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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

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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.