1. CATS in a Nutshell

The CATS system is a multi-sensor, body-worn, fully self-contained on the person, untethered physiological based data collection and analysis system that can assess aircrew cognitive performance in real world crew stations under a large range of mission parameters such as long endurance missions, fatigue, stress, or thermal comfort (Figure 1).

Figure 1. CATS Worn by Aircrew

We divided the CATS system into two separate areas: a Sensor Kit (SK) which includes all sensors and data collection hardware (ostensibly to be used in the operational environment) and an Analytics Application (AA) which encompasses the analytical software and its user interface (ostensibly to be used in the analytical environment). Requirements were then crafted for each of these areas. The Analytics Application is already well developed.

Figure 2 shows a high level process flow of CATS. The entire processing chain operates on the aircrew-worn, fully self-contained physiological data acquisition and processing package with no physical tethers to the platform (OPL, 2014) and was developed by OPL. Body-worn sensors acquire physiological signals from the person (see also Section 1.1.). The CATS system is sensor agnostic as we are using CATS providers (they are like device drivers) to translate sensor manufacturer proprietary protocols into the CATS provider protocol. This gives the customer great freedom in the choice of sensors and eliminates the cost for expensive, manufacturer specific, data collection systems licenses. In the case of CATS, this transmission happens on the computer worn by the person (see Figure 3). However, the provider system is based on a network protocol, where data can come through any data network from anywhere in the world, to be stored within CATS. This is a very power capability that facilitates simple integration of the CATS in complex systems. Aircraft state, for example is acquired on the platform in various avionics systems such as the Time-Space-Position-System (TSPI) which comprises of Global Positioning System and an Inertial Navigation System (GPS/INS), Air data computers, Flight Management System, mission computers, etc. An aircraft-side CATS provider streams that platform specific data to the data intake on the CATS computer. Using the provider data protocol, the data now flows to the CATS data management system (Data Synch and Storage box in Figure 2) where the data is sorted by time and stored in a relational database with the time stamp as primary key. This automatically synchronizes all incoming data, no matter when it arrived at the data manager.
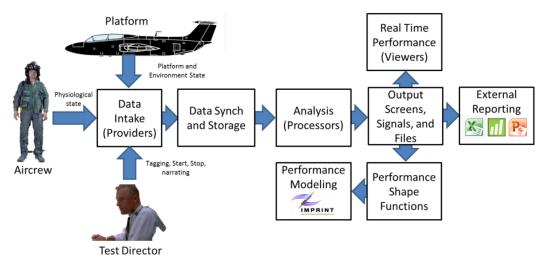
Figure 2. High Level Process Flow of the CATS

All data analysis in CATS is done by what we refer to as processors. Processors accomplish simple mathematical functions like sorting, truncating, taking the Root Mean Square (RMS). Processors also accomplish more complex functions such as, but nowhere near limited to, calculating Shannon Entropy, calculating flight technical errors (FTEs) and weapons impact performance, calculating Ergodicity Transition Matrices (ETMs), calculating workload and many other physiological based functions. Some processors run in real time and act upon the incoming data stream for real-time processing such as for example the real-time workload assessment that was demonstrated to NAWC during the Phase I closeout briefing (Real Time Performance Viewer Box in Figure 2). Other processors run when requested by a user for off-line data analysis or data output such as for use in external analysis and reporting tools such as Minitab, Excel, Powerpoint, etc. Users can enter data queries to extract combinations of data from the storage system and view it on graphs in CATS or export that data as Tab Delimited Text File. Graphs in CATS can be directly copied and pasted into external applications such as Powerpoint or Word.

1.1. CATS Body-Worn System Architecture

Based on over a decade of experience in real-world physiological assessment, we derived a set of Most Important Requirements (MIRs) that govern the design of a real-world physiological monitoring system. At the top of the MIR list are the requirements for the system to be unobtrusive and capable of supporting unimpeded emergency egress (bailout or ejection). In our laboratory, we have used the Cognitive Assessment Tool Set (CATS) for many years in airborne flight test applications in driving research and fixed and rotary wing applications. In our aircraft, the physiological signal processor resides within the aircraft instrumentation bay and the physiological sensor appliances are worn by the aircrew. This concept works fine in aircraft that can be easily (and persistently) modified such as those in our laboratory. However, for fleet applications such as those in the Navy, there may be cases where instrumentation cannot be installed in the aircraft. This gives rise to another MIR, which states that the system should be able to operate stand-alone and not depend on aircraft instrumentation or wiring. Therefore, we configured the CATS concept to be fully self-contained on the aircrew without any physical tether to the aircraft. Figure 3 shows a diagram of the resulting CATS architecture. The body-worn processor, an UP-Board, is very small (85.6mm x 56.5mm x 15.0mm) and connects via

BlueTooth (or wired interface) to the body-worn physiological signal amplifier (Nexus 4). The Up-Board and Nexus amplifier are about the size of a pack of cigarettes each. The amplifier supports a relatively wide range of body-worn physiological appliances such as EXG (electrocardiogram ECG, electromyogram EMG, electroencephalogram EEG, electrooculogram EOG), respiration belt, galvanic skin response (GSR), and body temperature sensors. The processor, amplifier, and battery are integrated in the pouches of the aircrew vest. The body-worn physiological sensor wires are routed through a hole in the flight suit to the amplifier in the vest. The aircrew wearing the CATS sensor kit are completely free to move around and ingress or egress the aircraft as needed. The CATS has a startup script that enables data collection on all sensors as soon as power is applied to the processor. This one-touch startup was instantiated from a MIR that states that data collection must be very simple. A tablet interface is incorporated through a secure (encrypted) Wi-Fi connection to the processor for additional system intervention such as starting and stopping data collection, tagging events in real-time, or activating higher level functions of CATS. We routinely use this capability in our research flight tests with great success. Through aircraft data links, the CATS can be accessed from a remote ground station for additional off-board experimental interventions. This capability is very useful in single seat aircraft or two-seat aircraft like our L-29 jets, where the front seat pilot must focus on flight related activities more so than experimental data collection activities.
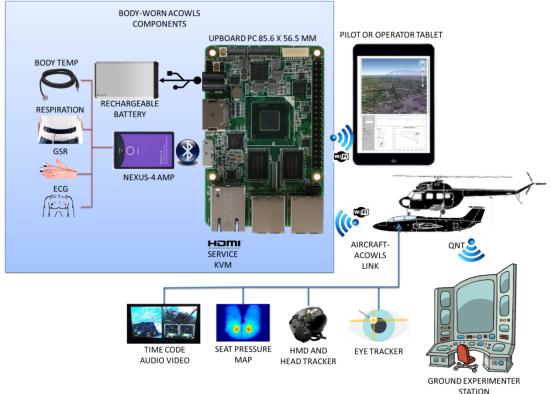

Figure 3. CATS Architecture Diagram

Sensors that are more elaborate in their configuration may need to be installed in the aircraft and cannot be body-worn. The CATS architecture enables collection of data from those sensors through a Wi-Fi link to an aircraft based data concentrator computer. This well proven software architecture is based on CATS sensor provider plug-ins and has been used by us in many flight tests. In our L-29 testbed, we have an F-35 helmet mounted display (HMD) that has a Polhemus

Scout head tracker. In the MI-2 testbed, we have a BAE Striker HMD with an Airbus optical head tracker integrated in the airframe. These trackers generate very accurate head movement data which we capture in CATS and process with regard to head motion entropy as a measure of fatigue, situation awareness, and focus of attention. The testbeds also have eye tracking systems integrated with the airframe. A portable FSA Inc. seat pressure map system comprising of a seat sleeve with pressure sensitive cells (seat pan and seat back) is available as well. It should be noted that this system is not ejection seat capable but we can use it in the L-29 which has inerted ejection seats. Audio visual recordings are often useful during data analysis. CATS supports on and off-person recording. In our applications, we use off-person recording with aircraft installed digital video recorders (DVRs). Synchronization is accomplished with SMPTE time code audio that is generated by the data collection system and sent to the DVRs. Additional data that flows from the aircraft data concentrator over the Wi-Fi connection to CATS includes button pushes, aircraft state, control input movement, etc. These variables provide very important contextual data that supports data and effects analysis. In CATS and CATS, we can quantify control input (elevator, aileron) entropy, which is a measure of smoothness of control. This measure relates strongly to stress and overload conditions.