

**Statement of
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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 toughest 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 O₂—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 (O₂) at lower altitudes can lead to absorption atelectasis.
2. The inevitable acceleration, which compounds the effects of high O₂.
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 O₂ flow, and current O₂ schedules provide higher than physiologically necessary O₂ 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.