to filter a toxic compound(s) in the O<sub>2</sub> to the pilot resulting in hypoxic-like symptoms that threaten safety of flight.

Hypothesis 1 (oxygen quantity) Task Force analytic efforts focused on the F-22 onboard oxygen delivery system's (OBOGS) ability to produce sufficient oxygen concentration levels and volume of breathable air to pilots. We conducted initial centrifuge and altitude chamber testing in the spring of 2012. This testing produced empirical data that verified the OBOGS' ability to meet F-22 system level specifications for oxygen concentration and breathable air volume. This initial data revealed a previously unknown characteristic of the F-22 aircrew flight ensemble. The pilot mask and upper pressure garment, when measured as an integrated ensemble, did not function in the manner they were designed to operate.

The Combat Edge upper pressure garment (UPG) was designed and introduced to the F-15/F-16 pilots in the early 1990's after years of research to counteract the effects of high G acceleration environments. The UPG was one of numerous changes made to pilot protection after G-induced loss of consciousness accidents began to occur in the 1980's. The Combat Edge UPG was designed to inflate in concert with positive pressure breathing schedules in the 4-9 G acceleration range. The Combat Edge UPG was also designed to provide pilot protection in the event of a rapid cockpit decompression at high altitudes (above 50,000 feet mean sea level). Notable, the Air Force made the decision to remove the Combat Edge UPG from legacy (F-15, F-16) fighter aircraft operations in 2005 when further research deemed it was not necessary to wear the garment in the high-G environment. The garment use was continued on the F-22 due to the routine high altitude flight regime used in F-22 flight operations to retain pilot protection in the unlikely event of a rapid decompression.

The Air Force Research Laboratory's (AFRL) 711<sup>th</sup> Human Performance Wing (HPW), Air Force Research Labs, and the US Air Force School of Aerospace Medicine (USAFSAM) determined that the Combat Edge upper pressure garment (UPG) prematurely filled and retained pressure at all times. This premature fill creates a condition that requires pilots to labor beyond normal breathing exertion rates under benign flight conditions. However, the F-22 is designed to provide a continuous low oxygen pressure flow to the pilot under all flight conditions and this positive pressure flow prematurely inflates the Combat Edge UPG and creates pilot breathing restrictions. The UPG garment inflates, and remains inflated, in all flight regimes. Hence this component of the aircrew flight ensemble which was designed to assist with pilot breathing

under high-G flight conditions makes it harder for F-22 pilots to breath under routine flight conditions.

The most recent unexplained F-22 physiological incident occurred on 15 Nov 2011. Task Force analysis, integrated with analysis/research conducted by previous investigative bodies, have identified multi-factorial contributors to subsequent previously unexplained incidents, as well as, most of the prior incidents that occurred in the 2008-2011 time frame. The Task Force recommended removing the Combat Edge UPG as a result of ground-based testing in the altitude chamber and centrifuge. The UPG was removed from F-22 flight operations on 8 June 2012. This past summer testing shifted from identifying life support system vulnerabilities, such as oxygen concentration and air breathing volume, to identifying corrective action to the Combat Edge UPG and its components. Testing at Brooks/Wyle is focused on a modified Combat Edge UPG valve, designed to integrate with F-22 specifications which differ from legacy aircraft specifications, as well as testing other life support system modifications to oxygen delivery hoses and connection points. The modified Combat Edge UPG valve will prevent the UPG from inflating during flight operations below 4 G's—as originally intended. The valve will support inflation of the UPG during high G maneuvering and rapid decompression—as originally designed.

We asked the Naval Surface Warfare Center Panama City Division (NSWC-PCD) and the Navy Experimental Diving Unit (NEDU) to evaluate the veracity of our oxygen delivery system and life support system components. The NEDU, based on their expertise and experiences with underwater breathing apparatus, identified potential vulnerabilities in the F-22

life support system components. The NEDU tested equipment at increased breathing rates and evaluated oxygen pressure drops (leaks, escaping oxygen) at various points in the oxygen delivery system located inside the F-22 cockpit. Extremely valuable, the NEDU evaluation was repeated at the Brooks City/Wyle facility. These two laboratories allowed us the opportunity to compare tests results and compare the outcomes to the international-accepted air breathing standards established in 1988 by the air standards coordinating committee (ASCC). The NSWC-PCD evaluated the F-22 life support system from an engineering aspect, isolated areas of concern, and recommended potential improvements. The Air Force provided key parts of the breathing system for evaluation by the Navy, including the following equipment:

1. Breathing Regulator and Anti-G Valve (BRAG) assembly
2. Emergency Oxygen System (EOS) Isolation Valve assembly
3. Integrated Terminal Block (ITB) Model CRU-122 or Model CRU-94
4. Combat Edge Upper Pressure Garment (UPG) Model CSU-17/P
5. Mask Assembly MPU-20/P
6. Hoses and fittings to connect all above components as installed in the aircraft

The Navy team focused on the F-22 life support system breathing characteristics between the Breathing Regulator Anti-G (BRAG) and the F-22 pilot's mask—all located inside the aircraft cockpit. Individual life support system component attributes and potential improvements to subsystem performance were addressed. Breathing simulator test measurements revealed excessive breathing resistance, as well as, insufficient breathing air volume during high demand conditions. It is important to note that current day testing capabilities allow us to measure these characteristics beyond the F-22 system specifications and international air breathing standards.

Analysis indicates minor modifications of one oxygen delivery hose and two oxygen delivery hose quick-connect fittings may reduce peak inspiratory resistance. These changes provide the opportunity to reduce pilot respiratory effort on every sortie flown by F-22 pilots. The impact of changes would vary for each pilot and would be dependent on sortie type. This proposed modification warrants further study and we are conducting the tests currently. Reducing the “work of breathing” during normal F-22 flight operation may eliminate some number of future in-flight physiological events for pilots who are operating on the margins of their normal physiological tolerances.

The Task Force sought NASA's assistance to review post-incident protocols and, if warranted, recommend enhanced procedures with a greater emphasis on integrated life support systems and cabin pressurization systems analysis. Concurrently, we requested NASA form an independent investigative team to review our investigative process, ongoing root cause analysis, and the entire F-22 Life Support System to determine potential vulnerabilities to the pilot. NASA completed their analysis on 31 August 2012.

The Task Force is confident that data derived from Hypothesis 1 (oxygen quantity) describes the major contributors to the previously unexplained physiological incidents reported by F-22 pilots over the past few years. The F-22 oxygen delivery system, largely due to life support system components located in the F-22 cockpit, is failing to deliver adequate O<sub>2</sub> to the pilot. We have taken necessary steps to eliminate the impediments, identify vulnerabilities and modify components to enhance the F-22's safety margin for flight operations.



Hypothesis 2, (oxygen quality) Task Force analytic efforts, examined the F-22 oxygen delivery system, including the onboard oxygen generation system (OBOGS), and the environmental conditioning system (ECS) that delivers ambient air to the cockpit. Air sampling and detailed analysis looked for the presence and/or production of a contaminant which could enter the F-22 cockpit of the pilot's mask. The Scientific Advisory Board's study group developed post-incident medical and analytic protocols that allowed us the ability to test for the presence of contaminants after a ground-based or in-flight incident occurred. Medical protocols included blood work, urinalysis and pulmonary function tests. Data collection protocols included air and swab samples from incident aircraft oxygen delivery system components.

The Task Force leveraged the SAB study group's contamination analysis by continuing research efforts by a panel of doctors and toxicologists from the government, industry and academia. They generated, under the supervision of the 711 Human Performance Wing, a Molecular Characterization Matrix (MCM) associated with the generic aerospace environment. This research indicated there are approximately 900 compounds present in the aerospace environment. They identified and detected low levels of 450/900 compounds in the F-22 breathing environment. Of those 450 compounds the team identified a subset of 220 compounds, which if exposed to high dosages, could cause potential physiological effects to humans operating the F-22 aircraft. These compounds were collected via numerous detection methods and sensors.

To date, we have conducted more than two-thousand four-hundred (2,400) samples, tests, and inspections. These activities have produced over 2 million data points that have been

analyzed by the panel of experts assembled to research the possibility of contamination in the F-22's air breathing systems. Fifteen (15) separate test media were used to collect and isolate toxic compounds across the four chemical spectrums. The four areas are: standard gases, volatile compounds, semi-volatile compounds, and particulate matter. Analysis of individual and cumulative compounds has shown levels well below quotients that could potentially cause central nervous system (CNS) effects that would lead to physiological incidents. To be clear, the level of research and depth of analysis to determine the presence/absence of contaminants/toxic compounds in the F-22 work environment is unprecedented.

The Task Force is confident that Hypothesis 2 (oxygen quality) is not the root cause of previously unexplained physiological symptoms reported by F-22 pilots and ground crew. There is a possibility that low level exposures, well below a hazard level, could show a causal relation in the future. However, we have exhausted the science that exists in 2012 to show any such relationship.

### **Solutions to the F-22 Physiological Problem**

The Task Force is confident that data derived from Hypothesis 1 (oxygen quantity) describes the major contributors to the previously unexplained physiological incidents reported by F-22 pilots over the past few years. The F-22 oxygen delivery system, largely due to life support system components located in the F-22 cockpit, is failing to deliver adequate O<sub>2</sub> to the pilot. We have taken necessary steps to eliminate the impediments, identify vulnerabilities and modify components to enhance the F-22's safety margin for flight operations.

The F-22 Life Support System Task Force recommends the following:

1. Redesign UPG Fill/Dump Valve
2. Revise OBOGS Oxygen Concentration Schedule
3. Continue to assess improvements to life support systems components
4. Modify Air Breathing Standard for High Performance Aircraft
5. Standardize Incident Response Protocols across the Air Force

### **Mitigating Pilot Risk While Implementing Solutions**

The Task Force implemented, as described earlier, the SAB study group's risk mitigations as part of the return-to-fly decision in September 2011. We have continued to adjust/modify these mitigations based on further analysis through the last year. The Task Force has held recurring communications with the F-22 community to share new information, emerging insights and to gain feedback from those who fly, operate, maintain and support F-22 operations across the Air Force. These communications include bi-weekly video teleconferences, targeted visits to F-22 operating locations twice by General Officer-led teams, F-22 community engagements hosted at Edwards AFB and Wright-Patterson AFB where F-22 testing and analysis resides, as well as, visits by the Commander, Air Combat Command. We also commissioned the Air Force Safety Center to conduct surveys and site visits to assess the climate of our F-22 operating locations. The safety center surveys identified that although the work force and their families have had concern about the physiological incident issue, they have high confidence in operating the weapon system and know the air force is working diligently to correct the system vulnerabilities.

The Air Force, acting on recommendations of the Task Force, has taken the following actions:

1. Removal of the Combat Edge upper pressure Garment (UPG) – eliminates breathing restrictions
2. Restricted the operational flight envelope (training environment) to 44,000 feet mean sea level – ensures enhanced pilot protection while the Combat Edge UPG is removed
3. Removal of the C2A1 chemical warfare filter – not required for protection; reduces breathing impedance
4. Directed the use of AUTO oxygen cockpit selection below 30,000 feet mean sea level – reduces oxygen concentration levels reaching pilots and reduces probability of atelectasis

The Task Force received additional direction in May 2012 after providing an update to the Secretary of Defense. The Secretary of Defense directed the following actions:

1. Expedite the installation of an automatic backup oxygen system in the F-22.
2. Conduct training sorties within proximity of landing locations.
3. Restrict F-22 aircraft from performing aerospace control alert sorties in Alaska
4. Aggressively pursue root cause analysis and include subject matter expertise from the Department of the Navy and National Aeronautics & Space Administration.

The automatic backup oxygen system has been accelerated and passed critical design review in July 2012. The system is on track for first installation in a combat air forces F-22 in January 2013. This marks a significant acceleration from the original schedule. We have

directed F-22 units to conduct training missions within a 30-minute flight duration of a suitable landing location. F-15 and F-16 aircraft have been performing the aerospace control alert mission at Joint Base Elmendorf-Richardson, AK. Finally, the Department of the Navy has contributed significantly to our investigative efforts.

## **Conclusion**

From 2003 to the spring of 2008 the total number of physiological incidents in the F-22 was six (6). That number doubled from the spring of 2008 to 2011 to thirteen (13). The increased numbers during this timeframe, the ambiguities/uncertainties at the time surrounded Captain Haney's fatal mishap, and the inability to determine a root cause gave the USAF grave concern and prompted a string of investigations and advisory boards to both find and fix the root cause.

An exhaustive effort to identify the root cause of these physiological unknown incidents has been completed with the help of over 70 organizations dedicated to the F-22 investigative effort. This cooperative cross-industry, cross-government, multi-service effort increased breadth of experience, enhanced scope of knowledge, and provided additional impartial expert analysis, which was critical in determination of root cause.

The Task Force has considered the inputs, findings and recommendations of the previously convened F-22 safety investigation boards, Scientific Advisory Board's study group, and the root cause & corrective action analysis team. We have integrated their findings, continued the investigative process, and drawn conclusions that could not have been reached

without the benefit of their efforts. The previously unexplained F-22 physiological incidents were a result of multi-factorial combinations. The trend over time has eliminated system specific factors related to oxygen delivery system components. Systemic factors such as the Combat Edge upper pressure garment and C2A1 filter functionalities have been identified, removed and corrective action is underway. We have reduced the potential negative effects created by high oxygen concentration levels produced by the OBGS through cockpit selectable oxygen concentration settings. We have communicated findings and corrective actions to the F-22 community. This communication has reduced the ambiguity and uncertainty while increasing pilot and ground crew confidence in the F-22's life support systems.

The Air Force has more work ahead as we transition to normal F-22 flight operations. The path to resuming normal flight operations hinges on the successful development, testing and fielding of the modified Combat Edge upper pressure garment valve. This modification will successfully integrate the key components of the F-22 life support system to ensure adequate oxygen flow to the pilot while providing protection in the high altitude and high-G environments where the F-22 flies. We expect this modification to be fielded by the end of 2012.

The development, testing and fielding of the automatic backup oxygen system will provide additional protection to F-22 pilots while flying at high altitude and under the most demanding oxygen delivery system scenarios that can be envisioned for the F-22 life cycle. We expect the first operational aircraft will be modified in early January 2013, the first operational squadron complete by spring 2013 and fleet completion by mid-2014.

Medical professionals will continue to study the 21<sup>st</sup> century high altitude/high-G flight environment and will continue to work with engineers, acquisition officers and the test community to develop enhancements to aircrew flight equipment and oxygen delivery systems. We are certain the F-22 cockpit and surrounding work space is a safe, effective place to operate. But, the Air Force is an organization that is built on the foundation of innovation, self-improvement and ingenuity. Continuous process improvements will ensure the safety of the F-22 work force now and in the future.

There will be physiological incidents in the future. The harsh high altitude/high-G environment is extremely demanding and our pilots are aware of those demands. We encounter physiological incidents in all high performance aircraft, it is a fact of life due to the demands placed on our aircrew. The measures taken by the Air Force, in my opinion, will reduce the incident rate significantly and over time bring the F-22 incident rates in line with comparable high performance fighter aircraft.

The Air Force is committed to implementing these changes to return the F-22 to normal operations; thus significantly contributing to our nation's vital interests by providing Air Dominance, when and where ordered, to protect and enable the joint U.S. military force. The Air Force will continue to leverage lessons learned throughout this investigative process and will invest in characterizing and understanding the high performance aircraft environment to optimize pilot performance not only in the F-22, but in all current and future weapon systems.