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F–22 PILOT PHYSIOLOGICAL ISSUES

HEARING

BEFORE THE

SUBCOMMITTEE ON TACTICAL
AIR AND LAND FORCES

OF THE

COMMITTEE ON ARMED SERVICES
HOUSE OF REPRESENTATIVES

ONE HUNDRED TWELFTH CONGRESS

SECOND SESSION

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F–22 PILOT PHYSIOLOGICAL ISSUES

HOUSE OF REPRESENTATIVES,
COMMITTEE ON ARMED SERVICES,
SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES,
Washington, DC, Thursday, September 13, 2012.

The subcommittee met, pursuant to call, at 10:02 a.m., in room 2118, Rayburn House Office Building, Hon. Roscoe G. Bartlett (chairman of the subcommittee) presiding.

OPENING STATEMENT OF HON. ROSCOE G. BARTLETT, A REPRESENTATIVE FROM MARYLAND, CHAIRMAN, SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES

Mr. BARTLETT. The hearing will come to order. The subcommittee meets today to receive testimony on F–22 pilot physiological issues which have resulted in reported hypoxia-like events by F–22 pilots over a period of several years.

The committee's concerns include the impacts of these physiological issues to the pilots and operational capability of these valuable aircraft, as well as the ultimate cost and time required to implement the recommendations that have been made to modify the F–22 life support system.

The committee also remains concerned that after all of the study of the issue, we need to understand what the level of confidence is that the cause or causes of the F–22 physiological issues are fully known.

From 2003 to April 2008, there were 6 F–22 physiological issues, but between April 2008 and January 2011, that number had doubled to 12. As a result of this, the Air Force Commander of Air Combat Command restricted the F–22's maximum flight attitude to 25,000 feet and directed a safety investigation board to review the F–22's oxygen system.

In May of 2011, the Secretary of the Air Force directed the Scientific Advisory Board to gather information and make recommendations to address concerns relative to the F–22 life support system. From May to September of last year, the F–22 fleet stood down as a result of an upward trend in reports of physiological incidents. The Scientific Advisory Board [SAB] completed its work in January of this year but did not determine a cause for the F–22 pilot physiological problems. However, the board did make findings and recommendations and concluded that either the supply or the quality of the oxygen is contributing to the F–22 pilots' hypoxia-like symptoms.

Air Combat Command established a Life Support System Task Force, which continued to examine both the issues of supply and quality of oxygen in the F–22. On April 23, 2012, the National Aeronautics and Space Administration, NASA, accepted a request from the Air Combat Command to form an independent investigative team to review Air Combat Command's investigative process, ongoing root cause analysis, and the F–22 life support system as a whole to determine potential vulnerabilities to the pilot.

On July 24th, the Department of Defense announced that Air Combat Command had determined that the root cause of the F–22 pilot physiological issues is the supply of oxygen delivered to the pilots, not the quality of oxygen delivered to the pilots.

To correct the supply issue and reduce the incidence of related hypoxia-related events, the Air Force has made two changes to the aircraft's cockpit life support system. First, the Air Force has increased the volume of air flowing to pilots by removing a filter that was installed as a part of the investigation to determine whether there were any contaminants present in the oxygen system. Second, the Air Force will replace a valve in the upper pressure garment worn by pilots during high-altitude missions. The upper pressure garment is designed to provide counterpressure to assist pilots' breathing and to help counteract the effects of G-forces. The garment valve was causing the vest to inflate and remain partially inflated under conditions where it was not designed to do so, thereby causing breathing problems for some pilots. Oxygen contamination was ruled out as potential cause.

The Air Force is also exploring ways to improve the oxygen delivery hose and its physical connections.

In the interim, the F–22 is under a temporary altitude limit of 44,000 feet. Since the F–22 returned to flying status in September of 2011, there have been 11 hypoxia incidents where the incidents were initially reported as cause unknown. The Air Force continues to investigate these incidents, and as of late July, less than half of those were still unresolved.

There have been no cause unknown hypoxia incidents in the F–22s since March of 2012.

From fiscal year 2002 to May 2011, the Air Force reports an incidence rate of 13 hypoxia events per 100,000 hours compared to 7.5 in the F–16, and 1.8 in the F–15E, and 6.6 in the F–18E, F and G, over roughly the same period.

I know from personal experience as a scientist working with these issues before I came to Congress that the Air Force faced a difficult problem in determining the root cause of these 22 pilot hypoxia-like events because symptoms of hypoxia and hypocapnia, also know as hyperventilation, are very difficult to distinguish. Indeed, pilot concerns about hypoxia will frequently result in hyperventilation, imperceptible to the pilot, which will produce hypoxia-like symptoms, eliciting even more hyperventilation, a vicious cycle.

A significant amount of effort has gone into solving the F–22 physiological issues, but much more needs to be done. Recommendations of the Air Force Scientific Advisory Board's Oxygen Generation Study Group needs to be implemented. The Air Force Air Combat Command Life Support Systems Task Force needs to complete its report and provide its final recommendations.

Additionally, NASA's Engineering and Safety Center needs to complete final report and provide its recommendations. The committee expects the Air Force to keep Congress up to date on the status of all of these reports and recommendations.

To address the F–22 physiological issues, we have asked the three key leaders involved in this project to testify today: Retired Air Force General Gregory S. Martin, Chairman of the Air Force Scientific Advisory Board Quick Look Study on Aircraft Oxygen Generation.

General Martin, welcome back.

Major General Charles Lyon, Director of Operations for the Air Combat Command. General Lyon leads the F–22 Life Support System Task Force.

Finally, Mr. Clinton H. Cragg, principal engineer at NASA's Engineering and Safety Center. Mr. Cragg leads NASA's independent investigative team, which has reviewed Air Combat Command's F–22 processes and analyses.

Gentlemen, we thank you all for your service to our country.

Before we begin, let me call on the ranking member of the subcommittee, Mr. Reyes, for his opening remarks.

[The prepared statement of Mr. Bartlett can be found in the Appendix on page 39.]

STATEMENT OF HON. SILVESTRE REYES, A REPRESENTATIVE FROM TEXAS, RANKING MEMBER, SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES

Mr. REYES. Thank you, Mr. Chairman.

And let me add my welcome to you this morning, gentlemen.

From a personal perspective, I want to thank the Chairman because as a scientist, he was able to explain some of these very difficult technical issues with the problem that we have been wrestling with now with the oxygen system of the F–22.

So, Mr. Chairman, I wanted to thank you publicly for—on this committee, for having the expertise to be able to do that, and thank you for your leadership as well.

Today's hearing on the F–22 will cover many technical issues, as I mentioned, that have been associated with the F–22's pilot life support system. On balance, I am pleased with the level of effort that the Air Force has put into this investigation. It is clear that the current senior Air Force officials have taken this issue very seriously and have put in place the necessary resources and organizations needed to identify the problem and eventually to get to a place where we fix this problem.

The scale of the testing and the evaluation effort for a tactical fighter aircraft is, from my view point, unprecedented. Rather than staying in a defensive posture, the Air Force reached out to other agencies and other military services for additional expertise and for advice. Based on the extensive work done by the Air Force and other DOD [Department of Defense] agencies, I am cautiously optimistic that the Air Force has indeed identified the primary causes of the hypoxia problems with the F–22, has identified fixes that, from a layman's perspective, seemed to make sense.

The next step is ensuring that the fixes identified are funded and installed as rapidly as possible. The United States clearly needs the F–22 to deter our enemies and to provide critical capabilities if we go to war. Despite Congress passing a long-term continuing resolution for defense spending, I personally want to ensure that efforts to fix the F–22 problems can continue at full speed.

So understanding the F–22's problems and how to fix them is one aspect of today's hearing and a very important one. However, the larger issue that I hope today's hearing will touch on is how this situation occurred in the first place, and how we avoid similar mistakes going forward.

As far as the cause of the F–22's problems, my overall impression from the testimony that we have received and other information provided to our committee is that the main problems with the F–22 were human failures of judgment and not technical failures.

One issue that appears to have gone wrong was a basic design of the aircraft's life support system. The F–22 is the most capable and, I should add, expensive fighter aircraft ever developed. The F–22 also operates at higher altitudes and in a more demanding performance envelope, perhaps more than any other fighter in the history of this country. Given these two factors, a cost per plane of more than $140 million and a unique flight environment, it is very surprising that it was designed, again from a layman's perspective, with—designed without a sophisticated backup oxygen system or even enough instrumentation to let the pilot know that he wasn't getting oxygen in time to actually do something about it.

So one question that confronts the subcommittee is, how did that happen? Why did the Air Force design and build such a sophisticated aircraft with such a relatively unsophisticated pilot oxygen support system?

In addition, why wasn't this issue identified during testing of the aircraft? That is normally when serious design issues are identified for future fixes. But that doesn't seem to have been the case with the F–22.

We are going to get a lot of information today, but in particular, I look forward to hearing from the Air Force witnesses and, again, welcome, how they think we got to this point and how we can avoid similar problems with other aircraft in the future.

And with that, Mr. Chairman, I want to yield back to you.

[The prepared statement of Mr. Reyes can be found in the Appendix on page 42.]

Mr. BARTLETT. Thank you very much.

Without objection, all witnesses' prepared statements will be included in the hearing record.

General Martin, please proceed with your opening remarks. You will be followed by General Lyon and Mr. Cragg.

STATEMENT OF GEN GREGORY S. MARTIN, USAF (RET.), AIRCRAFT OXYGEN GENERATION STUDY CHAIR, USAF SCIENTIFIC ADVISORY BOARD

General MARTIN. Thank you, Mr. Chairman.

Chairman Bartlett and Ranking Member Reyes and other distinguished members of this committee, I am honored to be here today representing the members of the Air Force Scientific Advisory Board Study Panel on Aircraft Oxygen Generation Systems.

During my remarks and during my responses to any questions that I receive, I will try to answer the questions as I believe the members of the study panel would answer them, as opposed to my own personal views.

The onboard oxygen generation system [OBOGS] on the F–22 is very similar to other onboard oxygen generation systems that we have on many fighter aircraft. And they were designed to reduce the servicing, logistic support and safety—and increased safety considerations. The F–22 aircraft is equipped with such a system to provide breathing air to the pilot, and this system usually, in the F–22 as well as the other aircraft, will take bleed air off of the engine, concentrate it into a higher level of oxygen and then match that amount of oxygen to the breathing air, based on the cabin pressure and altitude.

Beginning in 2008, as the chairman pointed out, the F–22 began to experience a significantly higher rate of hypoxia-like incidents with unknown causes, as reported by the pilots. At that point, the Air Force initiated what I will refer to as a four-tier approach to finding the root cause for these unexplained physiological incidents. The first tier was a collaborative effort between the F–22 system program office, the prime contractor and its key subcontractors responsible for the components of the F–22 life support system, and the normal Air Force safety investigation structure. So that collaborative effort started a process we have come to know as the Root Cause and Corrective Action [RCCA] analysis process that has continued for the last 4½ years.

The second tier was initiated after preliminary results of the tragic fatal F–22 mishap that occurred in November of 2010. When that mishap was out-briefed to the senior leadership in January of 2011, the Air Combat Command established a Class E safety investigation mishap board. That board was chaired by an Air Force Major General, and it was chartered to review all F–22 reported hypoxia-like incidents. So, in conjunction with the RCCA team, or the Root Cause and Corrective Action Analysis Team, this safety investigation team developed and implemented a multitude of tests and challenges to each of the F–22s life support system components.

At that time, the F–22 flight operations were limited to 25,000 feet and the pilots were directed to fly in the maximum oxygen production mode, known as max. These directions were provided to minimize the opportunity for any of the crews to be exposed to an environment that could cause hypoxia-like symptoms, so lower altitude and use of 100 percent oxygen direction was given to prevent or preclude future hypoxia-like incident. Nonetheless, there was an increase in the number of hypoxia-like events. And after two troubling incidents in May of 2011, the Air Force grounded the fleet of F–22 aircraft. At that point, the Safety Investigation Board, which had been unable to determine a failure mode that might lead to the hypoxia-like events, recommended that the Air Force modify one of its test aircraft with a specialized array of sensors and then execute a carefully developed series of flight test profiles to determine if the root cause could be assessed in the dynamic flight environment as opposed to the ground testing that had been done to that point.

Further, as a part of their investigation, the Safety Board determined there were decisions made during the engineering, manufacturing and development phase of the F–22's development that should be reviewed from a broader perspective, and they recommended a broad area review of the F–22 program be conducted. So, in June of 2011, the Secretary of the Air Force and the Chief of Staff of the Air Force tasked the United States Air Force Scientific Advisory Board to perform a quick-look study on aircraft oxygen generation systems and to cover three areas: First, continue the ongoing efforts to determine the root cause, to include gathering data during dynamic in-flight testing, full reviews of both the life support equipment and the aircraft's potential for passing contaminants into the cockpit and/or the breathing air, and finally, to better understand the similarities and differences between the F–22 oxygen generation system and other military aircraft; second, to better understand the conditions that would create hypoxia-like symptoms at altitudes not normally associated with hypoxia, along with an evaluation of the guidance associated with breathing air standards and the human response to operating in the F–22's extraordinary envelope with less than 90 percent supplied oxygen; third, to review the policies, processes and procedural changes that occurred during the F–22's development and fielding phase to evaluate the implications with respect to design limitations, risk analysis, program execution and the acquisition workforce.

The study began in June of 2011, with interim status reports provided to Secretary and the Chief until the final briefing was approved by the entire Scientific Advisory Board and delivered to the Secretary and the Chief on the 24th of January 2012. This activity actually represents the third tier of effort in determining root causes.

It is important to note that SAB study panel recognized from some initial statistical analysis that it was quite likely that in the initial flight test profiles conducted during the summer of 2011, that we may not determine the root causes in that limited sample of flight. With that in mind, it became clear that it would need to develop or help the Air Force develop an appropriate risk-mitigation procedure to allow the F–22 fleet to return to flight operations in a safe mode that would provide the Nation with its critical combat capabilities while at the same time offering Air Force—the Air Force the ability to collect and analyze the voluminous amount of data that would be collected during these flights and to continue their investigation in determining root causes for the unexplained physiological incidents.

As a result, the SAB study manual was able to develop a protocol of aircraft inspections, crew training, crew protection devices and procedures, along with a specific series of incident response protocols to assist the Air Force in zeroing in on the root causes or root causes. With that in mind, the Air Force chose to resume F–22 flight operations in September 2011.

Between that time and the AFSAB, or the Scientific Advisory Board's, out-brief to the Secretary and to the Chief in January 2012, the AFSAB continued to assess and evaluate data from approximately 7,500 sorties. As a result of analyzing the emerging stream of data, the study panel completed its study effort and made recommendations to the Air Force leadership in third areas that would, one, in the near term, allow the Air Force to complete its root-cause analysis and safely return the F–22 to its full operational flight envelope; two, over the next several years, modify the aircraft and develop specific F–22 tools to improve the margin of safety related to the F–22's entire life support system design and performance and develop procedures related to the human system's integration process that the Air Force uses to further explore the interaction between the human and the F–22 in all of its environment. They also directed that the Air Force take the lead in establishing comprehensive aviation breathing air standards applicable to the environments in which all of its aircraft would operate.

The key to implementing the AFSAB study panel recommendations was determined to be the establishment of a task force to continue the data-gathering and analysis process initiated by the AFSAB study panel, while at the same time developing the implementation plans to finalize and close out the remaining recommendations. Standing up this task force, which has been directed by Major General Lyon, next to speak, represents the fourth tier of the Air Force's overall effort to find the root causes to the unexplained physiological incidents.

As a final note, I would mention that the study panel did recommend a quarterly follow-up be established to review the process on completing the recommendations and that the AFSAB would be available for support, if required. To date, the task force has completed two quarterly follow-ups and presented their reports to the AFSAB. And their progress has been impressive.

In summary, I believe this four-tier approach, coupled with the Air Force's request from NASA for an independent assessment of their process and their recommendations represents that the Air Force is dedicated to being thorough, credible and transparent in its approach to solving this difficult issue.

This completes my initial statement, and I look forward to your questions.

[The prepared statement of General Martin can be found in the Appendix on page 46.]

Mr. BARTLETT. Thank you very much.

General Lyon.

STATEMENT OF MAJ GEN CHARLES W. LYON, USAF, DIRECTOR OF OPERATIONS, HEADQUARTERS AIR COMBAT COMMAND, U.S. AIR FORCE

General LYON. Chairman Bartlett, Ranking Member Reyes, distinguished members of the committee, thank you for the opportunity today to discuss an issue of great importance to the United States Air Force, the F–22 pilot physiological issue.

Mr. Chairman, I would like to thank you for the steadfast leadership of this committee and to your members for their unwavering support and commitment to the men and women of the United States Air Force and the entire Department of Defense. This committee has helped ensure our men and women are equipped and resourced to meet the responsibilities in support of national security objectives at home and abroad over the years.

The F–22 Raptor contributes significantly to our Nation's interest vital interest by providing air dominance when and where ordered to protect and enable the joint military force. Today, we have

F–22s 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 relationships.

We also have continental United States based F–22s contributing to homeland defense, while the remainder of the fleet conducts combat-mission-ready training, formal replacement unit training and operational test and 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 complementary 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 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, while enabling 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 never leave the ground. 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.

To set the context for this issue's history, as the chairman said, F–22 fleet experienced six physiological incidents in our initial phases over a 5-year period. The number of incidents more than doubled in the next 3 years. The increased number of incidents in 2008 to 2011, the ambiguities and uncertainties at the time surrounding Captain Haney's November 2010 tragic and fatal mishap, and the unexplained nature of these incidents gave the Air Force grave concern, which prompted the fleetwide standdown in May 2011.

Although the total percentage of physiological incidents at the time of the standdown represented less than 0.1 percent of all sorties flown to date, that wasn't good enough, and it did not meet our service established safety standards. The risk to the safety of our airmen posed by uncertainty and ambiguity exceeded our threshold.

During the standdown, 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, testing, and analysis, General Martin's study group provided a set of recommendations to the Air Force September of last year. This put us on the path to safely return the F–22 fleet to flight operations with an acceptable level of risk.

The recommendations were reviewed and implemented with the F–22 fleet returned to flying just under a year ago, September 21st, 2011. Between September 2011 and today, the Air Force has continuously analyzed the previously unexplained physiological incidents, implemented and adjusted risk-mitigation measures, and incorporated corrective actions to enhance the safety of the F–22 Raptor fleet.

General Martin's study group completed their investigative actions in January of this year. Following General Martin's presentation to Air Force leaders, the Secretary of the Air Force formed the F–22 Life Support Systems Task Force, led by me, to continue this analytic effort and implement corrective actions. Our integrated, collaborative, multi-service, cross-functional, government/industry team approach permitted an increased breadth of experience, enhanced scope of knowledge and provided additional and partial expert analysis, which was critical in the determination of root causes. The task force has considered the inputs, findings and recommendations of the previously convened F–22 Safety Investigation Boards, Scientific Advisory Board and Lockheed Martin's Root Cause and Corrective Analysis Team. We have integrated their findings, continued the investigative process, and drawn conclusions that could not have been reached without the benefit of this collaborative approach.

The previously unexplained F–22 physiological incidents were the result of multifactorial combinations. The trend over time has eliminated system-specific factors related to oxygen delivery system components. During our analysis timeframe, Major Dr. Marsha Mitchum, seated behind me, an F–22 flight surgeon at Joint Base Langley-Eustis, conducted independent research with Duke University and the Naval Surface Warfare Center in Panama City, Florida. 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 our Air Force investigative process. This would turn out to be a decisive moment for F–22 investigative efforts.

We convened an F–22 Restrictive Breathing Working Group at Langley in April of this year. The task force facilitated this session, lead by Lieutenant Colonel Jeff Hawkins, seated behind me, from the First Fighter Wing, an F–22 pilot. This group consisted of F–22 pilots, engineers, medical and safety professionals from the Air Force, Air Force Combat Command, Air Force Materiel Command; from the Navy, both the Experimental Dive Unit, their Surface Warfare Center; Naval Air Systems Command [NAVAIR] from NASA, Wyle Labs, Lockheed Martin and Boeing, an impressive group of professionals gathered together to work this issue.

Additionally, the task force sought NASA's assistance to review our 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 that NASA form an independent team to review our investigative process in the entire F–22 life support system to determine potential vulnerabilities to the pilot.

The NASA Engineering and Safety Center [NESC] provided that team, lead by Mr. Clint Cragg, sitting here to my left here today. I would like to thank Mr. Cragg and his team for their unique insight and contributions to our efforts. Two weeks ago, Mr. Cragg presented his findings and recommendations to me for incorporation in our analysis.

While corroborating much of what we had researched, the team also presented additional measures for our consideration.

The task force is confident that data derived from General Martin's group hypothesis one, oxygen quantity, describes the major contributors to the previously unexplained physiological incidents reported by F–22 pilots over the past few years. The task force is confident that the hypothesis two, oxygen quality, is not the root cause of previously unexplained physiological symptoms reported by F–22 pilots and ground crew.

Systemic factors in the life support system, such as the Combat Edge upper pressure garment and the C2A1 filter functionalities, have been identified, removed and corrective action is underway. We have reduced the potential negative affects created by high oxygen concentration levels produced by the OBOGS through cockpit selectable oxygen sittings.

Human factors at two F–22 operating locations were contributory. We have communicated findings and corrective actions to the community. This communication has reduced the ambiguity and uncertainty, while significantly increasing pilot and ground crew confidence in the F–22's life support systems.

Mr. Chairman, we have 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 flows 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.

I have had the opportunity to present task force interim findings, recommendations, and corrective actions to Department of Defense and Department of the Air Force senior leaders throughout this investigation. Department leaders have expressed keen interest to fixing the F–22's life support system vulnerabilities, to maximize the safety of the men and women who operate and maintain this aircraft, and have provided us the required resources and support to bring this issue to conclusion. The 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 lifecycle.

We expect the first operation aircraft will be modified in January 2013, the first operational squadron complete by the spring of 2013, and the entire fleet complete by mid 2014. We are certain the F–22 cockpit and surrounding workspace 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 workforce now and in the future.

To date, since we resumed flight operations last September, we have flown nearly 20,000 sorties, totalling over 25,000 hours, while encountering 11 previously unexplained in-flight incidents and 6 ground-related physiological incidents. None of these incidents have resulted in the loss of life, loss of aircraft control, nor lingering effects for our pilots and ground crews. Importantly, we have not encountered an unexplainable incident since March 8 of this year. Since that time, we have flown more than 10,000 sorties, totalling over 13,000 hours, without incident. The trend is on a positive vector not seen in years.

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 air crew. 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 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.

Mr. Chairman, I look forward to answering your questions.

[The prepared statement of General Lyon can be found in the Appendix on page 60.]

Mr. BARTLETT. Thank you.

Mr. Cragg.

STATEMENT OF CLINTON H. CRAGG, PRINCIPAL ENGINEER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) ENGINEERING AND SAFETY CENTER

Mr. CRAGG. Chairman Bartlett, Ranking Member Reyes, members of the subcommittee, thank you for this opportunity to discuss the NASA Engineering and Safety Center's independent assessment of the F–22 life support system. I am honored to be serving as the lead of this NESC team.

The NESC performs independent testing, analysis and assessments to help address some of NASA's tougher challenges.

We can draw upon technical experts from all 10 NASA centers, industry academia and other government agencies. This allows us to bring the country's best experts to bear on problems and challenges of NASA programs.

In April 2012, Major General Lyon requested NASA's assistance in their efforts to determine the cause of the hypoxia-like symptoms experienced by some F–22 pilots. NASA was requested to review current post-incident protocols and recommend enhanced procedures and also review the current investigative process, ongoing root cause analysis and the F–22 life support system as a whole.

The NESC assembled a team that included two NASA flight surgeons, two NASA human factor experts, an EPA [Environmental Protection Agency] forensic chemist, an industry oxygen generator system expert and several specialized NASA life support systems engineers.

In the course of this investigation, the team reviewed data from multiple sources, visited manufacturing sites and F–22 bases and held numerous discussions with knowledgeable personnel. The NESC team's findings and recommendations are based on this data and not on an exhaustive review of all F–22 documentation.

The NESC team concurs with the Air Force that the F–22 incidents can be attributed to several factors: One, the high concentrations of oxygen at lower altitudes; two, the inevitable acceleration which compounds the effects of high oxygen; three, restricted breathing due to the inappropriate inflation of the upper pressure garment; and four, contribution of uncharacterized F–22 life support system vulnerabilities, such as pressure drops [across] components in the cockpit.

The NESC team found a number of issues with the systems providing breathing air to the pilot. These systems are often treated as separate, but the events experienced are a result of the complex interactions of these systems, which, with the pilot included, are even more complex. Each flight puts extreme physiological demands on the pilot. The F–22 pilot community has come to consider a number of physiological phenomenon as a normal part of flying the Raptor, such as the difficulty in breathing and the Raptor cough. Acceptance of these phenomena as normal could be seen as a normalization of deviance.

The NESC team found no evidence of a contaminant producing a toxic exposure. However, in any jet fighter environment, irritant compounds can be present. The F–22 has no effective filtration of breathing air or cabin air, which means irritant compounds could potentially enter the cockpit.

The team found that the investigative process could have been more efficient. The F–22 task force was never given a directive that assigned the authority to conduct the investigation. They began with two narrow hypotheses and did not communicate well to all parties.

The NESC team agrees with many of the Air Force's planned corrective actions and has identified a number of other areas for further consideration. These include both near- and long-term recommendations. Many of the NESC near-term recommendations are actively being addressed by the Air Force. For example, the upper pressure garment and oxygen schedule are currently being modified. Post-incident protocols to establish standard case definitions and treatment guidance will require some additional effort.

Longer-term recommendations include conducting end-to-end testing of the life support system, environmental control system and air crew flight equipment. We also recommend a fundamental reassessment of the requirements for the life support system in high-performance aircraft and a formal lessons-learned review of the Air Force-led investigation.

In summary, the NESC team acknowledges that the F–22 Raptor is a high-performance aircraft that is expanding the capability of aircraft performance. The Air Force task force has made great strides this summer in understanding the complex, highly interrelated nature of this problem. The NESC's independent analysis supports the Air Force plan of corrective actions.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Cragg can be found in the Appendix on page 99.]

Mr. BARTLETT. Thank you all very much for your testimony.

Before we begin, I ask unanimous consent that nonsubcommittee members, if any, be allowed to participate in today's hearing after all subcommittee members have had an opportunity to ask questions.

Is there an objection?

Without objection, nonsubcommittee members will be recognized at the appropriate time for 5 minutes.

As is my usual custom in these hearings, I will reserve my questions until the other subcommittee members have had an opportunity to ask theirs.

Mr. Reyes.

Mr. REYES. Thank you, Mr. Chairman.

Gentlemen, thank you for your testimony.

Let me start off this morning with the first question dealing with what the long-term impact may be on pilots that have flown the F–22. The testimony indicates that since pilots have been flying the F–22 since 2005 with all the same equipment that has now been identified as causing the oxygen problems that we have discussed today and previously, over time, this means that hundreds of pilots have flown the F–22.

So the questions I have are the following: What does the Air Force know about any long-term health impacts from flying the F–22? Second, has the Air Force gone back and examined the health records of former pilots to perhaps look for clues on the impact? And third, does the Air Force plan to continue to research this issue and to track the health of current pilots?

So whoever wants to take those first three questions.

General MARTIN. Mr. Congressman, let me address that if I could as the Air Force Scientific Advisory Board considered those questions and in its recommendations presented the Air Force with some thoughts about actions it should take.

First of all, with respect to the long-term effects of flying the F–22, because the Scientific Advisory Board did not conclude its work with root causes, it was not sure at that point whether we had contamination getting into the breathing air, which could have some sort of irritation or effect on the pilot, or whether it was the interaction that General Lyon discussed between the percentage of oxygen, the upper pressure garment and breathing cycles associated with the work of breathing.

But it had no knowledge of long-term effects by reviewing pilots who had flown the aircraft before. It had no indications that the phenomenon that they experienced in the airplane had long-term effects. But nonetheless it, before returning to fly in September of 2011, had a battery of physiological samples, specimens taken from all of the pilots that would fly so that had you a baseline record of those pilots, who, of course, had not flown for 4 or 5 months, a baseline of their medical data, and as recommended, the Air Force establish a medical registry for all who fly the F–22 in case, as time goes on, there are things that are discovered that we would want to be able to go back and reference the conditions that may have changed within those pilots.

But from the Scientific Advisory Board perspective, they were unaware and were not able to find any long-term effects for those people that they questioned but did establish a medical baseline for those people who are currently flying the F–22.

Mr. REYES. Having said that, it is clear, at least from just a layman's perspective of reading and listening to your testimony, that individuals are affected differently by the same. And I point out by way of example that according to some of the testimony that I reviewed, that pilots were expected to recover quickly. In some cases, the expectation was within minutes or perhaps hours after flying and being affected by this. But in reality, some plots took days to recover. So is that—is that a cause of concern that we have one expectation and the reality is completely different?

General MARTIN. I think it is safe to say that the interaction that General Lyon discussed manifests itself in different ways with different people. Particularly depending on their breathing style and their blood saturation level, hypoglycemia, things like that. But from the Air Force Scientific Advisory Board perspective, since we did not know we had not discounted the potential of contamination, we were not led down the track of G atelectasis and other interactions that General Lyon discussed as aggressively because we were pursuing both hypotheses; one dealt with whether they are getting enough air, and the other dealt with whether they are getting contamination. And we had six sub-hypotheses for each of the major two hypotheses that we were pursuing at the same time.

And I'll let General Lyon speak to this, but as they continued the path of contamination and ultimately have stated that it is unlikely that there's a contaminant problem with the F–22 OBOGS system and focused more on the physiological effects of high concentrations of oxygen, interference with the upper pressure garment and perhaps some other physiological considerations, that area is one that I think General Lyon could address more completely than I.

Mr. REYES. General.

General LYON. Congressman Reyes, if I may, when we returned to flying last September, General Martin's group gave us a series of protocols to put in place, to take blood samples and pulmonary function tests as a baseline for our Raptor pilots, which has been very helpful for us to be able to determine once they have had an incident, is there something which is resident in their body, something which has a lingering effect? That was mostly aimed at the potential contamination, of which we found none. But I should step back a second and mention that everyone who flies in an Air Force aircraft who is a rated officer goes through a medical screening to be qualified for flight. And we have annual physical health assessments that we go through that recheck our pulmonary function, recheck our medical baselines from urinalysis to blood samples, et cetera. Very rigorous. In fact, every year, that's the day that pilots and aviators look least forward to, is that trip to see the doctor, hoping they still come out cleared to fly, as they do. We have a very rigorous process for evaluating the health of our aviators.

What we have found is, with our pilots who operate in harsh environments, whether it be high-G environment or high-altitude environment, there are additional protocols that need to be in place to understand the effects. High-G environments F–15s, F–16s, F–

22s, we learned in the 1980s that if pilots were not properly trained, educated and equipped with anti-G protection, they literally could knock themselves unconscious, and tragically, we have lost many pilots to G loss of consciousness. Years ago, the trend had increased significantly with that training, education, and the equipment we gave them.

What we are finding is that with the maturing that we have of the F–22 weapon system, we have been flying it operationally since 2003, but a small number of aircraft, so the sorties, it takes a while to get to numbers. What we are finding is this reaction to the interaction between the equipment, the oxygen delivery schedule, and we get this Raptor cough, what has been referred to as Raptor cough. We can talk about that a bit more, but those effects typically clear up within minutes, if not hours, after flight. We have had a small number of pilots who have had incidents that have had lingering effects that go out to 48 to 72 hours. But within 72 hours, with treatment by our aerospace medical professionals, those effects go away. All of our pilots, all of our ground crew who have had incidents, physiological incidents, have been returned to duty and fit for flight status.

Mr. REYES. And I have other questions, Mr. Chairman, but in deference to the members that are here I will wait another turn. But I did want to finish up by asking you, so your position, your effective positions are that we do have a way to go back and ensure that if something develops in the future for these pilots, there can be a way to evaluate and analyze how it might have been impacted by the F–22.

General LYON. If I may, to close that out, one of General Martin's recommendations was to establish a medical registry of all F–22 pilots and associated ground crew. We have done that with this baselining of their pulmonary tests and with their blood tests.

What we have also learned from our friends at NASA, from their expertise, is that there are other tests that we can put in place, which will give us greater understanding and depth of knowledge about pulmonary function. That is a recommendation which has been given to me to incorporate into our findings as we close out our analysis. Importantly, we know who has flown the F–22. We know who has been exposed to this environment. We have a registry of those people from the time that we have been flying and will continue to track them through their Air Force career and, if necessary, beyond.

We have a moral imperative, we understand that, that if something is discovered that would be tied to this aircraft or in servicing this aircraft, we have a moral imperative to take care of those Americans.

Mr. REYES. I thank the gentleman.

Mr. Chairman, I yield back.

Mr. BARTLETT. Thank you. As per committee rules, members present at gavel fall are recognized in the order of seniority on the committee; those appearing after gavel fall, in the order their appearance at the committee.

Ms. Hochul.

Ms. HOCHUL. Thank you, Mr. Chairman.

I would like to thank you for holding this important hearing, first of all. I share the same view as everyone in this room, that our pilots' safety has to be one of our highest priorities. I know today we are primarily speaking about the F–22 issue, and I have a closely related question. As we continue to invest in the F–35 Joint Strike Fighter, a program I do strongly support, is the Air Force aware of any problems or potential problems that are looming similarly to what we are experiencing with the F–22 with the F–35 program, is this something we have been proactive about and anticipating?

General MARTIN. Ma'am, I would say the charter that we had in the Air Force Scientific Advisory Board was to review other military aircraft equipped with OBOGS systems and determine if there were some lessons learned from those aircraft that we could apply in the F–22 and, additionally, were there some lessons from what we learned in the F–22 study that should apply or could apply to those aircraft. With respect to the F–35, it is an OBOGS system. It is manufactured by the same manufacturer. It has a little different scheduling activity.

We have shared all of our information with the F–35 program office, and I would say that their system was designed with a bit more redundancy and robustness. It has a backup oxygen system that is installed on the seat with a fairly large quantity of air available to the pilot should the OBOG system have a problem. And we know of no physiological incident that has occurred in any of the F–35 flight operations to date, through the flight test as well as some of the training activities that are occurring down at Eglin.

So to your question with respect to the F–35, we did review the system. It does have some differences, but it looks as if those differences are refinements and improvements over what the F–22 had, and we have shared the information that we learned with the program office and, as well, with the Navy and Marine Corps, who will be operating that airplane as well.

Ms. HOCHUL. That is all I have, Mr. Chairman.

I yield back the balance of my time. Thank you.

Mr. BARTLETT. Mr. Runyan.

Mr. RUNYAN. Thank you, Mr. Chairman.

General Martin, I am sure there is a classified answer to this, but specifically speaking to operating environment of the F–22, what really differs between that and say the F–16, F–15, F/A–18? What really sets it apart?

General MARTIN. Mr. Congressman, I will let General Lyon discuss perhaps some of the warfighting characteristics of the operational environment, but from a system design and human systems integration perspective, the F–22, unlike all other aircraft, can operate routinely and in a sustained manner above 50,000 feet. Typically, the Air Force has required its air crews to use a full pressure suit when operating above 50,000 feet, even though the cabin pressurization is adequate and safe. Should there be a rapid decompression at those altitudes, the effect on the blood and the effect on your ability to properly inspirate or breathe is very, very challenging without supplemental pressure to keep your lungs from exploding and to ensure that you are able to process the oxygen that is delivered.

The F–22 does not have a full pressure suit, and it was designed to operate with a partial pressure suit, the upper pressure garment, a different anti-G suit and those sort of things. So that airplane operates in an environment different than what we had operated. For instance U–2s, SR–71s, those airplanes, all of those air crew members fly in a full pressure suit. The F–22 pilots do not, and therefore, it is important they not only understand where they are vulnerable and the limitations of the equipment but also the performance of the equipment as they operate in those areas. So our concern was making sure that not only did we have the right equipment and that it would perform well and provide the protection that it was intended to, but that the air crews would also know what the differences were and how to operate in that environment.

So from a physiological perspective and from a design perspective, that is the area of focus for the Air Force Scientific Advisory Board.

With respect to the combat capability and advantages, General Lyon I think can best address those for that environment.

General LYON. Congressman Runyan, I have over 3,000 hours flying the F–16, and I can count the amount of time that I have spent above 40,000 feet in less than 10 hours.

When I look at the operating envelope that our F–22 pilots go into every day, every day, they go above 40,000 feet. They operate at higher altitudes routinely than we have in the F–16 in the past and even than we did in the F–15. And they also operate in a very high-G environment.

We have learned a lot over the last three decades about the impacts of operating in a high-G environment with our fourth-generation fighter legacy aircraft, and we have integrated those efforts into the F–22. We still learn today, after half a century of flying the U–2 at extremely high altitudes, we are still learning how to care for those pilots and continuously enhance their safety because of their exposure to very high altitudes.

As General Martin mentioned, we have a partial pressure suit in the F–22. It is a truly a hybrid aircraft that combines high altitude and high G. And some of the equipment that we found that we have is optimized for one of those environments but not integrated to help with the other environment. That is one of the key points that came out of our analysis over the last year, is that we need to continue to do research on the science, the physiology of both high altitude and high-G flying, and the end-to-end integration and testing of all of the components that have really one thing in mind. That is to ensure that the proper volume of oxygen with the proper concentration of oxygen gets to the pilot so he has full cognitive skills and can handle the immense tasks that they have in an environment that we have not flown routinely before.

Mr. RUNYAN. And I asked that question just to say we understand that we can change the physiology of a machine, but we can't change the physiology of a human being. We can push the threshold with technology all day long. And I think this a prime example of, we have spent a lot of money on developing weapons and tactics that are outside the envelope, but we are not going to be able to change the person that flies it. And I think sometimes as we step back and look at things like this, we really have to be cautious. I have the honor to actually sit on the VA [Veterans' Affairs] Committee, and the list you speak to, I don't want to really have to visit that—you know what I mean—especially with the Raptor cough and all that kind of stuff.

I would just say that technology is great, but at the end, it is about the people. It is the men and women that do this that we really have to look out for.

With that, Mr. Chairman, I yield back.

Mr. BARTLETT. Thank you very much.

Ms. Speier.

Ms. SPEIER. Mr. Chairman and ranking member, I really appreciate you holding this hearing. I am deeply concerned about this issue. And I must say, I don't have the confidence that we have come up with the answer yet.

Let me start by asking General Lyon, there was an article that appeared today in the Dallas Star-Telegram, and I don't know if you have seen it, but it suggests that the Air Force knew about this back in 2000, that it declined a fix in 2005 that would have cost about $500,000 per aircraft. And that alone I think deserves your response. So if you would, please explain to the committee if you knew this back in 2000, if there was a fix back in 2005 that you declined to incorporate because of cost, which was at that time about $500,000.

General LYON. Congresswoman Speier, I will be happy to answer that question.

During the engineering and manufacturing development phase of the F–22, we learned a lot. We had a lot of reports written about the status of different aircraft systems, subsystems, and how they interacted. And one of those reports was written in 2000 about the environmental condition system. Changes have been made since then. Changes were made based on that report. In 2005, when the report came out and suggesting yet a small incremental change that you describe to this system, the knowledge that we had at the time was that—the term Raptor cough didn't even exist at that time. We didn't even know it. We had some discussions about ear blocks, but we have discussions about ear blocks in other aircraft that we fly as well. So the determination in 2005 was what we knew about some of these interactions, is that they were at a small level, not widely spread, and we were still a very small fleet size at that time.

It is as we have grown to the final delivery of our aircraft and really expanded the people who fly and the numbers of hours that they fly that we have gained a bigger understanding of what is going on. And we continue to make changes to this oxygen delivery schedule based on what we learn along the way.

Ms. SPEIER. So the suggestion in 2005 has now been incorporated or has not?

General LYON. That suggestion has not been incorporated specifically. It was a minor modification to the ECS [environmental control system] system and the scheduling performance. We are looking at broader changes than that and making broader changes that envelop that one that was suggested then.

Ms. SPEIER. But wasn't that suggestion to give the pilot the opportunity to control the oxygen flow?

General LYON. The pilot does. The pilot has a switch setting in the aircraft, an automatic setting, which is a lower oxygen concentration, and a maximum setting, which is a higher oxygen concentration.

We have learned a lot about oxygen concentration. There was a period of time when we thought we may not have been delivering enough oxygen concentration. But what we have learned over the last few years is that there are these cases where the increased oxygen concentration does give some dryness. It does give some ear block, and it does create this Raptor cough, which is a temporary situation.

Ms. SPEIER. Thank you.

There has been some discussion about the fact that it is not just the suit, that those on the ground are also experiencing this condition, these hypoxia-like symptoms. Are you confident that the epoxy that is used in adhering the skin to the plane is not a contributing factor to this?

General LYON. Congresswoman, I am confident. We have done over 2,400 tests on the aircraft.

And if I may have the picture of the testing locations——

Ms. SPEIER. Excuse me, I am running out of time. You have answered the question. Thank you.

Let me move on to ask you whether or not the reports that you mentioned, one dating back to September, I guess, of last year, if those are going to be made public so that the findings and recommendations would be made available to the public?

General MARTIN. The Air Force Scientific Advisory Board report has been completed. It has gone through its review, several tiers of reviews, and will be released today. And the findings and recommendations will be there.

If I could, ma'am, I would make a comment that you will see in the report with respect to a better understanding of the interaction of this aircraft with the human operating the airplane, whether it be a maintenance technician or it be a pilot.

In the 1990s, the United States Air Force, through its manpower reductions and its prioritization of effort, brought about by the downsizing of the military after Desert Storm, did not continue with the robust effort it had for decades before, its human systems integration, its aviation physiology.

Ms. SPEIER. And you relied on contractors, correct?

General MARTIN. Sorry?

Ms. SPEIER. You relied on contractors as opposed to——

General MARTIN. In many cases.

Flight medicine and aviation physiology research and development atrophied significantly during those years. And at a time when the airplane was going into a different environment that we talked about earlier, the people that would normally have done the testing and the evaluation and all of the things that we do to learn about those new environments were no longer in the military, no longer in our civilian workforce.

One of the recommendations is that the Air Force reenergize its efforts with respect to human systems integration so that we will better understand some of the interactions that we are now learning about and actually, with the help of the Navy and with NASA, know more about today than we did a year ago.

Ms. SPEIER. Thank you.

My time has expired.

Mr. BARTLETT. Thank you very much.

I will ask a few questions, and then we will return, for those who are interested, to a second round of questions.

I would just like to return for a moment to my opening statement to make sure that a couple of statements there weren't misunderstood. I read and concluded that either the supply or the quality of the oxygen is contributing to F–22 pilots' hypoxia-like symptoms. I don't think those are the only two possible reasons for these symptoms. I was simply reporting what had been concluded. I didn't want this to be interpreted as a statement of fact.

Next was the statement I made that the Air Combat Command had determined that the root cause of the F–22 pilot physiological issues is the supply of oxygen delivered to the pilots, not the quality of oxygen delivered to the pilots. This is what they concluded. I am not sure that is the correct resolution of the problem. I just wanted to make sure that people understood because I read those statements, I didn't read them as statements of fact, I read them as an account of what had been reported by the people who were investigating it.

I hardly know where to begin. I spent a big part of my life in this area. And when I first came to work for the Navy as school physiologist in Pensacola, Florida, a great many years ago, they had just had an accident where the instructor and the student had penetrated a 10,000-foot floor and for several minutes were seen spiraling into the Pensacola sand. The commanding officer felt that there was a problem with the oxygen system. And since I was the physiologist, I was put on the Accident Investigation Board and we spent a very long time, as we appropriately do, looking at every aspect of this.

Let me ask a few questions.

The symptoms of hypocapnia, how early in your investigation were you cognizant of the fact that it was difficult to differentiate between hypocapnia and hypoxia? Hypocapnia is low carbon dioxide. If you sit and breathe deeply a number of breaths, if I sneeze three times, I have hypocapnia. I can feel the difference. I am dizzy. How far along were you in your investigation before you were cognizant of the fact that we ought to be looking at the symptoms of hypocapnia as well as the symptoms of hypoxia?

General LYON. Thank you for the question, Chairman Bartlett.

We started to learn over the winter that there were a variety of symptoms that were emerging. And it was in April of this year where we had our restricted breathing working group that met, the combination of F–22 pilots and the professionals across the medical field, where we really got into substantial discussions about symptoms, as well as the research that had been done with Duke University by Dr. Mitchum and with the United States Navy, where we broadened our aperture and understood that these symptoms, like light-headedness, dizziness, fatigue, are actually ambiguous across things like toxic exposure, hypoxia, hypocapnia, hypercapnia, hypoglycemia, dehydration.

But I would say for me as the task force lead, the "aha" moment came in April, when we got that full team of experts from different services, from NASA and from industry together. That is where it really started to emerge in our mind.

Mr. BARTLETT. How difficult is it to differentiate between the symptoms of hypoxia and hypocapnia?

General LYON. Chairman Bartlett, I tread on dangerous ground now engaging in a discussion with you with your level of knowledge about this. But what I have learned as the task force lead as I talk to professionals about this is that many of these symptoms are temporary. They emerge, and then they disappear. And it is hard to find any kind of DNA [Deoxyribonucleic Acid] trace that goes along with this. In fact, our protocols that have we put in place did not show any of these. So they are very temporary, and they come and go. So that has been one of the challenges.

The other thing that they have told me is there is an individual variability factor here as well, that every human is a dependent variable if we think of this in terms of a test. And not only that, but from day to day, a human being is going to interact differently depending on how much sleep they had. Are they well rested? Are they hydrated? What are their blood sugar levels?

So this understanding of the physiology and the science not only for, as Congressman Runyan was alluding to about the high altitudes and pushing the envelope, but just the basic physiology where we have let some of these skill set atrophy over the years as we downsized our Air Force during the post-Cold War period, that we were relearning old lessons. But in April, that is where it all came back to me.

Mr. BARTLETT. Is it not true that, in large measure, the symptoms of hypoxia and the symptoms of hypocapnia are indistinguishable?

General LYON. Mr. Chairman, in fact, that is what I found. I have to put things in fairly simple terms, and I asked them to give me a chart listing all of these different cases, hypocapnia, hypercapnia, et cetera, and then listing what are the symptoms. It looks almost like a complete ladder of Xs from left to right all filled in. They are almost a one-for-one match of symptoms across all of these various symptoms that we talked about in these causes.

Mr. BARTLETT. We have a very interesting dynamic here. If you think that you are hypoxic, the normal response to that is to try and get more oxygen. That is what you need, so you breathe deeper and maybe faster. And you can do that, and you will not be aware of the fact that you are breathing deeper and faster. And when you do that, you now drive down CO2 [carbon dioxide], and you create the symptoms of the thing that you were trying to avoid, that is hypoxia, because as you drive down the carbon dioxide concentration in your body, you have essentially exactly the same symptoms that you would have if you had a low oxygen concentration in your body. So now you begin a vicious cycle. I feel worse. I need to breathe deeper. You don't say that to yourself, but that is the physiological response to that. So now you breathe deeper. And the deeper and faster you breathe, the worse you feel. So you are kind of on a vicious cycle here.

What partial pressure of oxygen do you try to maintain in the breathing mixture? I am going to ask a question, too, about Raptor cough and try to make sure that people understand where that comes from, that this isn't something evil and it is just a natural consequence of doing what you do in flying these aircraft. This is what happens.

General LYON. Mr. Chairman, we mean well above the useful consciousness requirement for——

Mr. BARTLETT. We are roughly at sea level here. I think it is about 158, the partial pressure. And in our lungs it is diluted by CO2 and so forth, and it is down to about 100 millimeters of mercury.

General LYON. Yes, sir.

Mr. BARTLETT. Do we try to maintain the concentration of oxygen significantly above 158 millimeters of mercury?

General LYON. Significantly above it, in fact. We are approaching 90 percent, 80–90 percent pure oxygen at the higher altitudes that we fly.

Mr. BARTLETT. What happens when you have a very high percentage of oxygen in your lungs is if that oxygen is picked up by the capillaries in the lungs, there is nothing then—the nitrogen is gone. You have eliminated that by increasing the oxygen percentage. Ordinarily here, we have about 80 percent nitrogen. It just stays in there and holds the alveoli open. What you end up with is a situation like if you take two pieces of wet paper and put them together, you have to tug at them to get them apart. That is the surface tension of water. That is what happens when you have a very high oxygen concentration. You increase the probability—and I noted you were recommending that they go to max oxygen—you now increase the probability of atelectasis because you are driving down the concentration of nitrogen, so you increase the incidence of atelectasis. And that is an irritation, and you cough to try to open those alveoli up, and it could take quite a while to open the alveoli up, which is why it may persist for awhile.

You all have done an admirable job of pursuing this. All of these instances occurred at two of your eight bases, is that true?

General LYON. Mr. Chairman, we have six permanent operating bases.

Mr. BARTLETT. And at how many of those did this occur?

General LYON. And your eight is correct. We have two forward present bases.

Mr. BARTLETT. So eight total. And it occurred in only two.

General LYON. Only two.

Mr. BARTLETT. Which is another indication that what is happening here is not a problem with—and this is a very complex relationship between the pilot and his system. Pilots are taught early on that they can't really trust their senses. You have cockpit signals that tell you what is up and what is down, and you have learned to trust those rather than the seat of your pants, because you really can't trust that. And all of you have been, I gather, how many times do you go in that altitude chamber and they ask you to take off your mask? And you take off your mask, and you are doing something like writing something, and you think you are doing just fine. And then you put your mask back on, and you look at what you have done, and wow, how could I have done that? There is little perception that you are becoming hypoxic. And you think that you are doing just great, and the better you feel you are doing, the worse you are doing. So the pilots have learned that they can't really trust their senses. They have got to trust other things.

I am really pleased that you put two things in this system that now pilots can look to. One is an oximeter on the ear now, I gather, that tells you what your oxygenation is in your blood. If that is up, you have got enough oxygen. No matter how you feel about it, you have got enough oxygen if that is up. I think you also put a sensor in that tells them what the percent oxygen is in their delivery system?

General LYON. Yes, Mr. Chairman.

Mr. BARTLETT. There needs to be a protocol that keeps that as near 158 as you can. If you run it much above that, you are going to increase the incidence of atelectasis. And this kind of breeds some perception that there is a problem with the airplane or a problem with the oxygen system or something if you have atelectasis. It is not a problem with either, it is just a fact that if you are breathing a high percentage of oxygen and pulling Gs, which is going to exacerbate the thing, that you are going to have more atelectasis.

Well, I have asked enough questions for the moment.

Let me turn to Mr. Reyes for his questions. And we'll come back.

Mr. REYES. Thank you, Mr. Chairman.

Listening to the chairman, I was wondering, you know, we first deployed the F–22 in 2005, and it wasn't up until 2008 or so that these problems started to surface, so I am wondering what explanation is there for this time lag? Were the problems there all along and just not being reported, or did you change the operational, you know, operational capability—not capability but the operational environment of the F–22 that brought upon the pilots this problem?

General LYON. Thank you for that question, Congressman Reyes.

After a few years of operational flying, we started to get a large number of aircraft, a larger population. We get into the individual variability of the pilots who were flying. And in 2008, we had several incidents.

One of the things that was informative to me from Mr. Cragg's independent analysis was this thing known as the normalization of deviance, which was learned from their studies that they have done on some of their safety and engineering studies for things which have occurred with NASA in the past.

There was an acceptance early on by the Raptor pilots who flew this aircraft that it is a littler harder to breathe than it is in other aircraft. And they were taught that it is a little harder to breathe, and they began to accept it. But over time, as the pool of pilots got larger and we flew more, we started to see some of this individual variability come into play. And then we had some incidents, and we really started focusing on it.

What was also helpful for me as I worked through this analysis was looking at the Air Force's history in another aircraft, the F–16. The F–16 flew operationally for 4 years before it had the first

G loss of consciousness [G–LOC]. Same capabilities in the aircraft; same G available, the same qualification and criteria to get into the aircraft. But we flew for 4 years. And I asked myself, why? I still don't have an answer as to why it took 4 years for G loss of consciousness to become an issue and then continue on for awhile. But it is not uncommon from what I have seen in some case studies to fly aircraft for a number of years, very selective pilots and aviators at the very beginning part, very controlled environments, but we start to broaden the aperture and bring more folks in, and we start to see more variability over time.

Mr. REYES. The other question that comes to my mind is we are dealing with the F–22 in this hearing, but are there lessons to be learned as we transition to the F–35? Does the F–35—do we anticipate that it is going to have similar issues, or the fact that we are working our way through finding solutions for the F–22, is that going to be beneficial for the F–35?

General MARTIN. Congressman Reyes, I would say this, that the F–35 oxygen system is more robust than the F–22 in terms of its design and redundancy. The formula that it uses for computing the percentage of oxygen is slightly different. And from the lessons we have learned with respect to connections, potential for leakage, and of course the emergency oxygen system, they have applied those lessons in the F–35.

As General Lyon has indicated, that will not stop all potential hypoxia-like incidents or hypoxia incidents due to hyperventilation or other things that could occur. But in terms of the design, it seems as if the F–35 has gone to school on the F–22. And of course, both with what General Lyon's team has done and with what the AFSAB did, we have shared all of that information. In fact, during the early part of our study, NAVAIR systems people were fully integrated into our effort and shared with us the lessons they had learned in OBOGS in general and where they were with the F–35.

So we are doing our best to make sure what we have learned here will apply to the training and to the design and operation of the F–35.

Mr. REYES. Thank you.

And I have some other questions, but I will submit them for the record.

Mr. BARTLETT. Thank you.

Ms. Speier.

Ms. SPEIER. Thank you, Mr. Chairman.

Mr. Cragg, I was particularly struck by the statement in your report that reads, the acceptance of these phenomena as, quote, normal could be seen as, quote, normalization of deviance, that the F–22 has no effective filtration of breathing air or cabin air and although no conclusive evidence has been found indicating the effect of irritant compounds, they could enter the cockpit and the pilot's breathing air supply.

Could you comment a little more on those statements, please?

Mr. CRAGG. Sure. Thanks for the question.

NASA is very familiar with the term "normalization of deviance." It is when we get to a position where we accept the operation of some system or component that is not operating properly, and we start treating it as that is the way it normally is. And the best example from NASA's perspective was the foam coming off the external tank for the shuttle. It happened since the beginning, and we came to accept it as a normal part of doing business, but it wasn't. And we should have fixed it long before.

So when we began examining the F–22, things like the Raptor cough, things like the pilots going home at night being physically exhausted, said to us, there is something that may fit into this category of normalization of deviance. So we wanted to point that out. It is a way that you can almost fall into that type of a mind set if everybody says it is normal, and especially with the F–22 being the top of the line Air Force fighter, when people say, do you want to fly this fighter? Yes, yes, of course, I do. There are some things that are different about this; it is harder to breathe, but the pilots just apparently didn't care. They wanted to jump in and begin flying it.

So the normalization of deviance is a cultural thing that I think the Air Force needs to take a look at and help prevent from occurring in the future.

Ms. SPEIER. And your reference to this filtration system and the fact that these toxic compounds can get into the oxygen system, could you comment on that?

Mr. CRAGG. We began our review by trying to double-check some of the things that we understood that the Air Force had already done. One of the things they looked at quite extensively was the contamination issue. So I had my people examine all of the evidence, the data, and we came up with a conclusion that we found no contaminants that were getting into either the breathing supply or the cockpit that would cause a toxic condition for the pilot.

Having said that, during that examination, we found that the air coming into the cockpit and the breathing supply is not filtered. And so, it is not filtered, which would put the pilot in a position where he is breathing air like in any jet fighter environment. There are irritant compounds. There is potentially some exhaust gases that the individual may be breathing. We wanted to highlight the fact that the onboard oxygen generator is not a great filter. It is filtering a lot. Some of the cabin air that is coming into the cabin is being filtered by what is called coalescer socks. But we wanted just to point out that the air coming in is not completely pristine.

Ms. SPEIER. Are you suggesting that it should be completely filtered?

Mr. CRAGG. No. No. Ultimately what we are suggesting is that some of these irritant compounds could potentially cause a pulmonary problem or a restriction of breathing. One of the members of my team is from the EPA, who has done testing with irritant compounds and has found that to be the case in some individuals. It is highly an individual response to that.

Ms. SPEIER. Two more questions I want to try to get in in 42 seconds here.

The Air Force has said that none of the hypoxia incidents have resulted in long-term or lingering physiological effects. But a medical expert wrote in Flying Safety Magazine that a pilot who experienced these symptoms was restricted from flying for several days. Wives of pilots have also described what they believe to be long-term or lingering effects, and many of these pilots describe blackouts and memory loss when they experience symptoms. Some pilots also describe experiences of vertigo weeks later. To what degree do you think that we need to look at biomarkers as part of this evaluation?

Mr. CRAGG. I think that is a very good question. I had two NASA flight surgeons on my team, and they did some extensive review of what the Air Force has done. I would not like to speak for them. I wanted to make sure what we put in our report as far as the medical portion was exactly correct, so I ensured that that portion of our report was thoroughly peer-reviewed by other flight surgeons. So if you don't mind, ma'am, I will take that one for the record, and I will provide you an answer.

[The information referred to can be found in the Appendix on page 105.]

Ms. SPEIER. I appreciate that. One last question.

Have any of the pilots declined to fly the F–22 because of what has transpired?

General LYON. We have one pilot across the entire F–22 enterprise who is currently not on flying status based on his request.

Ms. SPEIER. Thank you.

Mr. BARTLETT. Thank you very much.

Mr. Reyes mentioned G–LOC; this is the unconsciousness you get when you are pulling Gs. And this is due to an apparent design defect in us. Essentially, every other part of our body has the ability to accumulate an oxygen debt, which is why you keep breathing, huffing and puffing, after you run hard. Our brain has zero ability to accumulate an oxygen debt. So the moment it doesn't have enough oxygen to operate, it just quits operating. And we try to avoid this, of course.

When you are pulling Gs, the blood, by centrifugal force, it is taken down to your legs and abdomen. And we try to avoid this by anti-G suits, something that as soon as you start pulling Gs, they start squeezing on your abdomen and your legs to make sure that the blood can't pool there. But you can't always do enough of that, and sometimes the blood still may pool there enough that you get some transience. I have no idea why there is that design defect. You would think that ought to be built in. If anything needs to work all of the time, it is the brain, isn't it? But if it doesn't have enough oxygen, it just quits.

Ms. Speier mentioned vertigo weeks later. I was just thinking, unless there is some pollutant in the oxygen, and I think you pretty much ruled that out with all of your testing, there is just nothing that can happen during flight, hypoxia or hyperventilation, that is going to—you might better look to what he did last night than look at the hypoxia or the hypocapnia that he experienced 6 weeks earlier.

I have a series of questions that we would like to get answers to.

Let me ask you, first of all, is there any evidence, other than circumstantial, that there was ever an hypoxic incident?

General LYON. Mr. Chairman, if I may lead and then if General Martin would like to add.

One of the things that we found is that early on, the discussion centered on hypoxia, and then the discussion became hypoxia-like.

But in the end, what our analysis said is these are physiological events, which get back to the things that we described a little earlier today that get into physiology. Physiological events is the umbrella, of which hypoxia is one of the parts of that. But most of these events are so ambiguous, and these multiple factors, that we didn't have the science early on when we had these incidents to really plumb to the depth required to determine hypoxia from exposure to compounds to hypoglycemia, et cetera.

It is only through the protocols and the learning that came out of General Martin's efforts that we have been able to understand these incidents in more depth over the last year, that have allowed us to rule out things like contamination as a root cause for what was happening to our pilots. And we start to see that it is these breathing restrictions and breathing impedances, as you referred to, which can lead to hypercapnia or hypocapnia or similar type events for restricted breathing.

But that is where I end the analysis with my conclusions, after I have taken all of the findings that have come in from the other bodies and looked at this in total. They are not hypoxia, per se. A small number of them are hypoxia.

We have had some pilots who have had interruptions in their pilot supplies, and we have tracked that, and we have noted that. So we do know that if there was an interruption, a malfunction, that they will get less air and they will, indeed, become hypoxic. But most of what we have been studying, what we have been concerned about, are the instances where there was no explanation at the time, and they do not lead you to hypoxia.

General MARTIN. During our review of the cases and after we initiated the return to fly phase, where we had the finger pulse oximeter, there were—we had data that seemed to correlate with the symptoms and the physiological presentation of what you would call hypoxia. For instance, a pilot cruising out through 15,000 feet began to sense his hypoxia symptoms, began to feel somewhat light-headed, looked at his pulse oximeter and saw that it was at 85 percent or 83 percent. As we went further into the data review over a period of months and gathered more data and became much more conversant with the strength and weaknesses of a tool such as that, we found that oftentimes what seemed to be a correlation turned out to be what the medical world refers to as artifact data or data that was not accurate. And we did not know at that time that perhaps the best indicator of whether the oximeter was working properly or not was the pulse. And if the pulse went away, then the oxygen dosage or the oxygenation number may not be accurate.

So we thought we had some fairly representative samples of someone not getting the oxygen that they needed to perform without impairment and their symptoms. And it turned out that in almost every case, that data was inaccurate. Hence, the pulse oximeter that will go in the head because the extremity is the last place that the body is going to push the blood when necessary to preserve function of the brain and the core of the body. So we should get better data with this, but still there will be some artifact data just based on the technology used to measure.

I have no doubt that some of the cases that we reviewed, that the pilot believed that he was suffering from hypoxia; but it may not have been hypoxia, it may have been the symptoms that were similar. And those are the symptoms that he or she felt in the physiological training unit. And when they went to high altitude, and one of the cases that you mentioned, not only do we do some exercises, but we are supposed to mark, if you will, perhaps a narrowing of the vision, perhaps a loss of color, perhaps a dizziness, perhaps a light-headedness, perhaps other symptoms. We are supposed to note that so if we felt that in the aircraft, then we would immediately go to 100 percent oxygen and recover the aircraft.

I have no doubt that there were air crew members or pilots who experienced those same symptoms, but we can't prove that it was due to a lack of oxygen from the OBOGS system itself.

Mr. BARTLETT. Are we now acquainting our pilots with the similarity and the symptoms between hypocapnia and hypoxia?

General LYON. Mr. Chairman, indeed, we are. In fact, we have visited five of the six permanent location sites. The one location they are deployed currently, so we haven't been out to see them. But we have pushed them the information.

Where we have shown them the results of the centrifuge and altitude chamber training, that was my next "aha" moment in about the May-June timeframe, where we, for the first time, put F–22 pilots, wearing their F–22 flying ensemble, into ground testing and altitude chambers and centrifuges, and we measured that the system was not performing the way we thought it had been performing over years.

We have advanced the state of testing and our ability to understand what the oxygen delivery is. We have shown the results of that to the pilots. In fact, 2 of the first 12 pilots who did centrifuge testing replicated their hypoxia symptoms on the ground in a centrifuge inside a closed building. That was an "aha" moment for me that really started to point toward one of the factors. As you rightly pointed out, Mr. Chairman, it is more than one factor. But one of the factors is this restriction in breathing or impedance in breathing, which can come—the restriction from the upper pressure garment, and the impedance from the C2A1 filter, which we have been flying with for a period of time to protect against the possibility of contaminants, and also the pressure drops that the Navy helped us with, in understanding it and NASA affirmed it. The pressure drops that occur inside the cockpit as the air flows through the oxygen hoses and the quick connects; we had measurable, objective data, and we have shown it to our pilots. And they are aware of that.

We have not had an incident since the 8th of March this year, over 6 months ago. This is longest period without a physiological unexplained incident in years.

Mr. BARTLETT. Did you have an increased incidence of these events when you had the filter in?

General LYON. Mr. Chairman, we did. When we returned to fly September of last year, we put a number of measures in place to protect our pilots, to ensure their safety, to enhance their safety. And some of these things we put in place actually increased the incidence. One of the measures that we put in place was guidance from me to the entire F–22 fleet that said, at the first sign, the first symptom of anything, you are directed to terminate your mission and come home. We injected a sensitivity because safety was paramount in our mind. And they responded to that. And they did safely recover every aircraft each time that we had an incident.

But I marked my guidance as the Air Combat Command Director of Operations with their safety as paramount, to come home and terminate it, that we have injected an increase in the incident rate during that timeframe.

Mr. BARTLETT. Yeah. I would have predicted an increase in the reported incidents if you put a noticeable resistance in the line because the response to that is, gee, it is hard to breathe; I am not getting enough oxygen; I need to breathe deeper. So when you do that, you create hypocapnia, and you create the symptoms of the things that you are trying to avoid, don't you?

General LYON. Mr. Chairman, you are exactly right.

And to also dovetail off of what Mr. Cragg has said, when we put this canister on pilots and told them to fly with it to protect them in the event of contamination, what we failed to tell them was this known breathing impedance. We knew about the breathing impedance. What we didn't know was about the restriction in breathing that came with the upper pressure garment. And the combination of the restriction from the upper pressure garment plus this impedance we believe is what in this individual variability sent a number of our pilots beyond their normal physiological limits to where they saw these first symptoms.

Mr. BARTLETT. Let me quickly go through some questions that the staff wants to make sure we have on the record so there is no misunderstanding in the general public about the intensity of our effort to solve this problem. You don't need to give a full answer here. You may give a more complete answer for the record, if you wish.

In your findings, you cite a number of failures in F–22 modeling and simulation of the F–22 life support system. Do you believe engine-to-mask modeling and simulation, dynamic response testing across the full range of simulated environments, statistical analysis for analyzing and predicting system performance and risk, and OBOGS performance when presented with a full range of ECS air contaminants should be accomplished for the F–22 program?

I guess a simple yes or no is okay.

General MARTIN. Yes.

Mr. BARTLETT. What causes what has become known as the Raptor cough? How frequently is it experienced by the average F–22 pilot, and how serious an experience is it for the pilot? Does the Raptor cough have any long-term effect on the pilots? Do you think the record needs any more than what we have discussed?

General LYON. Individual variability, there is no standard number of events. Some individuals don't have it at all. Some have it more than others. And we have no indication of long-term effect.

Mr. BARTLETT. You will reduce those incidents if you keep oxygen as low as is feasible, right. The blood is oxygenated not because you push a lot of oxygen pressure into it, because it has got hemoglobin, which carries blood. The amount of oxygen that is carried in the blood by solution in the blood is very small. So any time you get over 158 millimeters of mercury partial pressure, you are minisculely increasing the amount of oxygen available to the tissue, but you are considerably increasing the probability of atelectasis.

Is there any linkage between hyperventilation and the Raptor cough? I was trying to think of—can you increase the Raptor cough atelectasis by hyperventilation?

General LYON. We have not made that linkage yet. Although what we have mentioned is one of the institutional things that we will continue to work on is further study of this man-machine interface, not only for the F–22 but for other aircraft. Atelectasis and the Raptor cough, there is relationship between the two.

Mr. BARTLETT. Of course. That is why you have the cough.

How thoroughly did your study group examine this issue, and does your report draw any conclusions or make any recommendations to address the Raptor cough issue? Is there any modification to the F–22 oxygen system that would minimize or eliminate the Raptor cough and its effect?

I will answer my own question. If you keep the CO—or the oxygen level as close as you can to 158 millimeters of mercury, where your blood will be adequately oxygenated, you will reduce the incidences, I think.

As you fill the lungs with more and more oxygen and less and less nitrogen is there to hold the alveoli open, you are going to increase the incidence of that; am I correct?

General LYON. Yes, Mr. Chairman.

May I add one thing for the record, one of the reasons we are significantly above 158 is for protection against the possibility, however slight, but the possibility of rapid decompression at high altitudes. As you know, super-oxygenating the bloodstream will maximize our time of useful consciousness, should we have that take place.

Mr. BARTLETT. There is a press report this morning indicating that the Air Force medical experts linked the Raptor cough to the F–22's air supply system. I would hope so. The article indicates that the Air Force decided in 2005 not to make a fix to the F–22 oxygen system. Do you know if a modification to the F–22 air supply system was considered in 2005 to address the Raptor cough issue and why the modification was not made?

General MARTIN. Sir, let me give you a partial answer here. First of all, the bleed air satisfies many customers. It satisfies the cooling requirements for the flight control computer. It satisfies the communication navigation cooling system. It satisfies the fire control system. It provides pressurization to the cabin. And it also provides the pressurized air at a specific pressure and temperature to OBOGS, which then delivers breathing air to the pilot. It is controlled by a node, known as the air cycle machine, which meters the amount of air necessary to the customers, based on the pressurized air coming in as well as the temperature. If the temperature begins to creep up, which at high-altitude, low-power settings, it does, it then begins to shut down the delivery of the air to some of those customers down range, and the OBOGS is one of them. At that point, then, there is a restriction to the amount of air the pilot might get, to include zero, when the OBOGS has no pressure at the front.

We knew that in the early testing, and there were modifications to the air cycle machine's algorithms that controlled the metering of the air, and that, again, was brought forward in the 2005 timeframe as a part of the discussion there.

As a result of the SAB study, the program office has gone back into that algorithm and adjusted it again, because the number of ECS rollbacks or shutdowns was greater than predicted or expected, and they have tried to adjust that air cycle machine mechanism to reduce the number of shutdowns that would occur, therefore, shutting off the oxygen to the pilot.

Further, as you know, from what General Lyon said, there will be a backup oxygen system placed on the aircraft so that if that happens, you will still get breathable air from the backup system that will be much larger than the basic emergency activation system we have today.

Mr. BARTLETT. In early designs of the F–22, didn't we have a backup system, and wasn't it taken out to reduce cost?

General MARTIN. It was not a cost issue, sir. It is true that it was taken out. It did have an initial design of a backup oxygen in addition to the emergency oxygen system. A series of events occurred, but the catalyst for this particular decision was the term that every aircraft goes through, the war on weight.

After the prototypes had flown, they then begin to go into their engineering, manufacturing, development phase. And at that point, you begin to find out where the strengths and weaknesses are. The aircraft always gain weight. When it gains weight, it may not be able to pass its key performance parameters of sustained G or acceleration or altitude or whatever. So, at that point, they had to get the weight down.

The difficulty here was that as we went into acquisition reform, we created the IPT [Integrated Product Team] structure, and at that point, very tough decisions were made in terms of who had the authority to make certain decisions. That usually was generated as a result of a very conscientious review to determine where your safety-of-flight critical items were. And as the program evolved, the backup oxygen system, the OBOGS and the emergency oxygen system were not considered safety-of-flight critical. They were safety significant, which meant that the decision to take the backup oxygen system off could be made at a lower level than the chief engineer of the F–22, and it was. And it was not known at that time by the senior leadership that that—the analysis that went into that trade study that allowed the backup oxygen system to come off.

In retrospect, that was not an appropriate decision. But at that time, that is what the decision was. Now that decision was made also with the information that the environmental control system, ECS, IPT was going to put a shunt valve in that would always ensure there would be positive pressure to the OBOGS, and therefore, taking the backup system off would not be a problem, given that you had an emergency backup system should the OBOGS fail entirely.

So what looks like what I would consider to be a flippant decision turned out to be steeped in data and very well thought out, but it was perhaps not viewed by the more experienced and senior engineer responsible for the F–22.

Mr. BARTLETT. If weight is that critical, what do we prune now so we can put it back in?

General MARTIN. Sir, first of all, it was 15.4 pounds, as I recall. And they were looking for every pound they could find. The performance of the aircraft is so magnificent that 15 pounds is not going to hurt this aircraft.

Mr. BARTLETT. Is there any explanation of why the reported hypoxia incidents have been concentrated at only two of the six operating bases?

General LYON. We asked the Air Force Safety Center, Mr. Chairman, to go to all of the F–22 bases and talk to the crews, the air crew and the ground crew, to help us understand some of the factors beyond what I would call hard science, beyond engineering science, and get into the human factors.

One of the locations is Joint Base Elmendorf-Richardson, where tragically, in November 2010, Captain Jeff Haney lost his life. And there was a cluster of incidents that took place in May 2011, just before the standdown occurred. There is a residual effect within the community that occurs when you suffer through a tragedy. And as General Martin mentioned earlier today, there was a period of quite some time, nearly a year, uncertainty about what caused Captain Haney's crash and the loss of his life. So this built up and manifest inside the community, and there is residual effect that has come from that.

At the other base, Joint Base Langley-Eustis, we found that there was a set of factors there where the C2A1 canister—and I can tell you from my discussions with all of the wings, the C2A1 canister had a different meaning at that installation than it did at the other five. And we saw several clusters take place. And the human factors engineers and scientists tell us that this is to be expected, that if there is a perception of a problem, and somebody credible within the organization has a problem, others will begin to experience the same thing. And that is what we had; credible aviators who had a perception that we had helped them believe, there is a problem with your life support system which could have been contamination, and at the first sign, saying, I have a problem, terminating the mission. Their credibility extended to other people at their installation. That is how we explain it.

At the other installations, they never got to that point. But there were factors resident localized that had professionals make well-measured, good decisions to terminate missions because they had the perception that there was a problem.

General MARTIN. One other comment, Mr. Chairman.

When the Scientific Advisory Board recommended the return-to-fly protocols and the steps to be taken, it knew or it believed that it would be important for us to continue the return-to-fly process until at least March of 2012, because that would give us a fairly representative sample across the fleet of the different seasons. It also turns out that at Elmendorf and at Langley, those two bases fly with the protective gear for winter operations, which means if you haven't readjusted your upper pressure garment and you now fly with more stuff, the restriction to the breathing could be greater. And the incidents may very well have also been related to the fact that we didn't have a proper standard for the upper pressure garment fitting, and then we didn't change the upper pressure garment fitting when we put on the rubberized and cold-weather gear.

Mr. BARTLETT. Thank you.

General Lyon, I think you probably have articulated the major reason for this. A little anecdote may help put that in perspective.

If you are provided a breathing mask and you are sat behind a screen and you are getting your air supply through a tube and you are told that, by and by, you will smell violets and you are supposed to indicate to the investigator when you smell violets, essentially everybody will smell violets. The investigator has not done one thing to the air supply.

These are very subjective things, and it is kind of tough for us to recognize that we are not in full control of these things. But these are very subjective things. And if you think that there is going to be a problem with your oxygen supply system and you may become hypoxic, the least little thing will trigger this hyperventilation, unperceptible to the pilot, and he will then have exactly the symptoms of the thing that he dreaded, and that is hypoxia. It is a very interesting thing that has happened here, and I am sure that this was a learning experience for everybody who was involved in the investigation.

Is there an explanation—why do you believe that the pilots have not previously complained until recently about the chest constriction caused by the upper pressure garment now determined to be a causal factor in the F–22 physiological problems?

I am not sure, my statement seems to imply it was a causal factor.

Do you think there is any causal factor other than the fact that the perception was, gee, my breathing is impeded a little and I guess I need to breathe more to get oxygen. And so they end up breathing more and get hypocapnia, which are exactly the symptoms of hypoxia? Is there another explanation?

General LYON. If I have the question correctly, and I am not sure I do, Mr. Chairman, how did they go for so long with this upper pressure garment filling prematurely, restricting their breathing and not knowing it, this is—what helped inform us was the normalization of deviance that Mr. Cragg has mentioned.

When we put these F–22 pilots into the centrifuge with their gear on and they were accelerated to high G, we measured the fact that they were prematurely filling and restricting their breathing, and then we were able to measure, if we could have the chart that shows—as you can see on the chart in front you, Mr. Chairman, that without the upper pressure garment on, the tall blue spike shows how quickly they can inspire and get the required volume and that the red line shows that with the upper pressure garment on, they cannot get the depth that they need, and it takes longer to breathe. And as you already mentioned, Mr. Chairman, the brain just does this without the pilot knowing perceptibly that he is changing his breathing.

This is what we have come to know, which the Navy helped us with, this understanding of the work of breathing. Breathing restrictions integrated into the pilot's flight ensemble, forced them to work harder to get the required volumes of air, which can then lead to fatigue symptoms over time.

Mr. BARTLETT. When I got my doctorate and its emphasis was in this subject 60 years ago, I never dreamed that I would be sitting here at a subcommittee hearing where this information would be relevant.

Do all other fighter aircraft have a backup oxygen system?

General MARTIN. Could you repeat that question, sir?

Mr. BARTLETT. Do all other fighter aircraft have a backup oxygen system?

General MARTIN. Sir, they all have an emergency oxygen system, and they either have a backup oxygen system, or they have a plenum, which is like a reservoir that gives them additional air should the OBOGS system fail.

Mr. BARTLETT. Thank you very much for staying here through a very long subcommittee hearing. I hope that this puts at ease the minds of our pilots and their families. Thank you for doing a great job of investigating this, and thank you for your testimony today.

[Whereupon, at 12:00 p.m., the subcommittee was adjourned.]

A P P E N D I X

SEPTEMBER 13, 2012

PREPARED STATEMENTS SUBMITTED FOR THE RECORD

SEPTEMBER 13, 2012

HEARING ON F-22 PILOT PHYSIOLOGICAL ISSUES
SUBCOMMITTEE ON TACTICAL AIR AND LAND FORCES
OPENING STATEMENT
CHAIRMAN ROSCOE BARTLETT
September 13, 2012

The subcommittee meets today to receive testimony on F-22 pilot physiological issues which have resulted in reported hypoxia-like events by F-22 pilots over a period of several years.

From 2003 to April 2008, there were six F-22 physiological incidents, but between April 2008 and January 2011 that number had doubled to 12. As a result of this, the Air Force's Commander of Air Combat Command restricted the F-22's maximum flight altitude to 25,000 feet and directed a safety investigation board to review the F-22's oxygen system.

In May 2011, the Secretary of the Air Force directed the scientific advisory board to gather information and make recommendations to address deficiencies in the F-22 life support system.

From May to September of last year, the F-22 fleet stood down as a result of an upward trend in reports of physiological incidents.

The scientific advisory board completed its work in January of this year but did not determine a cause of the F-22 pilot physiological problems. However, the board did make findings and recommendations, and concluded that either the supply or the quality of the oxygen is contributing to F-22 pilots' hypoxia-like symptoms.

Air Combat Command established a Life Support System Task Force which continued to examine both the issues of supply and quality of oxygen in the F-22.

On April 23, 2012, the National Aeronautics and Space Administration (NASA) accepted a request from Air Combat Command to form an independent investigative team to review Air Combat Command's investigative process, on-going root cause analysis, and the F-22 Life Support System, as a whole, to determine potential vulnerabilities to the pilot.

On July 24th, the Department of Defense announced that Air Combat Command had determined that the root cause of the F-22 pilot physiological issues is the supply of oxygen delivered to the pilots, not the quality of oxygen delivered to the pilots.

To correct the supply issue and reduce the incidence of hypoxia-related events, the Air Force is making two changes to the aircraft's cockpit life support system.

First, the Air Force has increased the volume of air flowing to pilots by removing a filter that was installed as part of the investigation to determine whether there were any contaminants present in the oxygen system.

Second, the Air Force will replace a valve in the upper pressure garment worn by pilots during high-altitude missions. The upper pressure garment is designed to provide counter pressure to assist pilot breathing and to help counteract the effects of g forces. The garment valve was causing the vest to inflate—and remain partially inflated—under conditions where it was not designed to do so, thereby causing breathing problems for some pilots.

Oxygen contamination was ruled out as a potential cause.

The Air Force is also exploring ways to improve the oxygen delivery hose and its physical connections.

In the interim, the F-22 is under a temporary altitude limit of 44,000 feet.

Since the F-22 returned to flying status in September of 2011, there have been 11 hypoxia incidents where the case was initially reported as a cause unknown. The Air Force continues to investigate those cases, and as of late July, less than half of those were still unresolved.

There have been no "cause unknown" hypoxia incidents in the F-22 since March 8, 2012.

From fiscal year 2002 to May 2011 the Air Force reports an incidence rate of 13 hypoxia events per 100,000 hours compared to 7.5 in the F-16, 1.8 in the F-15E and 6.6 in the F-18E, F, and G over roughly the same period.

I know from personal experience as a scientist working these issues before I came to Congress that the Air Force faced a difficult problem in determining the root cause of these F-22 pilot hypoxia-like events because in either the case of insufficient oxygen quantity or poor oxygen quality, the symptoms to the pilot are largely the same. Hypoxia, or lack of oxygen, produces the same symptoms in humans that would result from toxic exposure, or hypocapnia, also known as hyperventilation.

A significant amount of effort has gone into solving the F-22 physiological issues, but much more needs to be done. Recommendations of the Air Force Scientific Advisory Board's Oxygen Generation Study Group need to be implemented. The Air Force Air Combat Command's Life Support Systems Task Force needs to complete its report and provide its final recommendations. Additionally, NASA's Engineering and Safety Center needs to complete its final report and provide its recommendations. The Committee expects the Air Force to keep Congress up to date on the status of all of these reports and recommendations.

To address the F-22 physiological issues, we've asked the three key leaders involved with this project to testify today.

- Retired Air Force General Gregory S. Martin, chairman of the Air Force Scientific Advisory Board Quicklook Study on Aircraft Oxygen Generation. General Martin, welcome back.

- Major General Charles W. Lyon, Director of Operations for the Air Combat Command. General Lyon leads the F-22 Life Support System Task Force.

- Finally, Mr. Clinton H. Cragg, Principal Engineer at NASA's Engineering and Safety Center. Mr. Cragg leads NASA's independent investigative team which has reviewed Air Combat Command's F-22 processes and analysis.

Gentlemen, we thank you all for your service to our Country.

Before we begin, let me call on the Ranking Member of the subcommittee, Mr. Reyes, for his opening remarks.

Statement of the Honorable Silvestre Reyes
Ranking Member, Subcommittee on Tactical Air and Land Forces
F-22 Pilot Physiological Issues

September 13, 2012

- Today's hearing on the F-22 will cover many technical issues associated with the F-22's pilot life support system.

- On balance, I am pleased with the level of effort the Air Force has put into this investigation.

- It is clear that current senior Air Force officials have taken this issue very seriously and have put in place the resources and organizations needed to identify the problem, and eventually fix the problem.

- The scale of the testing and evaluation effort for a tactical fighter aircraft is, I believe, unprecedented.

- Rather than staying in a defensive posture, the Air Force reached out to other agencies and military services for additional expertise and advice.

- Based on the extensive work done by the Air Force and other DOD agencies, I am cautiously optimistic that the Air Force has indeed identified the primary causes of the hypoxia problems with the F-22, and identified fixes that make sense.

- The next step is ensuring that the fixes identified are funded and installed as rapidly as possible.

- The United States needs the F-22 to deter our enemies and provide critical capabilities if we do go to war.

- Despite Congress passing a long-term continuing resolution for Defense spending, I want to ensure that efforts to fix the F-22s problems can continue at full speed.

- So, understanding the F-22's problems and how to fix them is one aspect of today's hearing, and an important one.

- However, the larger issue that I hope today's hearing will touch on is <u>how this situation occurred in the first place</u> – and <u>how can we avoid similar mistakes in the future</u>?

- As far as the cause of the F-22's problems, my overall impression from the testimony received and the other information provided to the subcommittee is that the main problems with the F-22 were human failures of judgment, not technical failures.

- One issue that appears to have gone wrong was the basic design of the aircraft's life support system.

    - The F-22 is the most capable – and expensive – fighter aircraft ever developed.

    - The F-22 also operates at higher altitudes, and in a more demanding performance envelope, than any other fighter aircraft.

    - Given these two factors – a cost per plane of more than $140 million and a unique flight environment – it is very surprising that it was designed without a sophisticated back up oxygen system, or even enough instrumentation to let the pilot know that he wasn't getting oxygen in time to do something about it.

- So one question that confronts the subcommittee is: how did that happen? Why did the Air Force design and build such a sophisticated aircraft with such a relatively unsophisticated pilot life support system?

- In addition, why wasn't this issue identified during testing of the aircraft? That is normally when serious design issues are identified for future fixes, but that doesn't seem to have been the case with the F-22.

- We are going to get a lot of information today, but in particular I look forward to hearing from the Air Force witnesses how they think we got to this point, and how we can avoid similar problems with other aircraft in the future?

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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

STATEMENT OF: General Gregory S. Martin, USAF (Retired)
Chairman, AFSAB Quicklook Study on Aircraft Oxygen Generation

September 13, 2012

Chairman Bartlett, Ranking Member Reyes, and distinguished Members of the Committee, I am honored to be here today representing the members of the United States Air Force Scientific Advisory Board's Quicklook Study on Aircraft Oxygen Generation Systems.

Introduction

Onboard Oxygen Generation Systems (OBOGS) are used on most fighter aircraft due to reduced servicing and logistics support, and safety considerations. The F-22 aircraft is equipped with such a system to provide breathing air to the pilot. This system takes engine bleed air and concentrates it to the appropriate partial pressure of oxygen as determined by the cabin altitude.

Beginning in 2008, the F-22 aircraft began to experience a significantly higher rate of hypoxia-like incidents with unknown causes as reported by the pilots. The Air Force was not able to determine the "root cause(s)" for these incidents and a further review was recommended to the Secretary of the Air Force. The Secretary then tasked the United States Air Force (USAF) Scientific Advisory Board (SAB) to perform a Quicklook Study on Aircraft Oxygen Generation (QLSAOG) to cover three areas:

1. Continue the ongoing efforts to determine root cause(s), to include: Gathering data during dynamic, in-flight testing; full reviews of both the life support equipment and the aircraft's potential for passing contaminants into the cockpit and/or breathing air; and finally, to better understand the similarities and differences between the F-22 oxygen generating system and other military aircraft.

2. A better understanding of the conditions that would create hypoxia-like symptoms at

altitudes not normally associated with hypoxia, along with an evaluation of the guidance associated with the breathing air standards and the human response to operating in the F-22's extraordinary flight envelope with less than 90% supplied oxygen.

3. Review the policies, processes, and procedural changes that occurred during the F-22's development and fielding, and evaluate the implications with respect to design limitations, risk analysis, program execution, and acquisition workforce.

The Study formally began in June 2011 with interim status reports provided to the Secretary of the Air Force and the Air Force Chief of Staff until the final briefing was approved by the entire SAB and delivered to the Secretary and Chief of Staff on January 24, 2012.

The recommendations made at that time were based on findings reached by the study panel after having reviewed, assessed and discussed the information available as a result of its document review, interviews, technical briefings and data from nearly 7,500 flights. Those findings and recommendations are presented later in this statement.

During the interim update in September of 2011, SAB did recommend to the Secretary and the Chief of Staff that the Air Combat Command (ACC) establish a Task Force to properly guide and oversee F-22 fleetwide maintenance inspections, pilot and maintenance technician training, and the gathering and assessment of data related to all F-22 flight operations. ACC did establish the F-22 Life Support Systems Task Force, directed by Major General Charles Lyon whom you will hear from later this morning.

Also as you will see in the recommendations section, quarterly updates to the AFSAB QLSAOG were recommended. The study panel has met twice with the F-22 Life Support Systems Task Force to review the Task Force's progress with regard to the study team's recommendations and to offer its assistance as appropriate.

Background

Most modern day aircraft use an On-Board Oxygen Generation System (OBOGS) to provide breathing air to the crew. Beginning in the 1980s, these systems began to be chosen over liquid oxygen (LOX) systems due to reduced logistics footprint and reduced servicing requirements. These systems make use of the principal of Pressure Swing Adsorption, where cylinders of synthetic zeolite are able to concentrate the oxygen (O2) output by eliminating nitrogen from the breathing gas when the cylinder is pressurized and venting the nitrogen overboard when the pressure is vented. Depending on the temperature, pressure, and cycle time, these concentrators are able to produce O2 concentrations of 93-94%.

The AOG Study Panel assessed the entire force of fighter aircraft of the USAF and US Navy. With the exception of the F-15C (which continues to use a LOX system) all of the other aircraft use some form of on-board oxygen generation provided by one of two corporations that dominate this market. A review of safety incident data showed that the F-22 aircraft was the only aircraft with an abnormally high rate of hypoxia-like incidents whose cause could not be determined. All aircraft experienced low rates of incidents caused by a hardware failure, a hose obstruction, or mask failures; however, the F-22 was the only mission design series with a high rate of unknown cause incidents.

While the pilots involved in these incidents reported a wide range of symptoms, they generally qualified as hypoxia-like. At the direction of the Air Combat Command (ACC) Commander, a Class E Safety Investigation Board (SIB) was formed to accomplish a fleet-wide assessment of oxygen generating systems and associated life support systems. This board thoroughly investigated each of the F-22 incidents of unknown cause and was unable to find a common root cause.

An F-22 and its pilot were lost on a night mission in Alaska in November of 2010, and the cause was unknown when this Study was initiated. As of May 2011 the cause was still not identified, and in that month several hypoxia-like incidents at Elmendorf Air Force Base (AFB) led to the grounding of the F-22 aircraft fleet. Eventual recovery of the aircraft data recorder showed the oxygen delivery system was not the cause of the aircraft loss, removing it as a primary case study for this inquiry.

With this background, this AOG Quicklook Study was initiated in June 2011. The SAB was tasked with also working with SIB members, the F-22 System Program Office (SPO), and ACC to identify necessary steps to return the F-22 to unrestricted operations. The "Return-To-Fly" section of this report defines those steps.

Assessments

The AOG Study Panel came to the view that the hypoxia-like incidents were being caused by the F-22 life support system either (1) delivering a lower amount of oxygen to the pilot than necessary to support normal performance, or (2) the system was producing or failing to filter toxic compounds in the breathing air. In the case of either hypothesis, the result would be hypoxia-like symptoms that could threaten safety of flight.

In evaluating the system against the two hypotheses, the Panel assessed the technical performance of the F-22 life support system, the human effectiveness considerations of the system, and also the policies, processes, and procedures used to develop and acquire the system.

The technical assessment of the F-22 life support system identified the following system design. The system is pressurized by bleed air from the ninth stage of the compressor. This air is then conditioned to the right temperature, humidity, and pressure by a series of heat exchangers that use either air or polyalphaolefin (PAO) as the thermal transport medium. The air is assumed to be "breathable" when it leaves the compressor and when it enters the OBOGS cylinders. There are no filters for potential contaminants, other than 0.6 micron filters on the entry and exit of the OBOGS unit, which are designed to filter particles from the breathing air. The output is then routed to the Breathing Regulator Anti-G (BRAG) valve and on to the pilot's mask. In the F-22, the pilot always breathes under a small positive pressure. A separate valve connects the emergency oxygen system (EOS) on the ejection seat to the pilot's mask.

The system is unique in that, unlike all other OBOGS-equipped aircraft, a back-up oxygen system or plenum is not available to provide breathing continuity in the event of an OBOGS shutdown. In this situation, the pilot must manually activate the EOS, descend to an altitude where oxygen is not required, and land as soon as possible. The EOS activation handle was found to be difficult to locate and rapidly activate. If the pilot fails to act appropriately, loss of consciousness could result, likely leading to loss of the aircraft as the F-22 aircraft does not have an automatic ground collision avoidance system (AGCAS). Additionally, the system provides delayed warning to the pilot of a failure to deliver the right partial pressure of O2 and there is no indication of the pilot's oxygenation level. The system was fielded with no recurring maintenance or inspection requirements. It is a Fly-to-Warn/Fail system with servicing driven by a warning light or a pilot writing a maintenance discrepancy. (Note: The aircraft will also generate maintenance Fault Reporting Codes when the OBOGS malfunctions. These are recorded on the Data Transfer Cartridge that is downloaded after each flight.)

The Study Panel benefitted from the availability of an F-22 aircraft at the Air Force Flight Test Center that had been specially instrumented to assess the performance of the entire system providing breathing air to the pilot. This aircraft flew operational profiles to duplicate those of incident aircraft in the field. Additionally, components of incident aircraft were removed and flown on the test aircraft. As this Study was ending, two incident aircraft from the field were brought to Edwards AFB and also instrumented.

During ground and flight tests, contaminants were found at levels well below those thought to be harmful. These contaminants contained elements of the ambient air, jet fuel, and PAO. As noted earlier, there was no contaminant filter in the breathing path. Tests have shown that the OBOGS itself can filter some elements and concentrate others, as it does with oxygen.

The assessment of the environmental control system (ECS) and life support system development programs indicated a major shortfall in the modeling and simulation of the system to determine performance under degraded conditions or in the presence of contaminants in the breathing gas. This assessment also identified major shortfalls in the application of Human System Integration (HSI) principles, availability of appropriate breathing standards, and a comprehensive understanding of the aviation physiology implications of sustained operations at high altitude without a full pressure suit.

The F-22 was developed during a period of major changes in the Air Force acquisition process. The majority of the Department of Defense military specifications and standards were rescinded and the acquisition workforce was reduced in favor of increased industry responsibility. A refined program management structure delegated many decisions to Integrated Product Teams (IPTs) for non safety-critical functions. These changes left major uncertainties as to what was an "inherently governmental responsibility." Additionally, the program underwent several major restructures driven by cost and funding constraints, to include major reductions in the size of the F-22 program office.

These assessments led the Study Panel to make the following Findings and Recommendations to both mitigate identified risks in allowing the F-22 to return to flight and to provide the data necessary to identify the root cause(s) of these hypoxia-like incidents.

Findings

- The F-22 OBOGS, Back-up Oxygen System (BOS), and EOS were not classified as "Safety Critical Items."
    - The Life Support System IPT eliminated the BOS to save weight.
    - The ECS IPT designed an Air Cycle Machine bypass to provide bleed air to the OBOGS in the event of an ECS shutdown.
    - The Emergency Oxygen System was deemed to be an adequate Backup Oxygen System.
    - The ECS IPT decided to forgo the Air Cycle Machine bypass.

- With an ECS shutdown, the pilot's flow of breathing air is cut-off thus requiring the pilot to activate the Emergency Oxygen System to restore the flow of breathable air

- Interrelated and interdependent decisions were made without adequate cross-IPT coordination.

- Over the past 20 years, the capabilities and expertise of the USAF to perform the critical function of Human Systems Integration have become insufficient, leading to:

  - The atrophy of policies/standards and research and development expertise with respect to the integrity of the life support system, altitude physiology, and aviation occupational health and safety.

  - Inadequate research, knowledge, and experience for the unique operating environment of the F-22, including routine operations above 50,000 feet.

  - Limited understanding of the aviation physiology implications of accepting a maximum 93-94% oxygen level instead of the 99+% previously required.

  - Specified multi-national air standards, but deleted the BOS and did not integrate an automated EOS activation system.

  - Diminution of Air Force Materiel Command (AFMC) and Air Force Research Laboratory (AFRL) core competencies due to de-emphasis and reduced workforce to near zero in some domains.

- Modeling, simulation, and integrated hardware-in-the-loop testing to support the development of the F-22 life support system and thermal management system were insufficient to provide an "end-to-end" assessment of the range of conditions likely to be experienced by the F-22.

  - Engine-to-mask modeling and simulation was non-existent.

  - Dynamic response testing across the full range of simulated environments was not performed.

  - Statistical analysis for analyzing and predicting system performance/risk was not accomplished.

  - Performance of OBOGS when presented with the full range of contaminants in the ECS air was not evaluated.

4. The F-22 life support system lacks an automatically-activated supply of breathable air.

    - ECS shutdowns are more frequent than expected and result in OBOGS shutdown and cessation of breathing air to the pilot.

    - The F-22 is the only OBOGS-equipped aircraft without either a BOS or a plenum.

    - The “OBOGS Fail” light on the integrated caution, advisory, and warning system (ICAWS) has a 12-second delay for low oxygen, providing inadequate warning.

    - When coupled with a rapid depressurization at the F-22’s operational altitudes, the “Time of Useful Consciousness” can be extremely limited.

    - The EOS can be difficult to activate, provides inadequate feedback when successfully activated, and has limited oxygen duration.

5. Contaminants identified in the ongoing Molecular Characterization effort have been consistently measured in the breathing air, but at levels far below those known to cause health risks or impaired performance.

    - Contaminants that are constituents of ambient air, Petroleum, Oils and Lubricants, and polyalphaolefin are found throughout the life support system in ground and flight tests.

    - OBOGS was designed to be presented with breathable air and not to serve as a filter.

    - OBOGS can filter some contaminants and there is evidence it may concentrate others.

6. The OBOGS was developed as a “fly-to-warn/fail” system with no requirement for initial or periodic end-to-end certification of the breathing air, or periodic maintenance and inspection of key components.

    - Engine bleed air certified “breathable” during system development.

    - OBOGS units are certified at the factory.

    - No integrated system certification.

    - No recurring Built-In Test, inspections, or servicing.

7. Given the F-22’s unique operational envelope, there is insufficient feedback to the pilot about the partial pressure of oxygen (PPO2) in the breathing air.

- Single oxygen sensor well upstream of the mask.
- 12-second delay in activating the ICAWS when low PPO2 is detected.
- Inadequate indication of EOS activation when selected.
- No indication of pilot oxygen saturation throughout the F-22 flight envelope.

8. The F-22 has no mechanism for preventing the loss of the aircraft should a pilot become temporarily impaired due to hypoxia-like symptoms or other incapacitating events.

   - Disorientation, task saturation, and/or partial impairment from hypoxia could result in loss of the aircraft and possibly the pilot.

9. The F-22 case study illustrates the importance of identifying, developing, and maintaining critical institutional core competencies.

   - Over the last two decades, the Air Force substantially diminished its application of systems engineering and reduced its acquisition core competencies (e.g., systems engineering, HSI, aviation physiology, cost estimation, contracting, and program and configuration management) to comply with directed reductions in the acquisition work force.
   - By 2009, the Air Force had recognized this challenge and developed a comprehensive Acquisition Improvement Plan (AIP) and an HSI plan.
   - Although the AIP has been implemented, the HSI plan is early in its implementation.
   - A clear definition of "inherent government roles and responsibilities" is not apparent.

Recommendations

1. Develop and install an automatic Backup Oxygen Supply in the F-22 life support system.

   - Consider a 100% oxygen BOS capability unless hazardous levels of contaminants in OBOGS product air can be ruled out.

2. Re-energize the emphasis on Human Systems Integration throughout a weapon system's lifecycle, with much greater emphasis during Pre-Milestone A and during Engineering and Manufacturing Development phases.

   - Identify and reestablish the appropriate core competencies.

- Develop the capability to research manned high altitude flight environments and equipment, develop appropriate standards, oversee contractor development, and independently certify critical, safety-of-flight elements.

3. Establish a trained medical team with standardized response protocols to assist safety investigators in determining root cause(s) for all unexplained hypoxia-like incidents.

4. Develop and implement a comprehensive Aviation Breathing Air Standard to be used in developing, certifying, fielding, and maintaining all aircraft oxygen breathing systems.

5. Create and validate a modeling and simulation capability to provide end-to-end assessments of life support and thermal management systems.

   - The initial application should be the F-22 followed by the F-35.

6. Improve the ease of activating the EOS and provide positive indication to the pilot of successful activation.

7. Complete the Molecular Characterization to determine contaminants of concern.

   - Where appropriate, alternative materials should be considered to replace potential sources of hazardous contaminants.

   - Develop and install appropriate sensor and filter/catalyst protection.

8. Develop and implement appropriate inspection and maintenance criteria for the OBOGS and life support system to ensure breathing air standards are maintained.

9. Add a sensor to the life support system, post-BRAG (Breathing Regulator Anti-G), which senses and records oxygen pressure and provides an effective warning to the pilot.

10. Integrate pilot oxygen saturation status into a tiered warning capability with consideration for automatic Backup Oxygen System activation

11. Develop and install an AGCAS in the F-22.

12. Clearly define the "inherent governmental roles and responsibilities" related to USAF acquisition processes and identify the core competencies necessary to execute those responsibilities.

13. Create a medical registry of F-22 personnel who are exposed to cabin air or OBOGS product gas, and also initiate epidemiological and clinical studies that investigate the clinical features

and risk factors of common respiratory complaints associated with the F-22.

14. Establish a quarterly follow-up to ensure SAB recommendations are implemented in a timely fashion or to respond to any event of significance. Note: The SAB is available for continued support if desired.

Return-to-Fly

As the AFSAB QLSAOG completed its work without having determined the root cause(s) for the unexplained hypoxia-like incidents, it did recommend that the Air Force continue in a "transitional" flying phase while pursuing the following "Near Term" and "Long Term" recommendations.

Near-Term:

- Implement improved access to, and ease of activation of, the EOS.
- Implement an independent post-BRAG O2 sensor providing indication, warning, and recording capability.
- Field helmet-mounted pulse oximeter.
- ACC Task Force should consider installing carbon monoxide and carbon dioxide detectors in the F-22 cockpits.
- ACC Task Force should consider using a vacuum canister during maintenance engine runs and assess the contents should there be an incident.
- Leverage the National Aeronautics and Space Administration, or similar independent capabilities, to develop and implement the appropriate post-incident protocols with greater emphasis on forensic analysis of the entire life support and cabin pressurization systems.
- Analyze data gathered to determine effectiveness of the C2A1 filter for safety and data collection.
- ACC Task Force and 711th Human Performance Wing identify the need for contaminant mitigation measures for both OBOGS and cockpit breathing air.

Long-Term:

- Install an automatically-activated Backup Oxygen System.

- Determine, through further data analysis, the need for aircraft mounted measurement and mitigation of contaminants in the breathing air.
- Develop and install an AGCAS for the F-22.

Summary

As of the completion of the SAB Study, neither the Air Force Scientific Advisory Board nor the Air Combat Command Task Force had yet determined the root cause(s) of the incidents, but had identified and mitigated a number of risks. While the data evaluated by this team identified minor system anomalies and a lack of robustness in the implementation, system performance exceeded pilot physiological needs. Contaminants identified were at levels far below those known to be harmful to humans. The measures taken to protect the crews and gathering of appropriate data have provided substantive and valuable information and have narrowed the possibilities while maintaining combat capability.

After completion of the Aircraft Oxygen Generation (AOG) Quicklook Study the AOG Study Panel was made aware that the Air Combat Command's F-22 Return-to-Fly Task Force has continued the testing and analysis recommended by the Study Panel and has determined what they believe to be a root cause. The Study Panel was recently briefed in some detail on the Task Force's findings. Continuing the aggressive ACC Task Force approach to implementing the SAB recommendations will be critical to fully addressing the unexplained hypoxia-like events and should provide the F-22 with a significantly improved margin of safety and operational effectiveness.

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SUBJECT: F-22 Pilot Physiological Issues

STATEMENT OF: Major General Charles W. Lyon
Director of Operations, HQ Air Combat Command

September 13, 2012

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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 that 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 polyalpholefin (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 threshhold 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-Janury 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 5th 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_2) 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, 1st Fighter Wing, 633rd 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 RGWB 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 CO2. 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 CO2. 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), 711th 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 O2 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 O2 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) 711th 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 O2 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 O2 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 21st 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.

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
September 13, 2012

Statement of
Mr. Clinton H. Cragg
NASA Engineering Safety Center Principle Engineer
National Aeronautics and Space Administration

before the

Subcommittee on Tactical Air and Land Forces
Committee on Armed Services
United States House of Representatives

Chairman Bartlett, Ranking Member Reyes and Members of the Subcommittee, I thank you for the opportunity to appear before you today to discuss the NASA Engineering Safety Center's (NESC's) independent assessment of the F-22A Life Support System. I am honored to be serving as the Lead for this NESC team. The NESC performs value-added independent testing, analysis, and assessments to help address some of NASA's tougher challenges. Led by director Ralph R. Roe Jr., the NESC is independently funded by the NASA Headquarters' Office of the Chief Engineer, with a dedicated team of technical experts from all ten NASA centers, industry, academia and other government agencies. The country's best experts are brought to bear on the problems and challenges of NASA programs. The NESC is an organization dedicated to promoting safety through engineering excellence, unaffected and unbiased by the programs being evaluated.

In April 2012, Major General Charles W. Lyon, United States Air Force (USAF) requested NASA's assistance in their aggressive ongoing efforts to determine the cause of the hypoxia-like symptoms experienced by some F-22 pilots. NASA was requested to review:

- "current post-incident protocols and, if warranted, recommend enhanced procedures with a greater emphasis on analysis of the entire life support and cabin pressurization systems."

- "current investigative process, ongoing root cause analysis, and the F-22 Life Support System as a whole to determine potential vulnerabilities to the pilot."

The NESC was tasked by NASA headquarters with leading this effort, and I was assigned as the team lead. We assembled a team that included two NASA Flight Surgeons, two NASA Human Factors experts, an Environmental Protection Agency Forensic Chemist, an industry On Board Oxygen Generating System (OBOGS) expert and several specialized NASA life support system (LSS) engineers. The NASA personnel came from seven different NASA locations across the country.

In the course of this investigation, the team reviewed data from multiple and varied sources, visited manufacturing sites and USAF F-22 bases, and held numerous discussions with knowledgeable personnel. The NESC team's observations, findings, and recommendations are, however, based on this data and do not represent an exhaustive review of all F-22 documentation. The NESC team acknowledges that the F-22 Raptor is a high-performance aircraft that is expanding the capability of aircraft performance. The USAF began receiving reports of unexplained hypoxia-like symptoms in F-22 aircraft as far back as 2008. Since then, a total of 21 reported incidents have taken place in multiple locations. There are seemingly few commonalities to link the reported incidents; while some episodes resolve with the simple application of O_2—suggesting classic hypoxia—other symptoms have been more prolonged in nature. This variation in incident presentation has made it difficult to identify the source(s) of the problem(s). The NESC team understands that this problem is very complex with multiple interactions, which include pilot physiology.

The USAF, and associated contractors, has conducted their own extensive investigations, including standing up the F-22 Task Force and holding a four month F-22 stand-down. As of Spring 2012, these investigations had not achieved a clear resolution. NASA was invited as an independent technical organization to review the on-going processes of investigation, and to render any commentary or suggestions for improvement. By August 2012, the F-22 Task Force under direction of the USAF had effectively identified a number of key contributors to the hypoxia problem. The NESC team concurs with much of what the USAF has done and has also identified areas for further consideration.

The NESC team concurs that the F-22 incidents can be attributed to several factors:

1. High concentrations of oxygen (O_2) at lower altitudes can lead to absorption atelectasis.
2. The inevitable acceleration, which compounds the effects of high O_2.
3. Restricted breathing due to the inappropriate inflation of the upper pressure garment (UPG) that not only prevented any relief of this atelectasis, but worsened the problem by reducing overall cardiac output.
4. Contribution of uncharacterized F-22 LSS vulnerabilities, such as pressure drops across components in the cockpit.

NESC Team Findings and Observations

The team found a number of issues with the systems providing breathing air to the pilot (i.e., Life Support System, Environmental Control System and Aircrew Flight Equipment). For example, the systems do not meet the physiological needs of the pilots in all cases. Pressure drops across portions of the systems can reduce O_2 flow, and current O_2 schedules provide higher than physiologically necessary O_2 concentrations. The systems are often treated, incorrectly in our view, as separate systems and controlled at the interfaces. This was the case, even back to the beginning of the program, where insufficient human-systems integration (HSI) testing was accomplished before operational deployment of the F-22. The events experienced, however, are a result of the complex interactions of these systems, and with the pilot included, are even more complex.

For the pilot, each flight does put extreme physiological demands on the body. The F-22 pilot community has come to expect a number of physiological phenomena as a "normal" part of flying the Raptor. These include the difficulty in breathing, the "Raptor cough," excessive fatigue, headaches, and delayed ear block. Differences in pilot breathing in the F-22 from other platforms was widely known and accepted as a normal part of flying the advanced aircraft. The acceptance of these phenomena as "normal" could be seen as "normalization of deviance."
The USAF has ruled out contamination as a cause. The NESC team found no evidence of a contaminant producing a toxic exposure for pilots flying the F-22. However, in any jet fighter environment irritant compounds like combustion exhaust gases, fuels, lubricants and also organic cleaning solvents can be present. The F-22 has no effective filtration of breathing air or cabin air and, although no conclusive evidence has been found indicating the effect of irritant compounds, they could enter the cockpit and the pilot's breathing air supply.

The investigative process, which included the Root Cause and Corrective Action (RCCA), could have been more efficient and more effective than it has been. The USAF F-22 Task Force was never given a directive that assigned the authority to conduct the investigation. Several issues noted in the medical arena (i.e., protocols) may have been resolved with a more direct chain of command. The RCCA tool itself began with too narrow a hypothesis that was later broadened. Although the RCCA process had plenty of data, it did not communicate well to all parties. Moreover, the process used did not lend itself to a systems approach to complex interactions. The NESC team agrees with many of the USAF's planned corrective actions (e.g., fixing the UPG, updating the O2 schedule, and retrofitting F-22s with a Back-up Oxygen Generator). During the course of the NESC team's review, a number of other areas that warrant further consideration were identified. These include the following near-term recommendations for the F-22 airframe and protocols and numerous long-term recommendations.

NESC Near-Term and Longer-Term Recommendations
Many of the NESC's near-term recommendations are actively being addressed by the USAF. For example, the upper pressure garment and OBOGS oxygen schedule are currently being modified. In other areas, modifications to the Protocols will require some effort on the part of the responsible USAF medical authority. The NESC recommended that post-incident protocols, established to better understand the nature of the F-22 incidents, have standard case definitions and treatment guidance for incident pilots.

Longer-term recommendations include conducting end-to-end testing of the Life Support System, Environmental Control System and Aircrew Flight Equipment to characterize actual capacity, margins, and vulnerabilities. This integrated system testing should have been completed during the initial F-22 testing. Any change to a system should trigger the appropriate human-systems integration testing. Given the insights the USAF has obtained this summer, we believe a fundamental reassessment of requirements and assumptions for the Life Support System in high performance aircraft should occur. Additionally, a formal lessons-learned review of the USAF-led effort to address and solve this issue should be accomplished.

Conclusion

The NESC team acknowledges that the F-22 Raptor is a high-performance aircraft that is expanding the capability of aircraft performance. The pilot's hypoxia-like symptoms presented an unusually complicated problem that required involvement of many of the USAF's major commands, both operational and material, and the F-22's manufacturer and several sub-contractors. The USAF's Task Force made great strides this summer in understanding the complex, highly interrelated nature of this problem and has identified a number of specific problem areas. The NESC's independent analysis supports the USAF's planned corrective actions.

WITNESS RESPONSES TO QUESTIONS ASKED DURING THE HEARING

SEPTEMBER 13, 2012

RESPONSE TO QUESTIONS SUBMITTED BY MS. SPEIER

Mr. CRAGG. The NESC Team report has described recommended medical courses of action for pilots who experience prolonged symptoms, based on what the NESC Team believes is the reason for these symptoms. Beyond that, the identification of precise biomarkers in hypoxic-ischemic injury in general, e.g. in victims of stroke, is still very much in the research phase, and not yet suitable for general diagnostic use, as in this case. [See page 26.]

QUESTIONS SUBMITTED BY MEMBERS POST HEARING

SEPTEMBER 13, 2012

QUESTIONS SUBMITTED BY MR. BARTLETT

Mr. BARTLETT. What have been the physiological consequences to the pilots in the reported hypoxia incidents? Have you categorized each of these incidents in terms of level of seriousness of the reported event? If so, what does the data show?

General LYON. There have been no long term physiologic consequences to pilots that have reported hypoxia incidents. Four pilots were treated in hyperbaric conditions due to the nature of their medical complaints. All pilots who reported hypoxia incidents have been medically returned to flying status. Level of seriousness is generally categorized by mishap/incident class. Classes of mishaps range from Class A (the most serious) to Class E (the least serious). Pilots who have reported hypoxia have categorically been Class E incidents.

The data shows there have been no biomarkers found in the aircraft or pilots pointing to contamination in the breathing gas.

Mr. BARTLETT. What are the operational impacts to the current restrictions on F–22 operations? Are F–22s capable of operating throughout their full operational envelope if required to do so?

General LYON. F–22 aircraft are currently restricted to 44,000 feet during training missions with limited operational impacts. If required to do so, F–22 aircraft can operate throughout their full operational envelope.

Mr. BARTLETT. What is the status of actions on recommendations of General Martin's Aircraft Oxygen Generation Study Group?

General LYON. The Scientific Advisory Board (SAB) made a total of fourteen (14) recommendations; eight (8) short term and six (6) long term. The Air Force has completed seven (7) of the eight (8) short term recommendations. The remaining short term recommendation for Helmet Mounted Pulse Oxygen (HMPO) is on schedule to be completed in December of 2012.

The six (6) remaining long term recommendations are on track for completion by the end of FY 2015.

Mr. BARTLETT. Is there a cost and time estimate to institute the planned actions to the F–22 life support system?

General LYON. Acquisition efforts are underway that include an Automatic Backup Oxygen System (A–BOS), Automatic Ground Collision and Avoidance System (AGCAS), Upper Pressure Garment Valve, Oxygen Hose Pass-Thru Panel, and Helmet Mounted Pulse Oximeter. These efforts are estimated to cost a total of \$82.5M to develop and install on the entire fleet of F–22 aircraft.

Mr. BARTLETT. On what basis was the F–22 returned to flight in September 2011, since the Scientific Advisory Board and your Study Group had not completed their work?

General LYON. The Commander, Air Combat Command tasked ACC/A3 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.

Mr. BARTLETT. What is the status of the Air Combat Command's Life Support Systems Task Force report, and when will it be released? Would you provide the committee a copy of the report when it is completed?

General LYON. The LSS TF final report is currently in draft with an estimated completion date of 31 Oct 2012. The report will be vetted through Headquarters Air Force and be available once released by Air Force leadership.

Mr. BARTLETT. We understand that the upper pressure garment was also used in F–15s and F–16s from the early 1990s through 2005. Why weren't vulnerabilities in the upper pressure garment determined while it was in use with the F–15 and F–16? Are there differences in the upper pressure garment system in the F–22 compared to the F–15 and F–16?

General LYON. The Upper Pressure Garment (UPG) system being used in the F–22 is fully functional, compatible with, and meets all requirements for use with F–15 and F–16 aircraft. The physiological root cause investigation concluded the UPG was prematurely inflating due to the F–22's safety positive pressure breathing system. Neither the F–15 nor F–16 has safety positive pressure breathing systems.

Mr. BARTLETT. Why have ground maintenance personnel experienced symptoms if the issue is primarily linked to life support systems inside the cockpit?

General LYON. All ground incidents which occurred between 22 Sep 2011 and 14 Dec 2011 were extensively investigated. All ground incident aircraft underwent contamination inspection prior to return to flight in September 2011 as well as more extensive post incident testing. This testing contributed to some of the overall F–22 contamination analysis. None of the ground incident aircraft cockpit testing revealed anything approaching a remarkable health guidance value. None of the maintainer blood, breath or urine samples indicated anything remarkable. Fluid found in the cockpit of one incident aircraft was evaluated and determined to be water with nothing remarkable.

During one incident, investigators suspected tailwind engine exhaust may reach the cockpit and possibly effect maintainers. However, post incident testing and continued testing on two F–22 aircraft has indicated nothing remarkable. Engine run qualified ground maintenance personnel did receive updated engine run procedures to increase awareness, and to allow them to shutdown and reposition aircraft or equipment in the event of excessive exhaust. Engine run maintenance personnel also carried air sampling canisters in the cockpit for several months to capture any air samples from any potential incidents.

However, no incidents occurred during this timeframe which was subsequent to the last ground incident in Dec 2011. Maintainers across the F–22 fleet perform in excess of a hundred engine runs every month—runs which do not include aircraft movement. The Air Force has trained and implemented procedures for maintainers to quickly and safely shut down a running aircraft in the event of any future incidents. Additionally, appropriate aircraft and medical protocols are in place to respond to any future incidents.

Mr. BARTLETT. Please describe the Air Force's efforts to definitively determine that stealth coatings, along with other contaminants, did not cause any of these incidents. Could stealth coatings that were heated either on the ground or in flight cause contamination in that manner?

General LYON. LO Coatings and its breakdown products, along with other potential contaminants were incorporated into an extensive Molecular Characterization Matrix effort that thoroughly characterized, analyzed and documented over 900 compounds that could be present in aircraft environments. After several years of exhaustive testing both on the ground and in flight, no detected compounds levels have ever exceeded safe limits, or even been close to safe limit thresholds.

All potential compound sources in an F–22 were evaluated including fuel, hydraulic fluid, engine oil, radar coolant, ambient air, engine exhaust, aircraft cleaning products, sealants, and coatings. Source breakdown analysis was performed and potential source information was incorporated into the Molecular Characterization Matrix for each compound. Of the 900 compounds characterized, only approximately 450 were ever detected on an F–22 aircraft.

Compound detection methods used on F–22 aircraft were capable of detecting a full spectrum of compounds. Detection media included Thermal Desorption Tubes, SUMMA canisters, multi-RAEs, sock and swab analyses, Greywolf, PUF/XAD, Silica Gel, C2A1 filters and GRIMM/CPC particulate counter, among others. The detection methods used were capable of detecting a wide range of particulate matter, volatile and semi-volatile compounds, and standard gases. Over 2,000 total samples were taken using these devices, at different times, both on ground and in-flight. Chemists and toxicologists performed countless reviews of sampling techniques and methods and culminated their effort with a detection methods expert forum to ensure that the full spectrum of aircraft compounds would have been adequately detected by the methods used in testing and sample analysis.

Post incident protocols were established as part of Return to Flight in September 2011 and completed after each incident flight and maintainer incident. The protocol directed sampling at various areas of the aircraft including cockpit and breathing line air. All incident aircraft had levels of detected compounds well below established safe limits.

Safe limits were developed with a team of over 20 experienced toxicologists, doctors, and scientists from contractor, NASA, University, and USAF personnel. These limits were derived from established OSHA guidelines, existing available research, Permissible Exposure Limits (PELs), Short Term Exposure Limits (STELs), and other established guidelines for each compound. In addition to aircraft sampling, blood, urine, and exhaled breath samples were taken from all incident pilots and maintainers and reviewed by an independent medical team of 5 physiologists, toxicologists, and aerospace physicians from the contractor, USAF, University and NASA. No abnormalities were noted in any tests. If a pilot was exposed to reactive LO coating materials, pilot blood tests should have revealed abnormal levels of heavy metals present. None were detected.

A thorough review of maintenance activities on incident aircraft was completed and there were no maintenance trends prior to incident flights. Incidents have not been linked to any specific maintenance activities, including initial LO application and/or coating repair.

In addition, compounds unique to LO coatings are unlikely to still be present in their reactive state during flight operations, since precautions are taken when coatings are applied. The aircraft is isolated to prevent exposure to personnel and Technical Order Documents (TOD) dictate that the aircraft are not returned to flight line operations until coatings are cured and paints are dry. Therefore, it is highly unlikely that these coatings were present during ground or in-flight operations.

Based on the exhaustive research conducted to date, the team believes that contamination is not the root cause of the F–22 Physiological Incidents.

Mr. BARTLETT. How do F–22 g-forces cause what is referred to as "Raptor cough"? Why does the Air Force feel it is not related to the physiological incidents pilots are experiencing?

General LYON. The term "Raptor Cough" is commonly known as acceleration atelectasis. Acceleration atelectasis results from pilots breathing high concentrations of oxygen (above 60%) while wearing anti-G trousers, and exposure to G-forces. Atelectasis refers to the closure of alveoli in the terminal bronchioles as oxygen is absorbed into the blood stream, leaving no component of normal breathing gas (i.e. nitrogen) to keep them open. The normal physiologic response to re-open the alveoli is to cough. The F–22 consistently delivers higher concentrations of oxygen compared to legacy fighters increasing susceptibility to developing atelectasis.

The Air Force feels that atelectasis may be a contributor to the "Raptor Cough" issue. The Air Force will continue to explore further potential causes through long term breathing air analysis and human systems integration efforts.

Mr. BARTLETT. What is the Air Force's level of confidence in whether or not the life support equipment issues are contributing to all of the physiological incidents with pilots and ground personnel in the F–22 community?

General LYON. The Root Cause Corrective Action (RCCA) team exhaustively investigated 414 separate fault tree branches to arrive at high confidence in the overall F–22 Life Support System equipment. The Upper Pressure Garment (UPG) valve is the only remaining vulnerability, and is on-track for resolution in December 2012.

The F–22 LSS Task Force is very confident that we know what was causing physiological incidents. No single cause was identified; rather multiple factors defined during the root cause corrective action (RCCA) combine to produce symptoms. These factors include human factors, breathing system impedance, high O2 concentration, and Upper Pressure Garment restriction caused by a fill/dump valve that was not specifically designed for the F–22. Pilot/Maintainer variability contributes to symptom manifestation differences. We are also confident that factors other than the life support system or the aircraft caused the ground incidents.

Mr. BARTLETT. You have previously indicated that of the 11 reported "cause unknown" hypoxia events since return to fly in September 2011, less than half of those events are still unresolved. How many of the reported incidents can you contribute to an insufficient supply of oxygen?

General LYON. Of the 11 reported "cause unknown" events since September 2011, all 11 have been resolved under the general cause of restricted breathing. This determination was made through the independent investigations made at each mishap wing, supported by personnel and resources at the major command level along with experts from the F–22 program office, Lockheed-Martin, and outside support from experts at the U.S. Navy and NASA.

20–Oct-11	Hypoxia symptoms on departure—restricted breathing
20–Oct-11	Post flight personnel recognized cognitive degradation from pilot—restricted breathing
31 Oct 11	Pilot experienced symptoms in flight—restricted breathing
15 Nov 11	Pilot experienced symptoms during high-G sortie—restricted breathing
14 Dec 11	Hypoxia symptoms in flight—restricted breathing
14 Feb 12	Confusion during/post flight—restricted breathing
17 Feb 12	Confusion during intercept trng—restricted breathing
17 Feb 12	Confusion during RTB—restricted breathing
23 Feb 12	Hypoxia symptoms during RTB—restricted breathing
1 Mar 12	Pilot confusion, Spatial D in IMC—restricted breathing
8 Mar 12	Hypoxia symptoms during night RTB—restricted breathing

Mr. BARTLETT. You have previously indicated that of the 11 reported "cause unknown" hypoxia events since return to fly in September 2011, less than half of those events are still unresolved. Could you provide an update on the status of each of those events including which are resolved with a cause for each, and which are still unresolved and actions being taken to address those unresolved cases?

General LYON. All of the events since September 2011 have been resolved under the general cause of restricted breathing. This determination was made through the independent investigations made at each mishap wing, supported by personnel and resources at the major command level along with experts from the F–22 program office, Lockheed-Martin, and outside support from experts at the U.S. Navy and NASA.

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Mr. BARTLETT. Were you provided access to any Air Force data or facilities your team deemed necessary to carry out your review of the Air Force's investigative process and root-cause analysis?

Mr. CRAGG. Yes, the USAF provided the NASA Engineering and Safety Center (NESC) F–22 Life Support System (LSS) Independent Analysis Team with access to all of the data and facilities needed.

Mr. BARTLETT. You mentioned in your written statement that you believed insufficient human-systems integration testing was accomplished before operational deployment of the F–22. What additional testing do you believe should have been accomplished?

Mr. CRAGG. One of the NESC's Team's recommendations was to ensure appropriate human system integration testing is performed before operational use of any new system or implementation of a change to an existing system. Life support components (e.g., the On-Board Oxygen Generator (OBOGs)) were all individually qualified and put into the system by a system integrator. The original F–22 qualification testing did not utilize the same Aircrew Flight Equipment (AFE) that is in use today. Many of the complex interactions between the end-to-end system and the pilots were just recently identified during the human centrifuge and altitude chamber testing.

Mr. BARTLETT. You noted in your written statement that in any jet fighter environment, irritant compounds like combustion exhaust gases, fuels, lubricants, and organic cleaning solvents can be present. Are you confident in the Air Force's analysis that irritant compounds could not be in the pilot's breathing air supply thereby causing hypoxia-like effects?

Mr. CRAGG. As stated, irritant compounds are present in any jet fighter environment, including the F–22. The NESC Team found no evidence of a contaminant producing a toxic exposure for the pilots flying the F–22. The NESC Team recommended that the USAF "Consider a fundamental reassessment of requirements and assumptions for LSS in high performance aircraft." Such an assessment would provide a better understanding of the physiological effects of irritant compounds in high performance aircraft.

Mr. BARTLETT. What is the status of the NASA Engineering and Safety Center report, and when will it be released? Would you provide the committee a copy of the report when it is completed?

Mr. CRAGG. The USAF requested NASA's review of hypoxia-like issues with the F–22. On August 31, 2012, the NESC presented the USAF with the final report. Accordingly, the USAF is responsible for any further use or release of the report, and NASA has agreed to defer to the USAF on such requests.

Mr. BARTLETT. Are you confident that, in addition to removing the filter, improvements to the pilots' gear, such as the upper pressure garment, will fix the F–22's physiological problems?

Mr. CRAGG. The NESC Team believes that there are multiple issues affecting the pilot's physiology in the F–22. Addressing each of these issues will ensure that the hypoxia-like symptoms will become less likely. Removing the C2A1 filter that exacerbated the problems and fixing the Upper Pressure Garment are major improvements.

QUESTIONS SUBMITTED BY MR. RUNYAN

Mr. RUNYAN. General Martin, in your testimony before the subcommittee, you stated that the decision to pull the backup oxygen system was made by a lower level team, not the chief engineer supervising the program. It was also stated that this was done to save weight and that assumptions were made that the main oxygen system would be improved to accommodate, however there was no coordination between the two teams and the main oxygen system did not receive any improvements to make up for the lack of a backup system. General Lyon and General Martin, please provide the full name(s) of each of the person(s) who made the decisions, what his/her/their current position is for each person who signed off, and what actions have been taken to hold these people accountable for their decisions in light of subsequent events. Thank you.

General MARTIN. The decision to remove the F–22 Back-Up Oxygen capability was made at an F–22 Cockpit Requirements/Design Review Update on Wednesday, 15 Jan 92. "B/U Oxygen—OBOGS" was one of the 7 trade studies reviewed during this requirements/design review. The minutes of this review clearly show concurrence with the trade study recommendation to "delete dedicated standby oxygen supply requirement for OBOGS backup" and "use emergency oxygen for emergencies." There were 25 government members at this meeting. After a thorough review of the Air Force's historical F–22 records, we are unable to determine who, specifically, made the decision to remove the F–22 Back-Up Oxygen capability from the F–22 design. Similarly, we have identified no instances in which adverse action was taken against an Air Force employee as a result of his/her making such a decision.

Mr. RUNYAN. Do you think that you have found the actual cause of the problem? What is the source of the "Raptor cough"?

General MARTIN. The source of the "Raptor Cough" is a combination of breathing high concentrations of oxygen, wear of anti-G trousers, and exposure to G forces. Raptor Cough is commonly known as acceleration atelectasis. Acceleration atelectasis results from pilots breathing high concentrations of oxygen (above 60%) while wearing anti-G trousers, and exposure to G-forces. Atelectasis refers to the closure of alveoli in the terminal bronchioles as oxygen is absorbed into the blood stream, leaving no component of normal breathing gas (i.e. nitrogen) to keep them open. The normal physiologic response to re-open the alveoli is to cough. The F–22 consistently delivers higher concentrations of oxygen compared to legacy fighters increasing susceptibility to developing atelectasis.

The Air Force feels that atelectasis may be a contributor to the "Raptor Cough" issue. The Air Force will continue to explore further potential causes through long term breathing air analysis and human systems integration efforts.

Mr. RUNYAN. Can the F–22 be retrofitted with a current oxygen system that we can have full confidence in?

General MARTIN. The Air Force has full confidence in the current F–22 On-Board Oxygen Generation System based on our extensive testing during the F–22 Life Support System root cause investigation.

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General LYON. The Air Force has full confidence in the current F–22 On-Board Oxygen Generation System based on our extensive testing during the F–22 Life Support System root cause investigation.

Mr. RUNYAN. Why is the ACC commander, General Hostage, not at the hearing? Does he not consider this situation a serious problem? As a member of both the House Armed Services and House Veterans Affairs Committees, I would also like to have heard testimony directly from him since this all ultimately falls under his responsibility as ACC Commander.

General LYON. General Mike Hostage is happy to address any additional concerns of the committee anytime he is called. On this occasion, Maj Gen Lyon was called by the committee to appear on 13 September. As General Hostage's most senior staff officer and ACC's Director of Air and Space Operations, Maj Gen Lyon was appointed to lead the F–22 Life Support System (LSS) Task Force by the Secretary of the Air Force. This represented a major commitment of headquarters efforts. As LSS lead, Maj Gen Lyon was empowered to speak for the Air Force on the subject. He holds the seniority and position to speak authoritatively, and has the most comprehensive knowledge of the subject.

General Hostage made F–22 pilot safety and operational capability a top priority for ACC through his orders, commitment of time and resources, and personal actions. Due to the seriousness of his concerns, General Hostage closely monitored the situation and made all the key decisions on this issue, such as approving the F–22s return to flying operations.

Lastly, General Hostage took the step of becoming an F–22 pilot himself in order to gain firsthand knowledge of operating the aircraft, and to demonstrate his belief that the overall risk levels our pilots take while operating the F–22 is comparable with that associated with most other high performance aircraft, given the numerous corrective actions and operating guidelines now in place.

Mr. RUNYAN. Do you think that you have found the actual cause of the problem? What is the source of the "Raptor cough"?

Mr. CRAGG. The NESC Team believes that there are multiple issues affecting the pilot's physiology in the F–22. Addressing each of these issues will ensure that the hypoxia-like symptoms will become less likely. Removing the C2A1 filter that exacerbated the problems, adjusting the oxygen schedule down from "Max," and fixing the Upper Pressure Garment are major improvements. The NESC Team believes that the "Raptor Cough" is likely caused by a combination of atelectasis, high oxygen concentrations, and other physiological factors.

Mr. RUNYAN. Can the F–22 be retrofitted with a current oxygen system that we can have full confidence in?

Mr. CRAGG. The NESC Team believes that the current Honeywell On Board Oxygen Generator (OBOGs) is operating properly and as designed.

QUESTIONS SUBMITTED BY MS. SPEIER

Ms. SPEIER. General Martin, you mentioned that the F–22 program's ability to detect these issues was degraded by the Air Force's increased reliance upon contractors. Do you know approximately what the ratio of government to contractor employees working on human systems integration was in the Air Force then, and what that ratio is now?

General MARTIN. Thank you for the opportunity to clarify and expand on this issue. Although the Panel did not specifically review the ratio of government to contractor manning with regard to the human systems integration competencies, based on what the Panel members heard from contractor and USAF personnel with deep experience in the human system fields, the degradation in the "detection of issues" resulted from an overall reduction in government and contractor expertise in the field of human systems expertise within both the Air Force and the contractor community that occurred over a more than 20-year period beginning in 1990.

In this context, "human systems" encompasses human factors engineering, human systems integration, aerospace physiology (research and operational), and aerospace life support systems design/development/testing/evaluation. A significant reduction in manning and funding, for both the government and contractor workforces dealing with Human System Integration, Aviation Physiology, or Flight Medicine (especially in altitude physiology, altitude protection, oxygen generation systems, and occupational toxicology) occurred during the years of the F–22's engineering, development and manufacturing (EMD) phase and during its operational fielding. In Appendix E of the SAB's Aircraft Oxygen Generation Study Final Report, a discussion of that reduction is more fully described. Specifically, during the 1996–2000 period, Air Force Research Laboratory Human Effectiveness manpower (and the associated research funding) for continuing human effectiveness activities (including research and development of human systems integration, aviation physiology and flight medicine) was reduced by 44 percent. The Air Force indicated at the time it was willing to accept a higher risk in the application of human-centered technologies; and in particular, aircraft cockpit design technologies, environmental protection research, and life support systems were considered sufficiently mature that future research and development could therefore be accomplished by industry.

While the Air Force can and does rely on contractor expertise in many fields that type of contractor-provided "expert force in being" exists only when funded over a period of time so that expertise can be developed and maintained at a high level. The contractor community does maintain certain (limited) "core" sets of technical expertise from within its own resources for vital future business reasons. However, the aerospace physiology and life support areas, especially as applicable to high performance military aircraft, represent a long term high commitment/low return area and in general, contractors have not maintained that technical expertise without significant continuing support (i.e., government funding/contracts for basic and applied research). Although in a slightly different context, the USAF faces much the same problem and, as mentioned above, has reduced its research capabilities and expertise accordingly.

Ms. SPEIER. One of the findings of the Scientific Advisory Board was that the Air Force had insufficient capabilities and expertise for human systems integration. How does the Air Force plan to improve this expertise?

General LYON. The Air Force recognized the need to reestablish the Human Systems Integration competency in 2007 when we created the Air Force Human Systems Integration Office (AFHSIO) as a direct reporting agency to the Vice Chief of Staff of the Air Force. A recognition of the relationship of this office to weapon systems development resulted in a realignment of this office to the Undersecretary of the Air Force for Acquisition in 2009. The AFHSIO serves as a central policy source and tracking center for human systems integration (HSI) in acquisition programs. The team is currently assessing the number of HSI practitioners required, developing a concept of operations (CONOPS) for supporting program offices, determining training and certification required, and establishing a reporting mechanism.

Ms. SPEIER. General Lyon, the Safety Advisory Board recommended more clearly defining inherently governmental roles and responsibilities in the Air Force's acquisition processes and core competencies. How has the Air Force responded to this recommendation?

General LYON. The Office of the Deputy Assistant Secretary of the Air Force for Acquisition Integration (SAF/AQX) reviewed, updated, published guidance, and reported the results of their review to the Military Deputy, Office of the Secretary of the Air Force for Acquisition (SAF/AQ).

Ms. SPEIER. Mr. Cragg, you said that your team's conclusions "do not represent an exhaustive review of all F–22 documentation." What other documentation would an exhaustive review include?

Mr. CRAGG. The NESC Team would define "exhaustive review" to include review and evaluation of every single document and data source. An exhaustive review requires a significant amount of time and personnel. Based on the NESC Team's experience, the key documents necessary to understand the situation and to provide significant recommendations to the USAF were identified and reviewed.

Ms. SPEIER. Mr. Cragg, what issues should the Air Force explore in any studies of the long term impacts of the F–22's physiological strain?

Mr. CRAGG. The NESC Team believes that in some cases there could be a hypoxic-ischemic injury to certain areas of the brain that accounts for the prolonged neurocognitive symptoms experienced by some pilots. Based on early discussions with USAF medical representatives, a more objective assessment of neurocognitive function (e.g. computerized testing), as well as certain imaging studies (e.g. MRI of the brain), may be warranted in pilots who experience prolonged hypoxia-like symptoms associated with F–22 flight. Pulmonary function and diffusion testing for all F–22 pilots should also be considered. Further specifics of such testing (e.g. type and frequency) would best be addressed by technical experts in this field.

QUESTIONS SUBMITTED BY MR. LOEBSACK

Mr. LOEBSACK. What solutions has the Air Force reviewed to solve the hypoxia problems experienced by pilots? Specifically, what oxygen delivery system changes have been reviewed and were all available solutions reviewed?

General MARTIN. The Air Force has reviewed various proposed solutions to the hypoxia problems experienced by pilots. Included are modifications to the breathing assembly such as the Raptor 2 modification which introduced a chemical warfare canister in-line with air supply to the pilot. This was done to mitigate potential contamination before this theory was disproven. Further, the Air Force required pilots to wear pulse oximeters for the first time in history in an attempt to quantify arterial blood saturation.

We have reviewed numerous other potential solutions including modifications to the aircraft and have concluded that adding an automatic back-up oxygen system would meet requirements to have immediate 100% oxygen available in the event of a rapid decompression at extreme high altitudes. Other potential solutions investigated included changing the oxygen source from the current on board system to liquid and/or gaseous oxygen systems.

Mr. LOEBSACK. Since the Air Force pointed to the recent travel of F–22s to Japan as an indicator that the hypoxia problem has been solved, does that mean that there were no risk mitigation restrictions placed on the F–22s during the transit?

General MARTIN. The Air Force has kept all risk mitigation measures in place during F–22 long duration flights. Since resuming long-distance F–22 missions in February 2012, the Air Force has completed over 100 long-distance F–22 sorties, totaling over 650 hours. There have been zero conditions or physiological incidents during any of these sorties that would require the use of these risk mitigation measures. After thorough investigation there is no data to suggest that these risk mitigations are any more necessary on long-duration F–22 movements than with any other USAF fighter aircraft.

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